Status of Freshwater Unionid Populations at Sleeping Bear Dunes National Lakeshore, 2000-2003.

S.J. Nichols, J. Allen, G. Black, G. Kennedy, and J.M. Craig
U.S. Geological Survey, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI 48105.

Funded by the U.S. Geological Survey's National Resources Preservation Program and the U.S. National Park Service

Corresponding author: Nichols
Email: s_jerrine_nichols@usgs.gov phone: 734-214-7218

TABLE OF CONTENTS

INTRODUCTION.....5
Objectives 6

METHODS 7

RESULTS 11
Unionid population diversity, distribution, and density.....11
Length-frequency.....30
Age-frequency and growth for *Pyganodon grandis* 35
Contaminants 39

DISCUSSION 40
Unionid population diversity, distribution, and density.....40
Contaminants 45
Unionid habitat restrictions.....45
Zebra mussels as a threat to unionid populations 46
Mitigation and restoration.....47

REFERENCES.....50

TABLES
Table 1. Bivalve distribution in waters of Sleeping Bear Dunes National Lakeshore, 2000-20004. 12
Table 2. Distribution of unionid species found in Sleeping Bear Dunes National Lakeshore, 2000-2003. 24
Table 3. Comparison of unionid and fish species richness (S) per water body, Sleeping Bear Dunes National Lakeshore, 2000-2003. 25
Table 4. Unionid density (#/m^2) descriptive statistics for 10 water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003.....26
Table 5. Analysis of variance of unionid density (#/m^2) among water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003.....27
Table 6. Analysis of variance of unionid density (#/m^2) by depth zone within water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003. 29
Table 7. Calculated amounts of contaminants sequestered in soft tissue of unionids in water bodies associated with Sleeping Bear Dunes National Lakeshore, 2000. 40

FIGURES
Figure 1. Visual survey and quantitative sample sites for Bass and School Lakes, Sleeping Bear Dunes National Lakeshore, 2000. 13
Figure 2. Visual survey extent and quantitative sample sites for the Crystal River, Sleeping Bear Dunes National Lakeshore, 2001. 14
Figure 3. Visual survey extent and quantitative sample sites for Loon Lake, Sleeping Bear Dunes National Lakeshore, 2003. 15

Figure 4. Visual survey extent and quantitative sample sites for North Bar Lake, Sleeping Bear Dunes National Lakeshore, 2000. 16
Figure 5. Visual survey extent and quantitative sample sites for North Manitou Lake, Sleeping Bear Dunes National Lakeshore, 2001. 17
Figure 6. Visual survey extent and quantitative sample sites for Otter Creek, Sleeping Bear Dunes National Lakeshore, 2002. 18
Figure 7. Visual survey extent and quantitative sample sites for Otter Lake, Sleeping Bear Dunes National Lakeshore, 2002. 19
Figure 8. Visual survey extent and quantitative sample sites for the Platte River, Sleeping Bear Dunes National Lakeshore, 2002. 20
Figure 9. Visual survey extent and quantitative sample sites for Shell Lake, Sleeping Bear Dunes National Lakeshore, 2000. 21
Figure 10. Unionid shell morphology. 22
Figure 11. Length-frequency data for unionid species collected from the Crystal River, Sleeping Bear Dunes National Lakeshore, 2000. Lengths were grouped into 10 mm increments. 30
Figure 12. Length-frequency data for unionid species collected from Lake Manitou, Sleeping Bear Dunes National Lakeshore, 2001. Lengths were grouped into 10 mm increments. 31
Figure 13. Length-frequency data for unionid species collected from Otter Lake, Sleeping Bear Dunes National Lakeshore, 2001. Lengths were grouped into 10 mm increments. 32
Figure 14. Length-frequency data for unionid species collected from the Platte River, Sleeping Bear Dunes National Lakeshore, 2001. Lengths were grouped into 10 mm increments. 33
Figure 15. Length-frequency data for unionid species collected from the Platte River, Sleeping Bear Dunes National Lakeshore, 2003. Lengths were grouped into 10 mm increments. 34
Figure 16. Length-frequency data for unionid species collected from Shell Lake, Sleeping Bear Dunes National Lakeshore, 2000. Lengths were grouped into 10 mm increments. 35
Figure 17. Growth model for one *Pyganodon grandis* from four different water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003. 36
Figure 18. Age-frequency for *Pyganodon grandis* collected from Otter Lake, Sleeping Bear Dunes National Lakeshore, 2001. 37
Figure 19. Age-frequency for *Pyganodon grandis* collected from Platte River, Sleeping Bear Dunes National Lakeshore, 2001. 37
Figure 20. Age-frequency for *Pyganodon grandis* collected from Platte River, Sleeping Bear Dunes National Lakeshore, 2003. 38
Figure 21. Age-frequency for *Pyganodon grandis* collected from School Lake, Sleeping Bear Dunes National Lakeshore, 2000. 38
Figure 22. Age-frequency for *Pyganodon grandis* collected from Shell Lake, Sleeping Bear Dunes National Lakeshore, 2000. 39
Figure 23. Zebra mussels biofouling dragonfly larvae and unionids from Otter Lake, Sleeping Bear Dunes National Lakeshore, 2002. 47
Figure 24. Pictures of unionid species found at Sleeping Bear Dunes National Lakeshore. 96

APPENDICES

Appendix A. Detailed Study Plan Including Quality Assurance/Quality Control Project Plan (QAPP).....53
Appendix B. Contaminant analysis of soft tissue of native clams sampled from Isle Royale National Park and Sleeping Bear Dunes National Lakeshore, 2000. 85
Appendix C. Background on the Unionid Genera and Species Found at Sleeping Bear Dunes National Lakeshore. 91

INTRODUCTION

Unionid mussels (freshwater clams) are the most endangered group of animals in North American waters (Williams et al. 1993). North America has the largest diversity of unionids in the world (Metcalfe-Smith et al. 1998), and most of these are located in the midwestern region of the United States. When compared to historical populations, many streams in eastern North America now possess depauperate mussel fauna. Williams et al. (1993) listed 297 species of native freshwater mussels in the United States and Canada. Of these, 213 species (71.7%) are considered endangered, threatened, or of special concern. In the United States, 51 species are listed as endangered, and more are under review.

Unionid populations are declining due to a number of factors relating to habitat alteration and human interference. Problems stem from changes in physical habitat such as increased siltation, sedimentation, and channelization; changes in water quality due to increased pollution such as heavy metals, radionucleides, pesticides, human and feed lot wastes, mining wastes, and acid runoff; and harvesting for shell and pearls (Turner and Rabalais 1994, Schloesser et al. 1996). The increased spread of exotic species (e.g., the zebra mussel) has placed additional stress on fragile populations, causing major extirpations of all unionid species in many regions (Schloesser and Nalepa 1994, Strayer and Smith 1996). Perturbations of communities have caused resource managers to recognize the need for a transition from management of individual species to community management approaches (Christie et al. 1987; Evans and Waring 1987). Holistic management of communities has been hampered by lack of information on community structure, which is particularly scarce for unionid mussels. Managing mussel

communities in any habitat requires describing each community, defining objectives for the structure of each community, and developing a means of measuring progress toward achievement of these goals. The goal of this project is to determine the population structure (distribution and diversity) and current status of native unionid mussel species at a number of national parks within the Great Lakes Basin, including Sleeping Bear Dunes National Lakeshore.

Objectives

1. What unionid and other easily identified species of bivalves are present in the lakes and streams of Sleeping Bear Dunes National Lakeshore?
2. At these same sites, which species are actively recruiting based on size?
3. What is the overall status of the population – stable, marginal, or at-risk?
4. What is the quantity of each species present based on randomized quadrats or transects?
5. What are the key environmental variables associated with each habitat sampled and are specific unionid communities associated with certain variables? Variables to be considered will be such things as which fish and other aquatic organisms are present in the same area, type of substrate, dissolved oxygen, total calcium, pH, turbidity (secchi depth), water depth, and water velocity.
6. What is the amount and type of chemical contaminant present per gram of soft body tissue for each species sampled? This will be a limited

survey designed to locate impacted areas where further study would be warranted.

7. Management, regulatory, or additional study decisions or potential actions that might hinge on the results of the study include deciding:
    a. Are unionid and other bivalve populations in various Sleeping Bear Dunes National Lakeshore lakes and rivers in good shape, under stress, or at risk based on current status?
    b. What type of long term monitoring of unionids and other bivalves is needed (if any) to keep an eye on trends?
    c. Should we try to eradicate or otherwise manage non-native bivalve species, hosts, or other biota that might be threatening native bivalve species?

METHODS

The sampling program in Sleeping Bear Dunes National Lakeshore included initial visual scouting of rivers and lakes in order to determine where unionids are presently located, followed by quantitative sampling by SCUBA divers in waters where unionids were found. Details of the sampling regime can be found in the attached QAPP (Appendix A).

The location of quantitative samples, associated GPS coordinates, and further intensive diver surveys of unionid areas are presented in Figs. 1-9. Polygon maps representing the surface area of each lake were constructed using Arc/Info (ESRI, Inc.) Geographic Information Systems (GIS) software. Geospatially referenced, digital

orthophotography images (US Geological Survey, Mid-Continent Mapping Center, 1992 and 1998) were obtained and used for digitizing the shoreline, which provided segment areal calculations. GPS positions collected at each of the sample sites were then overlain on top of these surface area polygons. Based on interviews with the SCUBA divers, boundaries were then drawn on the surface polygon combining the sample point locations and the diver transects to determine the 'qualitative' survey areas. These boundaries were joined to the whole water surface polygon to obtain the aerial calculations for the qualitative surveys and percent of waters in each area covered by these surveys.

Site selection for quantified samples relied on both distance and habitat. Before field sampling occurred, a 100-m^2 grid overlay was prepared for each water body to be surveyed. Each 100-m^2 grid in the overlay was assigned a numerical number. Using a random numbers table, grids were selected for quantitative sampling. The total number of grids chosen equaled 10% of the entire surface area of the water body. Additional grids were added in the field to target habitat type to ensure that all habitat types present were sampled. In the field, at each selected 100-m^2 grid, each diver randomly surveyed ten 1-m^2 plots. All unionids found were collected and species, shell length, sex (if shell dimorphic), gravidity, and any other characteristics were noted for every animal. Except for a few representative dead shells, all live unionids and dead shell were returned to the substrate. In 10% of the grids, a few smaller areas (0.25-m^2) were selected and excavated to a depth of 15 cm. Each quadrat (1 m^2) was fully excavated to a depth of at least 15 cm and all substrate material sieved. Three to five such transects per 90° on the compass rose were sampled. All unionids were handled as described above. Population statistics included descriptive statistics (mean, median, quartile, range, etc.). Habitat information

on features such as depth, fish presence, pH, substrate type, vegetation, and temperature were recorded for each station and grid. Other habitat data such as dissolved oxygen profiles, fish species, secchi depth, trophic status, and water hardness for each lake and river sampled was obtained from ongoing water quality monitoring conducted by SLBE staff.

Species identification was based on collected dead shell and verified by Dr. Stansberry at Ohio State University. Identified voucher specimens for most species, based on dead shell will be submitted separately.

Estimates of age and growth rates for representative clams from each site were determined by sectioning the shell on a line from the umbo to the ventral margin of the shell. The cut sections were ground and polished using a series of fine grade emery papers, followed by polishing with a felt wheel and jewelers rouge. The shell sections were then examined under a 10-60 X power dissecting scope. Internal annular rings were determined using techniques described in Tevesz and Carter (1980). Length and age frequencies were then plotted using a curvilinear regression. Comparisons between internal and external annuli (examination for non-annular external rings) were done according to the techniques described in Downing et al. (1992).

The amount and type of chemical contaminant present per gram of soft body tissue for each species sampled was determined for clams from three water bodies sampled. Individual clams were collected, placed on ice as quickly as possible and sent to the Great Lakes Science Center (GLSC). Soft tissues from each animal were removed from the shell and frozen at –40°F. The following contaminant array was surveyed: pesticides including hexachlorobenzene, pentachlorobenzene, octachlorostyrene, α- and

γ-BHC, aldrin, dieldrin, endrin, α- and β-heptachlor epoxide, cis- and trans- nonachlors, p,p'-(DDE, DDD, and DDT), mirex (including 8-monohydro mirex), α- and γ-chlordanes, oxychlordane, toxaphenes (Cl 6 to Cl 10), dacthal, and pentachlorophenyl methyl ether; PCBs (80 congeners, including most of the planar dangerous ones) and mercury. Analysis techniques and QA/QC protocols are described in Schmidt (1997), Schmidt and Hesselberg (1992), and Wilford et al. (1973).

Tissue samples were also sent out to a contract laboratory (Edglo Laboratories, Fort Wayne, Indiana) for metal analysis. Tissues were analyzed for barium, cadmium, chromium, copper, lead, mercury, nickel, and zinc using inductively coupled plasma (ICP) in conjunction with ultrasonic nebulization sample introduction. This technique allows for ICP multi-parameter analysis with graphite absorption spectroscopy detection limits.

The contaminant concentrations in clam tissues were screened for toxicity by comparison with sediment benchmark values for toxicity to freshwater biota. These benchmark values had been assembled by scientists at the Great Lakes Science Center in two tables, used for screening residues in the Lake Erie/Lake St. Clair NAWQA and the Illinois River basin NAWQA. The former table relied on benchmarks from the Oak Ridge National Laboratories (URL http://www.hsrd.ornl.gov/ecorisk/tm95r4.pdf) and NOAA (URL http//www.orca.nos.noaa.gov/projects/nsandt/sedimentquality.html). The latter table incorporated consensus-based sediment quality guidelines for freshwater ecosystems from MacDonald et al. (2000). For chemicals without consensus values, available values from the first table were used instead. In evaluating the residues in the

lakes, we did not normalize by organic content of the sediment, although some benchmark values are normalized to 1% organic carbon.

All statistical analyses were performed using Excel. Unionid density and associated descriptive statistics for each water body were calculated. Grids were used as replicate samples and therefore grid density is considered the raw data used in the analyses. Analysis of variance (ANOVA) was used to determine if differences in unionid densities existed among water bodies and among depth zones within water bodies in which >50 unionids were collected over at least three 5-ft depth zones. Length-frequency data was compiled for those water bodies in which >50 unionids were collected. *Pyganodon grandis* growth models were developed from one individual per water body and were used to estimate age from individuals collected from one river and three lakes. Age-frequency data was compiled for *P. grandis* for all lakes in which it was found.

RESULTS

Unionid population diversity, distribution, and density

Water bodies associated with Sleeping Bear Dunes National Lakeshore were sampled for clams during the summer in 2000, 2001, and/or 2003. Bass Lake (BL), Loon Lake (LL), Lake Manitou (LM), North Bar Lake (NBL), Otter Creek (OC), Otter Lake (OL), School Lake (SCL), and Shell Lake (SHL) were sampled in one of the three years; the Crystal River (CR) and Platte River (PR) were sampled two of the three years, and the data are present separately by year for these two. Maps showing sample sites are presented as Figs. 1-9. Presence or absence of unionids and zebra mussels was noted for

each water body (Table 1). Figure 10 illustrates unionid shell morphology with terms of reference used in measuring and aging.

Table 1. Bivalve distribution in waters of Sleeping Bear Dunes National Lakeshore, 2000-2004. ZM=zebra mussels or other exotic dreissenids.

WATERBODY	UNIONIDS	INFESTATION	ZM
Bass Lake (Leelanau Co.)[a]	Dead shell only		Not found
Bass Lake (Benzie Co.)[b]	Present	Light[1] (2000); Heavy[2] (2004)	Present
Crystal River[a]	Present	Light (2004)	Present
Lake Manitou[a]	Present		Not found
North Bar Lake[a]	Present	Light	Present
Loon Lake[a]	Present	Light	Present
Mud Lake[b]	Present		Not found
Otter Creek[a]	Present		Not found
Otter Lake[a]	Present	Light (2000); Heavy (2003)	Present
Platte River[a]	Present	Light (2001); Heavy (2003)	Present
School Lake[a]	Present		Not found
Shell Lake[a]	Present		Not found

[a]sites that were quantitatively sampled for unionid density (#/m^2); [b]qualitative sampling only.
[1]<1 zebra mussel/unionid; [2]>5 zebra mussels/unionid

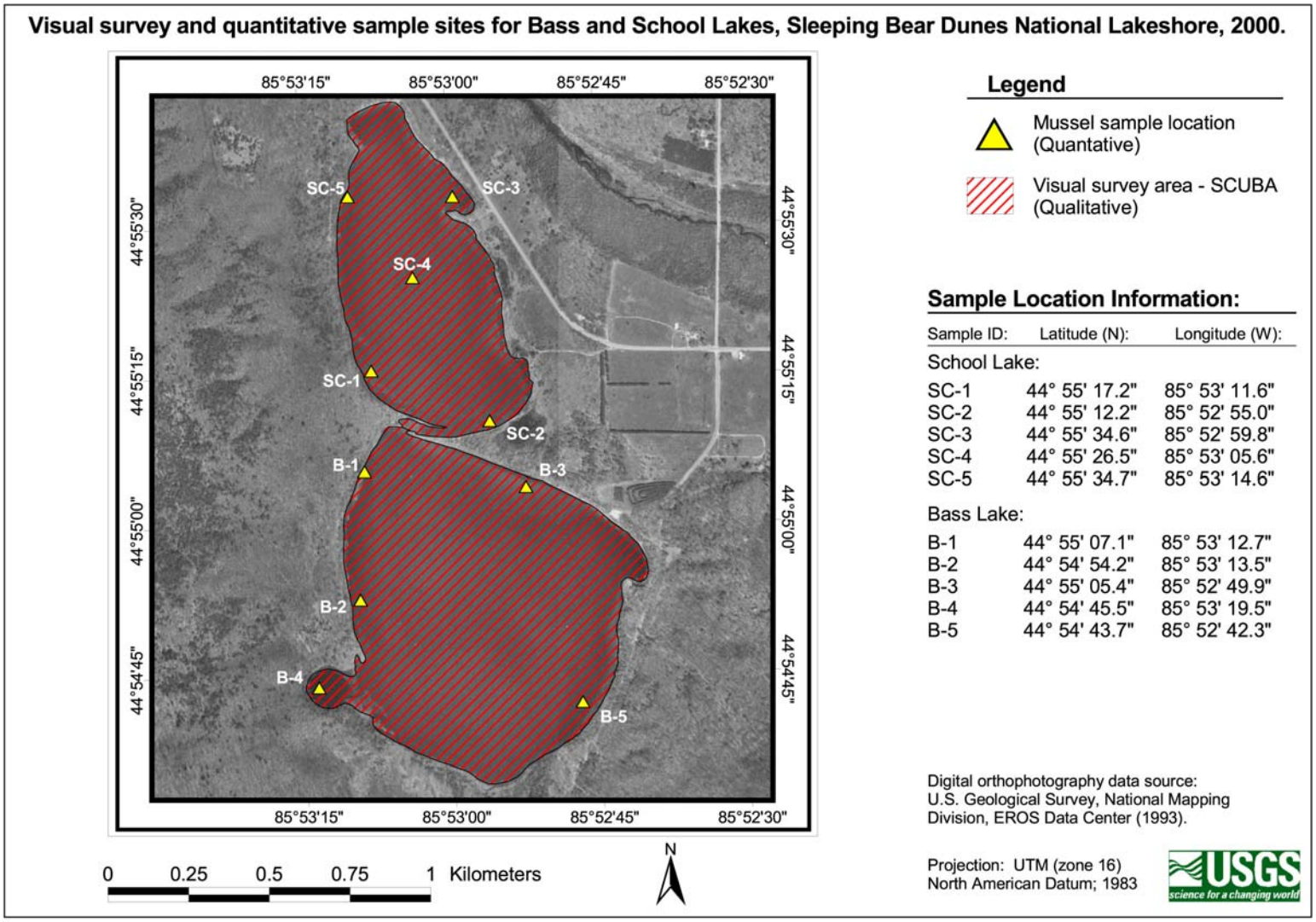
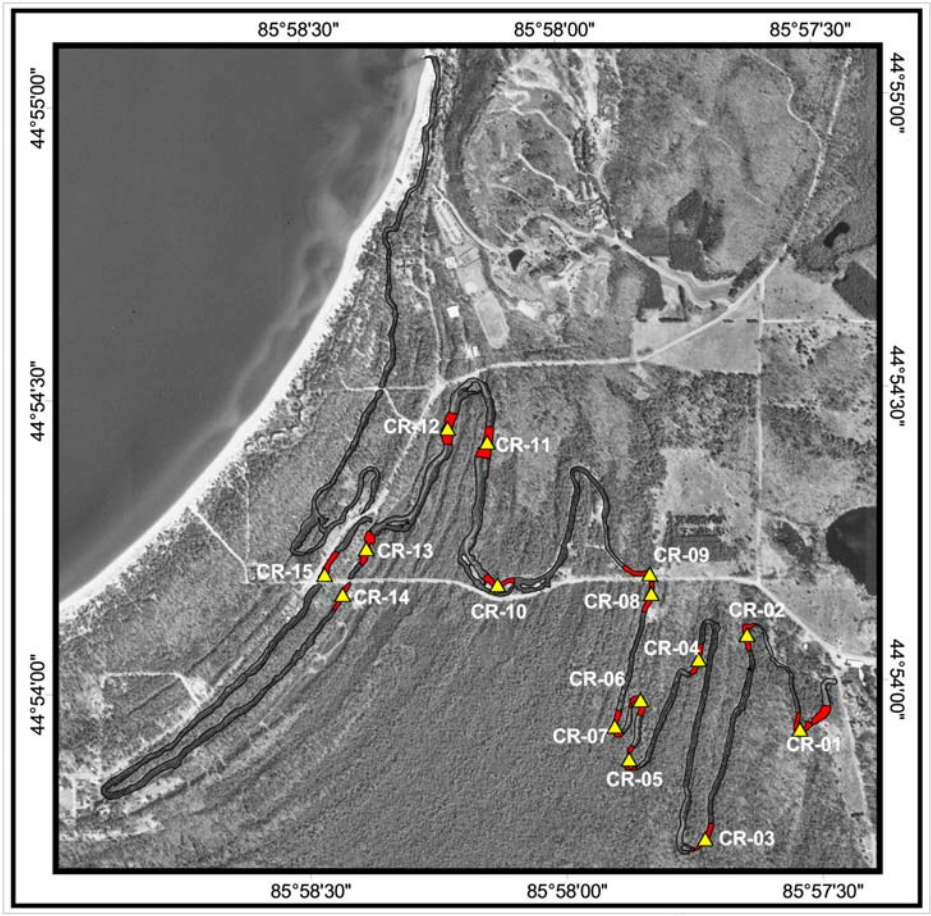

Visual survey and quantitative sample sites for Bass and School Lakes, Sleeping Bear Dunes National Lakeshore, 2000.
85°53'15"
85°53'00"
85°52'45"
85°52'30"
44°55'30"
44°55'15"
44°55'00"
44°54'45"
SC-5
SC-3
SC-4
SC-1
SC-2
B-1
B-3
B-2
B-4
B-5
0 0.25 0.5 0.75 1 Kilometers
N
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
School Lake:
SC-1 44° 55' 17.2" 85° 53' 11.6"
SC-2 44° 55' 12.2" 85° 52' 55.0"
SC-3 44° 55' 34.6" 85° 52' 59.8"
SC-4 44° 55' 26.5" 85° 53' 05.6"
SC-5 44° 55' 34.7" 85° 53' 14.6"
Bass Lake:
B-1 44° 55' 07.1" 85° 53' 12.7"
B-2 44° 54' 54.2" 85° 53' 13.5"
B-3 44° 55' 05.4" 85° 52' 49.9"
B-4 44° 54' 45.5" 85° 53' 19.5"
B-5 44° 54' 43.7" 85° 52' 42.3"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world

Figure 1.

Visual survey extent and quantitative sample sites for the Crystal River, Sleeping Bear Dunes National Lakeshore, 2001.



0 0.25 0.5 0.75 1 Kilometers

N

Legend

Mussel sample location (Quantative)

Visual survey area - SCUBA (Qualitative)

Sample Location Information:

Sample ID:	Latitude (N):	Longitude (W):
Crystal River:		
CR-01	44° 53' 55.7"	85° 5'7 23.7"
CR-02	44° 54' 05.4"	85° 57' 30.9"
CR-03	44° 53' 44.7"	85° 57' 37.7"
CR-04	44° 54' 02.9"	85° 57' 37.5"
CR-05	44° 53' 52.6"	85° 57' 48.2"
CR-06	44° 53' 59.1"	85° 57' 46.2"
CR-07	44° 53' 56.3"	85° 57' 50.5"
CR-08	44° 54' 09.8"	85° 57' 44.7"
CR-09	44° 54' 11.7"	85° 57' 44.7"
CR-10	44° 54' 11.8"	85° 58' 06.5"
CR-11	44° 54' 25.5"	85° 58' 08.7"
CR-12	44° 54' 26.9"	85° 58' 14.4"
CR-13	44° 54' 14.8"	85° 58' 26.1"
CR-14	44° 54' 10.1"	85° 58' 29.4"
CR-15	44° 54' 11.6"	85° 58' 30.8"

Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).

Projection: UTM (zone 16)
North American Datum; 1983

USGS science for a changing world

Figure 2.

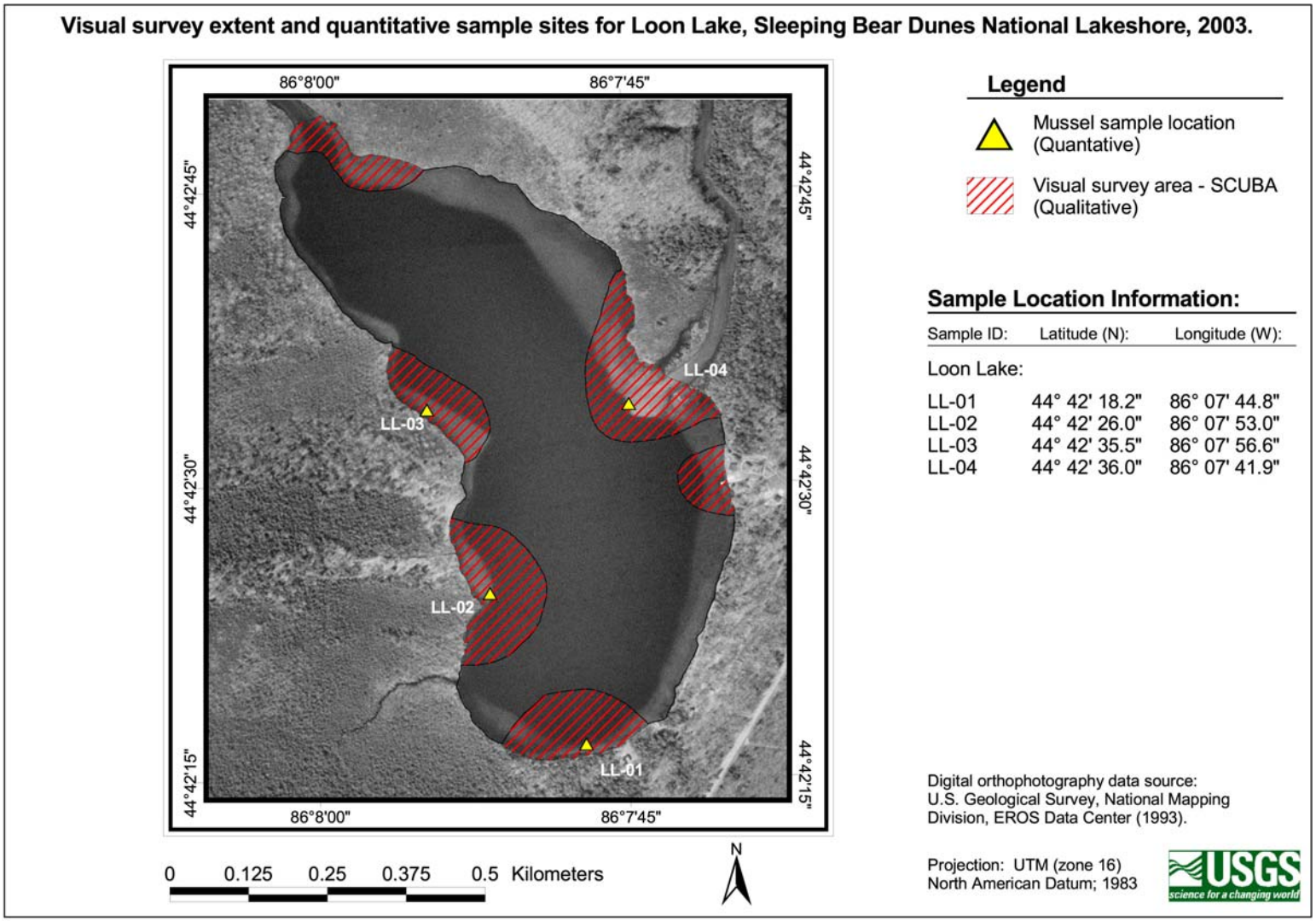

Visual survey extent and quantitative sample sites for Loon Lake, Sleeping Bear Dunes National Lakeshore, 2003.
86°8'00"
86°7'45"
44°42'45"
44°42'30"
44°42'15"
LL-01
LL-02
LL-03
LL-04
0 0.125 0.25 0.375 0.5 Kilometers
N
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
Loon Lake:
LL-01 44° 42' 18.2" 86° 07' 44.8"
LL-02 44° 42' 26.0" 86° 07' 53.0"
LL-03 44° 42' 35.5" 86° 07' 56.6"
LL-04 44° 42' 36.0" 86° 07' 41.9"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world

Figure 3.

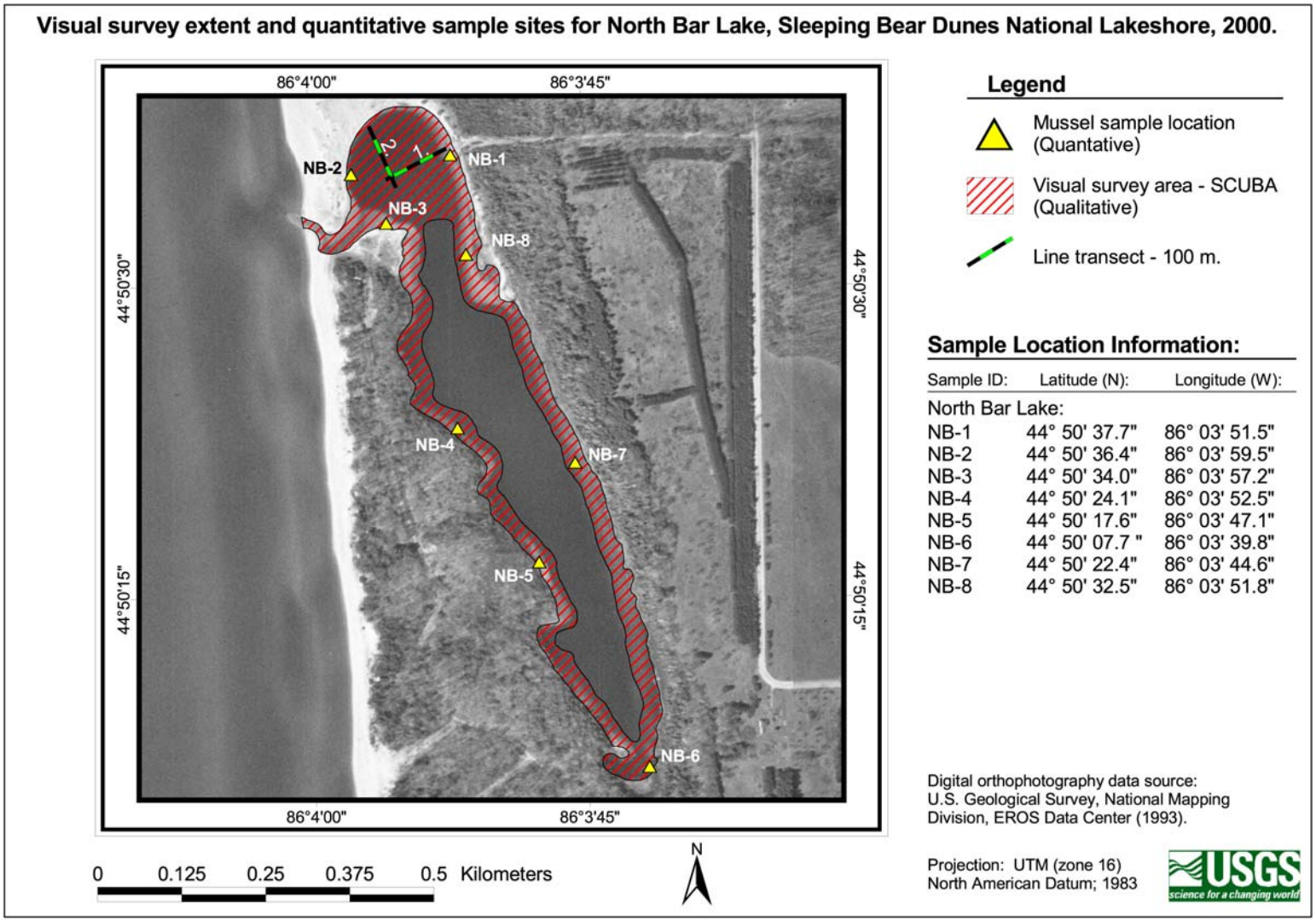

Visual survey extent and quantitative sample sites for North Bar Lake, Sleeping Bear Dunes National Lakeshore, 2000.
86°4'00"
86°3'45"
44°50'30"
44°50'15"
NB-1
NB-2
NB-3
NB-4
NB-5
NB-6
NB-7
NB-8
1
2
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Line transect - 100 m.
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
North Bar Lake:
NB-1 44° 50' 37.7" 86° 03' 51.5"
NB-2 44° 50' 36.4" 86° 03' 59.5"
NB-3 44° 50' 34.0" 86° 03' 57.2"
NB-4 44° 50' 24.1" 86° 03' 52.5"
NB-5 44° 50' 17.6" 86° 03' 47.1"
NB-6 44° 50' 07.7 " 86° 03' 39.8"
NB-7 44° 50' 22.4" 86° 03' 44.6"
NB-8 44° 50' 32.5" 86° 03' 51.8"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world
0 0.125 0.25 0.375 0.5 Kilometers
N

Figure 4.

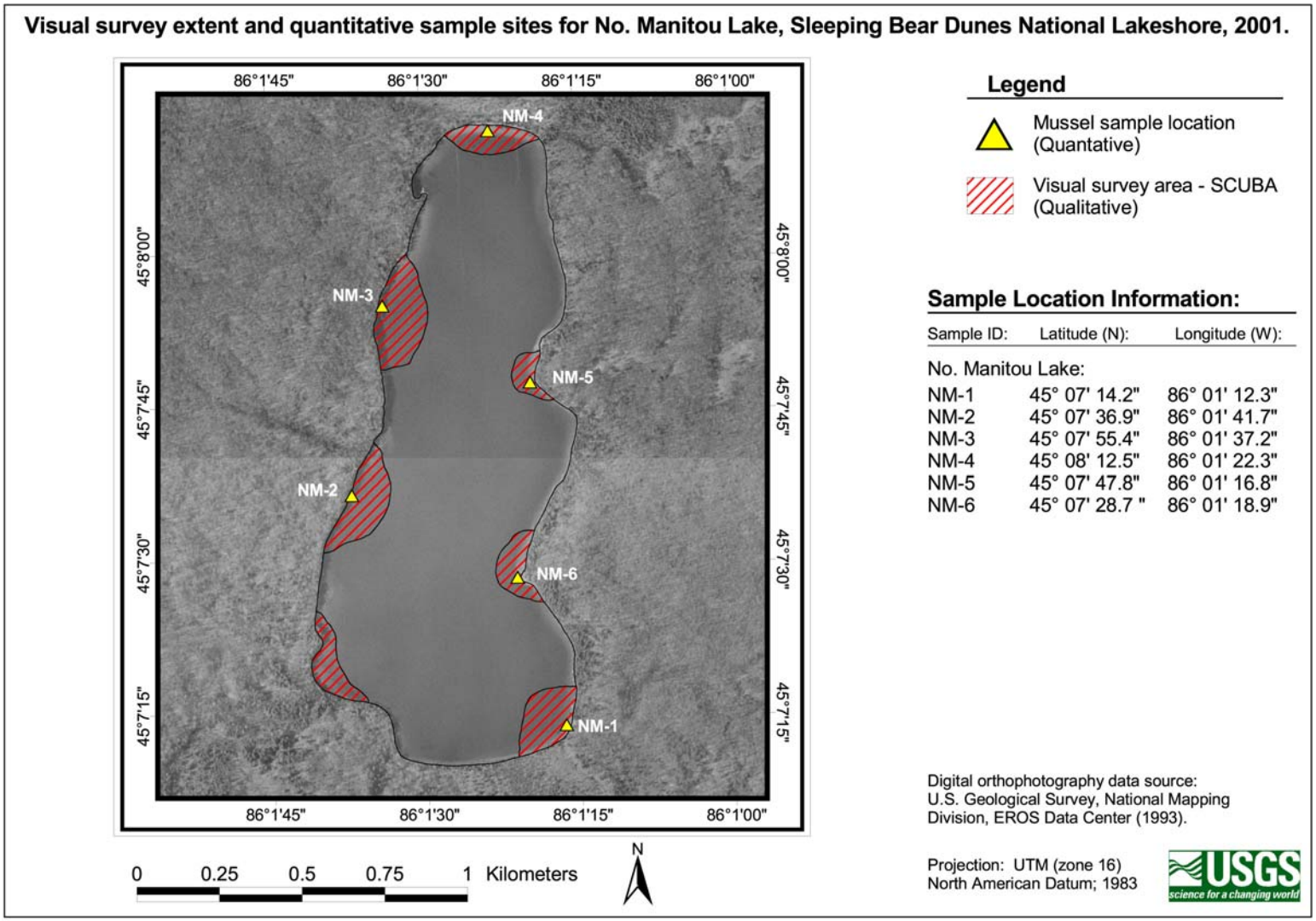

Visual survey extent and quantitative sample sites for No. Manitou Lake, Sleeping Bear Dunes National Lakeshore, 2001.
86°1'45"
86°1'30"
86°1'15"
86°1'00"
45°8'00"
45°7'45"
45°7'30"
45°7'15"
NM-4
NM-3
NM-5
NM-2
NM-6
NM-1
0
0.25
0.5
0.75
1 Kilometers
N
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
No. Manitou Lake:
NM-1 45° 07' 14.2" 86° 01' 12.3"
NM-2 45° 07' 36.9" 86° 01' 41.7"
NM-3 45° 07' 55.4" 86° 01' 37.2"
NM-4 45° 08' 12.5" 86° 01' 22.3"
NM-5 45° 07' 47.8" 86° 01' 16.8"
NM-6 45° 07' 28.7 " 86° 01' 18.9"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world

Figure 5.

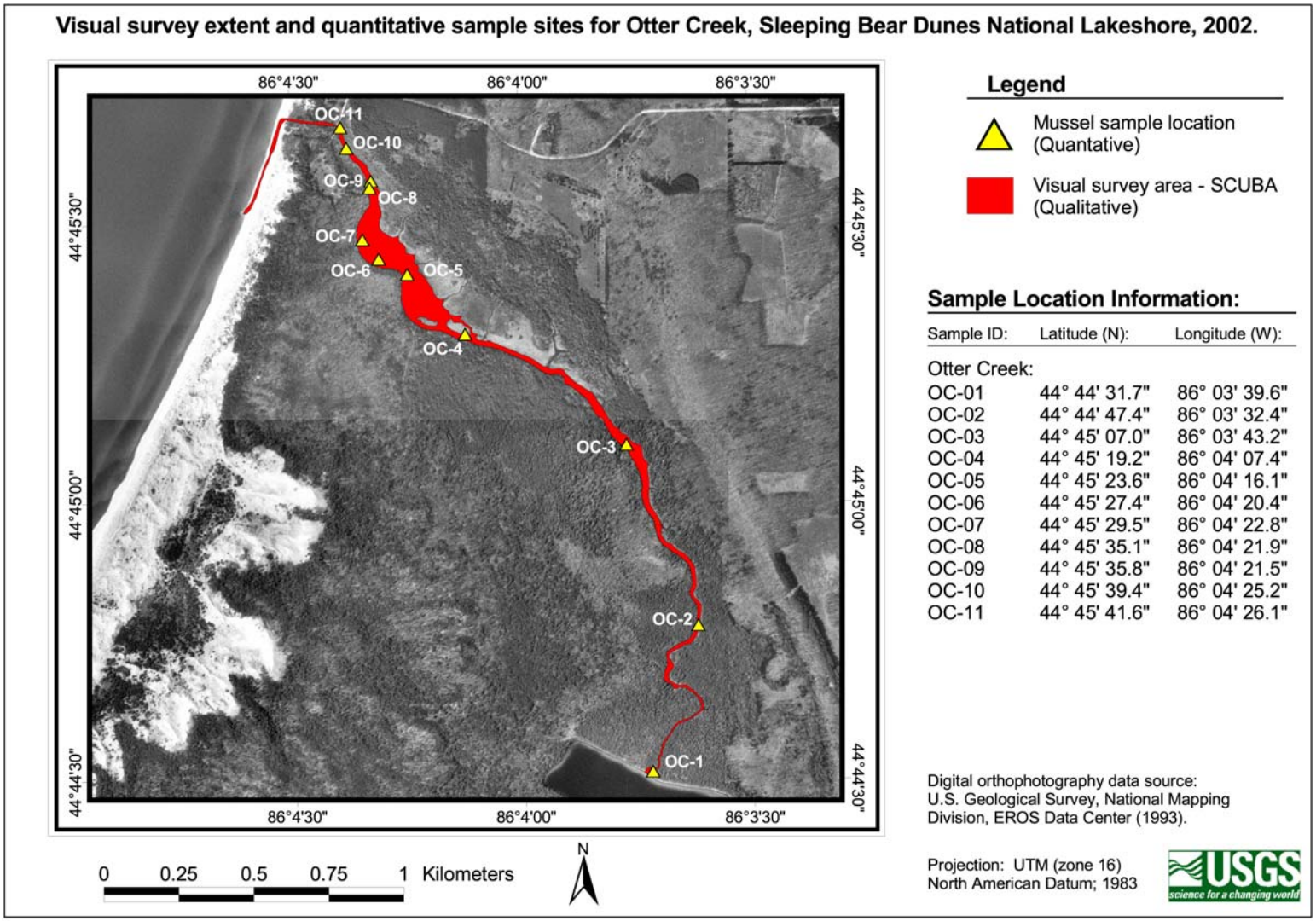

Visual survey extent and quantitative sample sites for Otter Creek, Sleeping Bear Dunes National Lakeshore, 2002.
86°4'30"
86°4'00"
86°3'30"
44°45'30"
44°45'00"
44°44'30"
OC-11
OC-10
OC-9
OC-8
OC-7
OC-6
OC-5
OC-4
OC-3
OC-2
OC-1
0 0.25 0.5 0.75 1 Kilometers
N
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
Otter Creek:
OC-01 44° 44' 31.7" 86° 03' 39.6"
OC-02 44° 44' 47.4" 86° 03' 32.4"
OC-03 44° 45' 07.0" 86° 03' 43.2"
OC-04 44° 45' 19.2" 86° 04' 07.4"
OC-05 44° 45' 23.6" 86° 04' 16.1"
OC-06 44° 45' 27.4" 86° 04' 20.4"
OC-07 44° 45' 29.5" 86° 04' 22.8"
OC-08 44° 45' 35.1" 86° 04' 21.9"
OC-09 44° 45' 35.8" 86° 04' 21.5"
OC-10 44° 45' 39.4" 86° 04' 25.2"
OC-11 44° 45' 41.6" 86° 04' 26.1"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world

Figure 6.

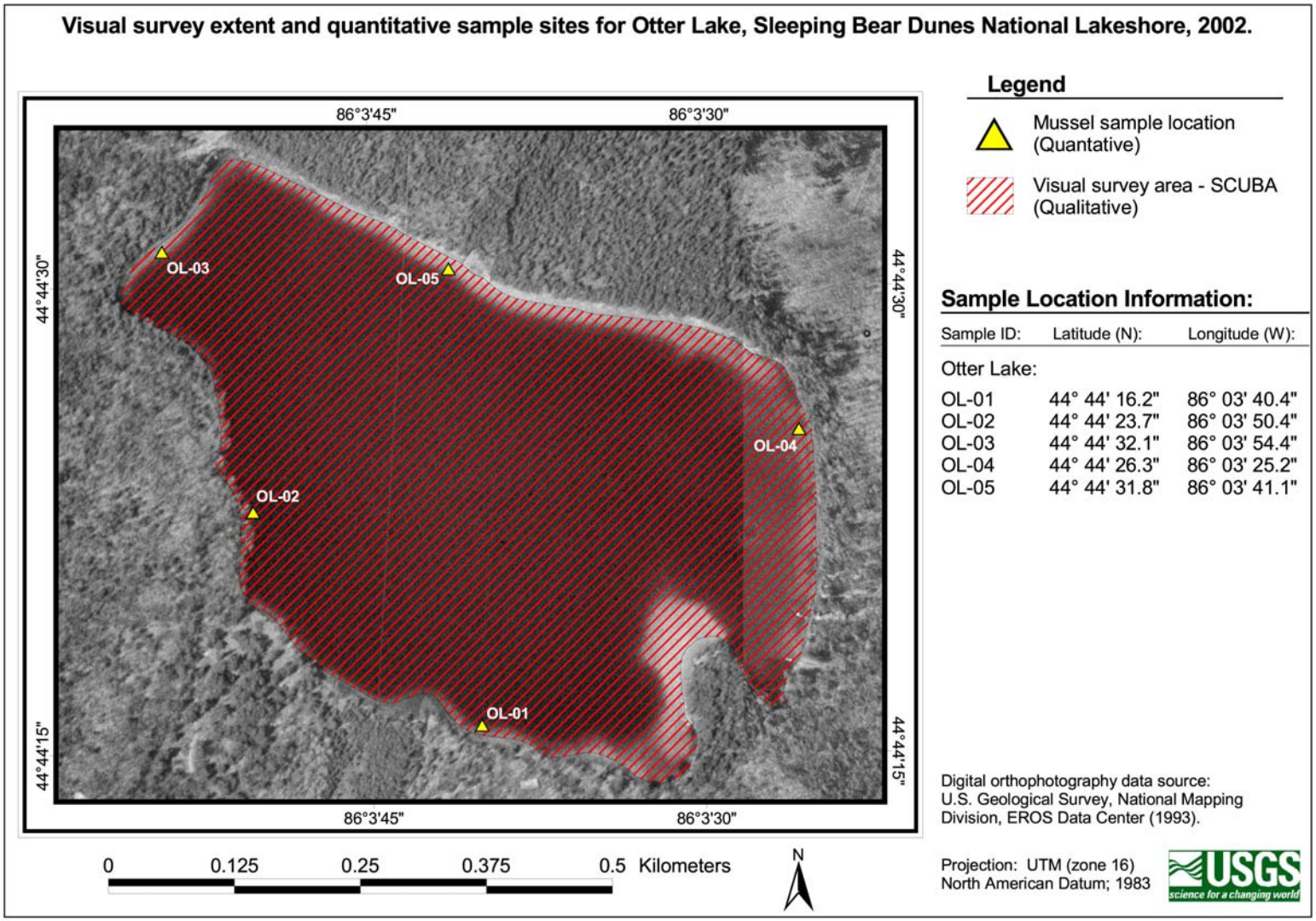

Visual survey extent and quantitative sample sites for Otter Lake, Sleeping Bear Dunes National Lakeshore, 2002.
86°3'45"
86°3'30"
44°44'30"
44°44'15"
OL-03
OL-05
OL-04
OL-02
OL-01
0
0.125
0.25
0.375
0.5 Kilometers
N
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
Otter Lake:
OL-01 44° 44' 16.2" 86° 03' 40.4"
OL-02 44° 44' 23.7" 86° 03' 50.4"
OL-03 44° 44' 32.1" 86° 03' 54.4"
OL-04 44° 44' 26.3" 86° 03' 25.2"
OL-05 44° 44' 31.8" 86° 03' 41.1"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world

Figure 7.

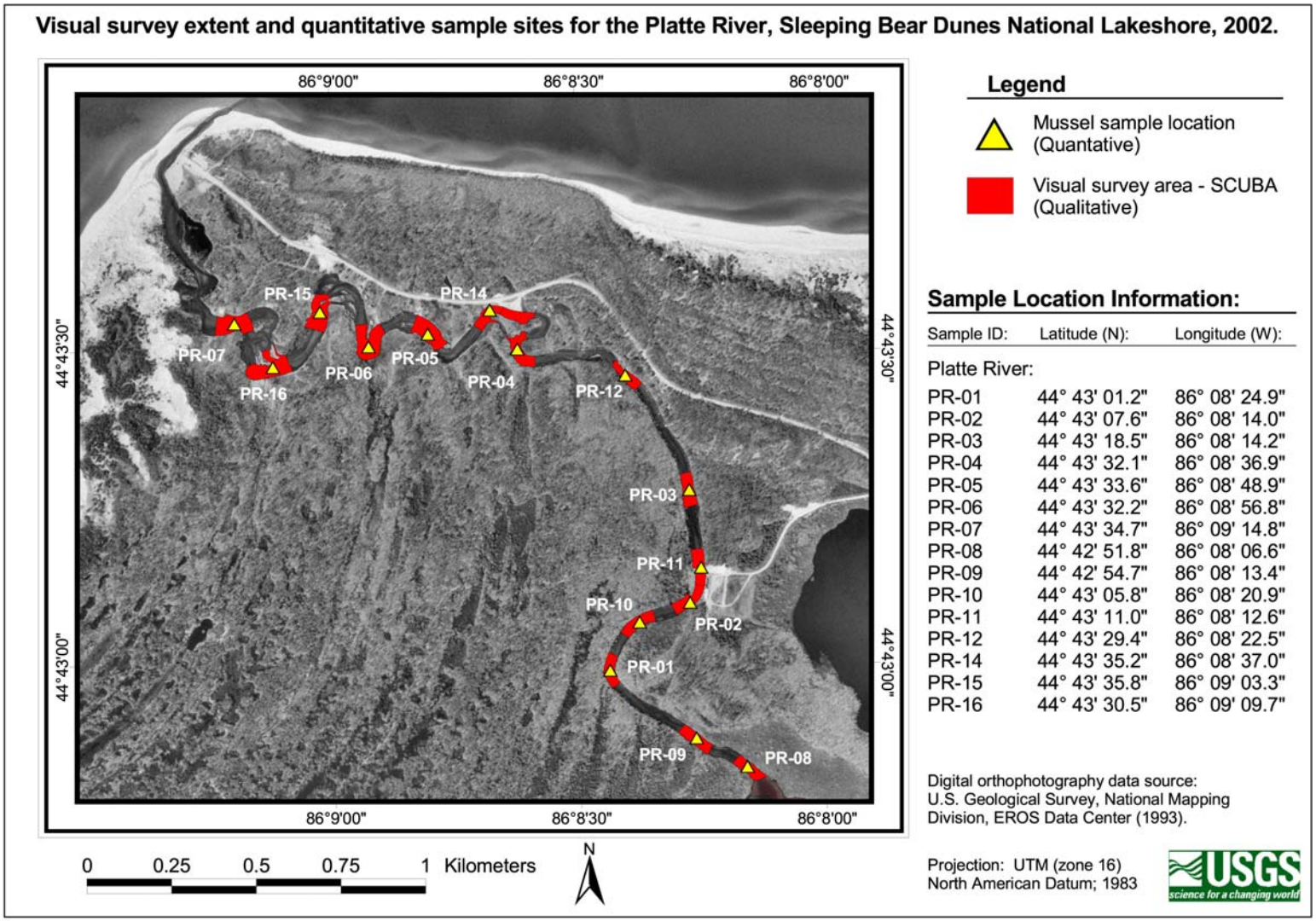

Visual survey extent and quantitative sample sites for the Platte River, Sleeping Bear Dunes National Lakeshore, 2002.
86°9'00"
86°8'30"
86°8'00"
44°43'30"
44°43'00"
PR-15
PR-14
PR-07
PR-06
PR-05
PR-04
PR-16
PR-12
PR-03
PR-11
PR-10
PR-02
PR-01
PR-09
PR-08
0 0.25 0.5 0.75 1 Kilometers
N
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
Platte River:
PR-01 44° 43' 01.2" 86° 08' 24.9"
PR-02 44° 43' 07.6" 86° 08' 14.0"
PR-03 44° 43' 18.5" 86° 08' 14.2"
PR-04 44° 43' 32.1" 86° 08' 36.9"
PR-05 44° 43' 33.6" 86° 08' 48.9"
PR-06 44° 43' 32.2" 86° 08' 56.8"
PR-07 44° 43' 34.7" 86° 09' 14.8"
PR-08 44° 42' 51.8" 86° 08' 06.6"
PR-09 44° 42' 54.7" 86° 08' 13.4"
PR-10 44° 43' 05.8" 86° 08' 20.9"
PR-11 44° 43' 11.0" 86° 08' 12.6"
PR-12 44° 43' 29.4" 86° 08' 22.5"
PR-14 44° 43' 35.2" 86° 08' 37.0"
PR-15 44° 43' 35.8" 86° 09' 03.3"
PR-16 44° 43' 30.5" 86° 09' 09.7"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world

Figure 8.

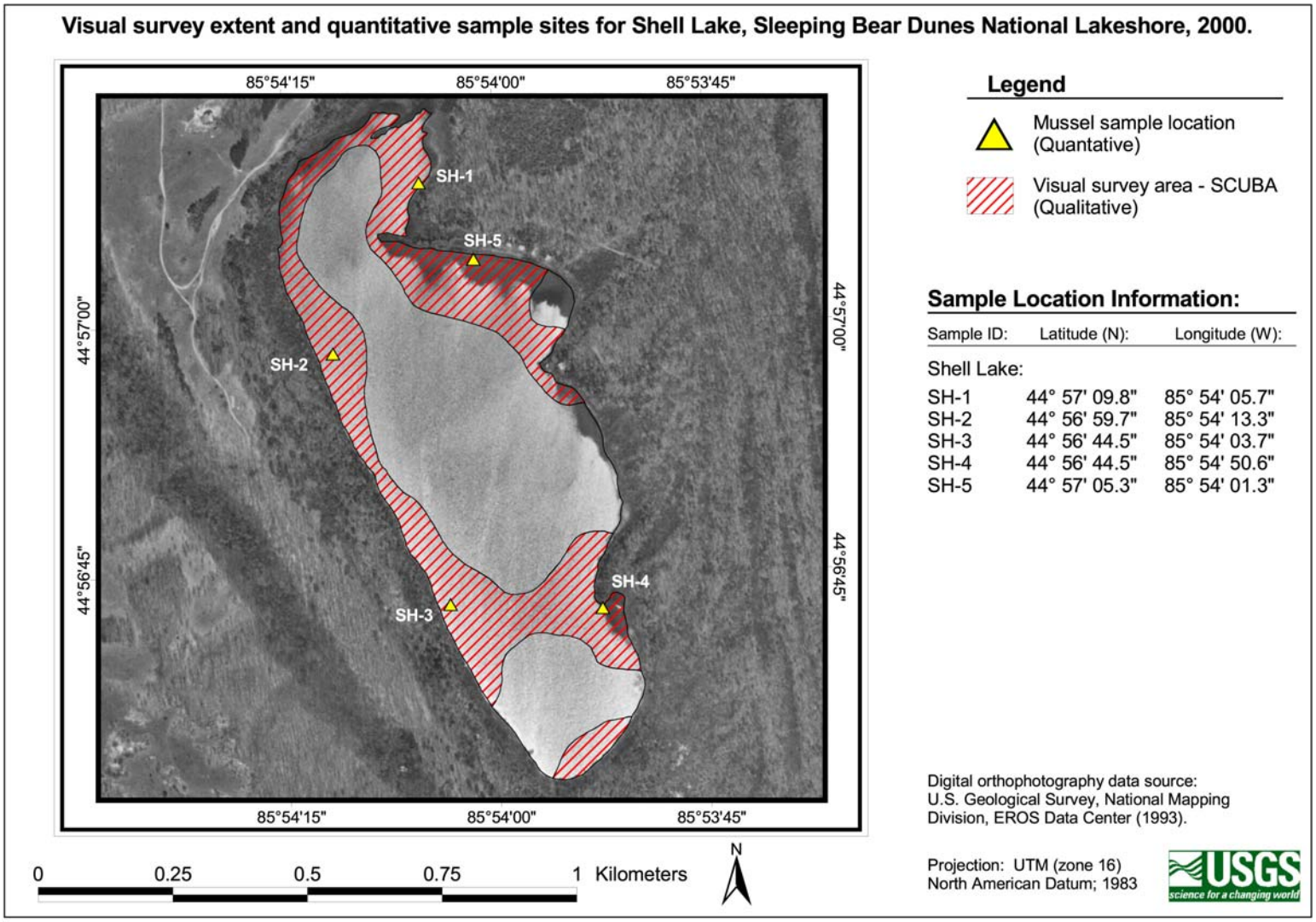

Visual survey extent and quantitative sample sites for Shell Lake, Sleeping Bear Dunes National Lakeshore, 2000.
85°54'15"
85°54'00"
85°53'45"
44°57'00"
44°56'45"
SH-1
SH-5
SH-2
SH-4
SH-3
Legend
Mussel sample location (Quantative)
Visual survey area - SCUBA (Qualitative)
Sample Location Information:
Sample ID: Latitude (N): Longitude (W):
Shell Lake:
SH-1 44° 57' 09.8" 85° 54' 05.7"
SH-2 44° 56' 59.7" 85° 54' 13.3"
SH-3 44° 56' 44.5" 85° 54' 03.7"
SH-4 44° 56' 44.5" 85° 54' 50.6"
SH-5 44° 57' 05.3" 85° 54' 01.3"
Digital orthophotography data source:
U.S. Geological Survey, National Mapping Division, EROS Data Center (1993).
Projection: UTM (zone 16)
North American Datum; 1983
USGS
science for a changing world
0 0.25 0.5 0.75 1 Kilometers
N

Figure 9.

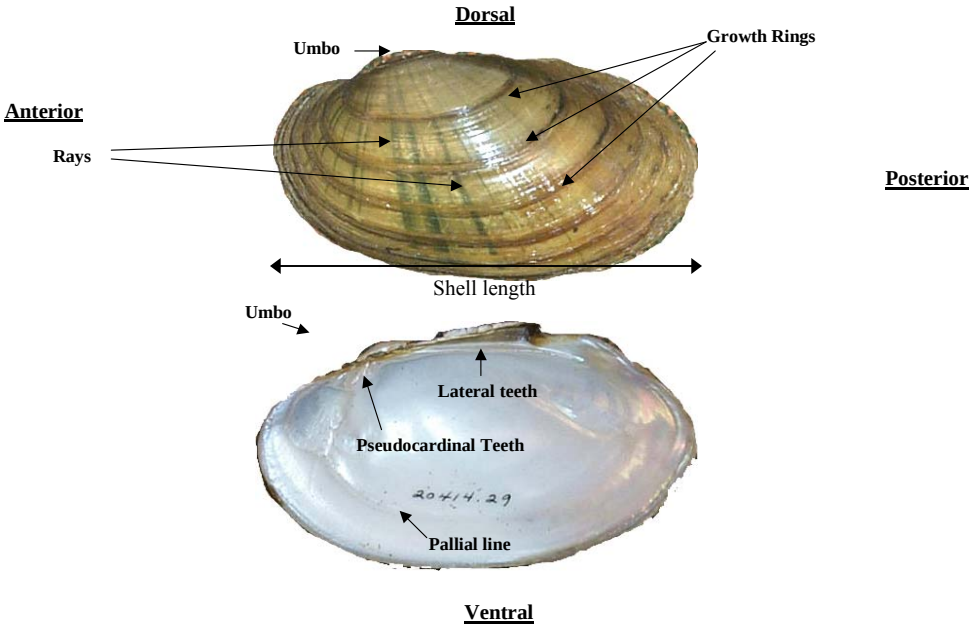


Figure 10. Unionid shell morphology.

Sixteen unionid species were found distributed throughout the 10 quantitatively sampled water bodies, though not all species were found in all water bodies (Table 2). Only 4 dead shells of one species were found in Bass Lake in 2000 (Table 2), therefore no data are presented for this lake. The Platte River had the greatest species richness, with 12 and 9 species collected in 2001 and 2003, respectively, with a total of 13 different species for both years; School Lake (2000) had only one species (Table 2). Two species, *Pyganodon grandis* (giant floater) and *Lampsilis siliquoidea* (fat mucket) were the most common species found throughout the park. These two species dominated the unionid communities in all the lakes where unionids were present. *Lampsilis siliquoidea* was the dominant species in the Platte and Crystal Rivers. *Pyganodon grandis* is

generally not common in fast flowing water. The *Lampsilis fasciola* found in the tailrace of the Crystal River is a Michigan threatened species (Michigan Department of Natural Resources 1999). Only one live individual and one dead shell were found there, and nowhere else in the river.

Unionid species richness, density, and distribution could not be correlated to any measured environmental parameter such as fish species present, water quality parameters, water body trophic status, substrate type, or water depth. Fish species composition data was taken from Vana-Miller (2002) and is compared to clam species composition for Sleeping Bear Dunes National Lakeshore in Table 3. Although clams are dependent on fish as hosts for successful reproduction (see Appendix C), there appears to be no direct correlation between species richness and fish species occurring at Sleeping Bear Dunes National Lakeshore (Table 3). Comparisons were made using water quality data obtained from Murphy (2004). Parameters known to affect unionid survival such as calcium levels (must be above 20 ppm), dissolved oxygen levels (>3 ppm), and pH (>4) were at acceptable levels for all the water bodies measured. Unionid density was also compared to the trophic status of the water body, with no apparent correlation between the two in the park (Table 4).

Table 2. Distribution of unionid species found in Sleeping Bear Dunes National Lakeshore, 2000-2003. **X**=present. ***=absent. **X**=dead shell only.

	BL2000	CR2000	CR2001	LL2003	LM2001	NBL2001	OC2001	OL2001	PR2001	PR2003	SCL2000	SHL2000
Anadontoides ferussacianus	*	X	*	*	*	*	X	X	X	*	*	*
Elliptio complanata	*	X	X	*	*	*	*	*	X	X	*	*
Elliptio dilatata	*	X	*	*	*	*	*	*	X	X	*	*
Lampsilis fasciola	*	X	*	*	*	*	*	*	*	*	*	*
Lampsilis siliquoidea	*	X	X	*	*	X	*	X	X	X	*	X
Lampsilis ventricosa	*	*	*	*	*	*	*	X	X	X	*	*
Lasmigona complanata	*	*	*	X	*	*	*	*	X	X	*	*
Lasmigona costata	*	X	X	*	*	*	*	*	X	*	*	*
Ligumia recta	*	*	*	*	*	*	*	*	*	X	*	*
Ligumia subrostrata	*	*	*	*	*	*	*	*	X	X	*	*
Pyganodon cataracta	*	*	*	*	X	*	*	X	X	*	*	X
Pyganodon grandis	X	X	*	X	X	X	X	X	X	X	X	X
Pyganodon lacustris	*	*	*	*	*	*	*	X	X	*	*	*
Pyganodon spp. hybrid	*	*	*	*	X	*	X	X	X	*	*	X
Strophitus undulatus	*	X	X	*	*	*	X	X	X	X	*	*
Venustaconcha ellipsiformis	*	X	X	*	*	*	*	*	*	*	*	*

BL: Bass Lake; CR: Crystal River; LL: Loon Lake; LM: Lake Manitou; NBL: North Bar Lake; OC: Otter Creek; PR: Platte River; SCL: School Lake; SHL: Shell Lake

Table 3. Comparison of unionid and fish species richness (S) per water body, Sleeping Bear Dunes National Lakeshore, 2000-2003. There was no correlation between unionid or fish species richness.

Water body	Clam S	Fish S*
Bass Lake (Leelanau Co.)	ND	12
Bass Lake (Benzie Co.)	0	16
Crystal River	8	31
Lake Manitou	3	8
Loon Lake	2	23
North Bar Lake	2	16
Otter Creek	3	25
Otter Lake	8	18
Platte River	13	ND
School Lake	1	11
Shell Lake	4	12

* Fish species richness data taken from Vana-Miller (2000).

Table 4. Unionid density (#/m^2) descriptive statistics for 10 water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003.

	BL2000	*CR2000*	*CR2001*	*LL2003*	*LM2001*	*NBL2001*	*OC2001*	*OL2001*	*PR2001*	*PR2003*	*SCL2000*	*SHL2000*
# grids sampled (grid area m^2)	17(5)	9(15)	9(5)	140(1)	155(1)	52(5*)	42(1)	48(1)	150(1)	50(1)	27(5)	29(5)
Total area sampled (m^2)	85	133	45	140	155	860	42	48	150	50	135	145
Total live clams sampled	0	131	17	2	55	3	3	293	433	202	14	58
Mean grid density (#/m^2)	ND	2.61	0.38	0.01	0.35	0.01	0.07	6.10	2.89	4.04	0.10	0.40
Standard Deviation	ND	4.9	0.4	0.1	1.0	0.0	0.3	9.8	6.1	7.9	0.2	0.3
Standard Error	ND	1.6	0.1	0	0.1	0	0.1	1.4	0.5	1.1	0	0.1
95% Confidence Level	ND	3.7	0.3	0	0.2	0	0.1	2.8	1.0	2.2	0.1	0.1
Minimum	ND	0	0	0	0	0	0	0	0	0	0	0
25th percentile	ND	0.2	0	0	0	0	0	1.0	0	0	0	0.2
Median	ND	0.8	0.4	0	0	0	0	2	1	2	0	0.4
75th percentile	ND	1.2	0.6	0	0	0	0	6.3	2.8	5	0.2	0.6
Maximum	ND	15.2	1	1	7	0.2	2	49	31	41	0.6	1.4
Mode	ND	1.2	0	0	0	0	0	0	0	0	0	0.2
Trophic Status	M	.	.	E/M/O	E/M	E/M/O	.	E/M/O	.	.	H/E/M/O	H/E/M/O

H=hypereutrophic; E=eutrophic; M=mesotrophic; O=oligotrophic; based on Carlson's TSI values. Water quality data from 2003 Year-End Water Quality Report and Water Resources Management Plan (2002). *Two 300-m^2 surveys were conducted in addition to the grid Surveys, resulting in a much larger total area sampled than in the other water bodies.

Unionid density (#/m^2) and associated descriptive statistics for each water body are presented in Table 4. Grids were used as replicate samples and therefore grid density is considered the raw data used in analyses. Different size grids (1, 5, or 15 m^2) were used depending on the water body and year sampled. Otter Lake (2001) had the greatest mean grid density, and Loon Lake (2003) and North Bar Lake (2001) had the lowest mean grid density (Table 4). There was a statistically significant difference in grid density among water bodies (Table 5), though this should be interpreted with caution because of the many replicates of zero and unequal sample sizes (due to the use of different sized grids and varying depths between water bodies). For example, the Crystal River (2000 & 2001) had 9 replicates while Lake Manitou (2001) had 155.

Table 5. Analysis of variance of unionid density (#/m^2) among water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003.

SUMMARY

Water body (year)	*# grids*	*Mean density (#/m^2)*
CR(2000)	9	2.61
CR(2001)	9	0.38
LL(2003)	140	0.01
LM(2001)	155	0.35
NBL(2001)	52	0.01
OC(2001)	42	0.07
OL(2001)	48	6.10
PR(2001)	150	2.89
PR(2003)	50	4.04
SCL(2000)	27	0.10
SHL(2000)	29	0.4

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2450.035	10	245.0035285	12.78615	<0.001	1.8442137
Within Groups	13413.14	700	19.16162952			
Total	15863.18	710				

Analysis of variance was conducted within water bodies in which >50 unionids were collected over at least three 5-ft depth zones (Table 6). There were significant differences in grid density among depth zones for both Lake Manitou (2001) and Shell

Lake (2000), but not for Otter Lake (2001) (Table 6). Again, interpretation should be cautious due to the same caveats mentioned above. However, unionid distribution was limited to areas above the thermocline, particularly in the deeper Lake Manitou.

Other than Lake Manitou and Shell Lake, unionid distribution in the lakes was basically random, and could not be associated with any environmental feature. Distribution in the Platte River was also random, but more highly clumped, though this pattern could not be related to any observable factor. The Crystal River had highest densities just below the dam followed by a decreasing density gradient, which is typical of invertebrate densities below regulated dams (Marangelo 1997).

Table 6. Analysis of variance of unionid density (#/m^2) by depth zone within water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003.

LM2001

SUMMARY

Depth Zones (ft)	*# grids*	*Mean density (#/m^2)*
0-5	30	0.97
6-10	30	0.57
11-15	35	0.11
16-20	25	0.08
21-25	25	0.12
26-30	10	0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.12768	5	3.825536098	3.842137	0.00265	2.274902
Within Groups	148.3562	149	0.995679131			
Total	167.4839	154				

OL2001

SUMMARY

Depth Zones (ft)	*# grids*	*Mean density (#/m^2)*
0-5	11	9.09
6-10	13	9.54
11-15	14	4.43
16-20	8	0.75
21-25	2	0.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	582.9107	4	145.7276838	1.612709	0.188432	2.588834
Within Groups	3885.568	43	90.36205655			
Total	4468.479	47				

SHL2000

SUMMARY

Depth Zones (ft)	*# grids*	*Mean density (#/m^2)*
0-5	22	0.49
6-10	4	0.15
11-15	3	0.07

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.765152	2	0.382575758	3.833353	0.034757	3.36901
Within Groups	2.594848	26	0.099801865			
Total	3.36	28				

Length-frequency

Length-frequency data was compiled for those water bodies in which >50 unionids were collected (Figs. 11-16). It should be noted that very small animals (<20 mm) are traditionally very difficult to find as they live deep in the sediments and under rock, and therefore the sample length-frequency distributions may be skewed toward older individuals. While length may not always accurately reflect age, multiple size classes indicate that successful reproduction, recruitment, and long-term survival is occurring.

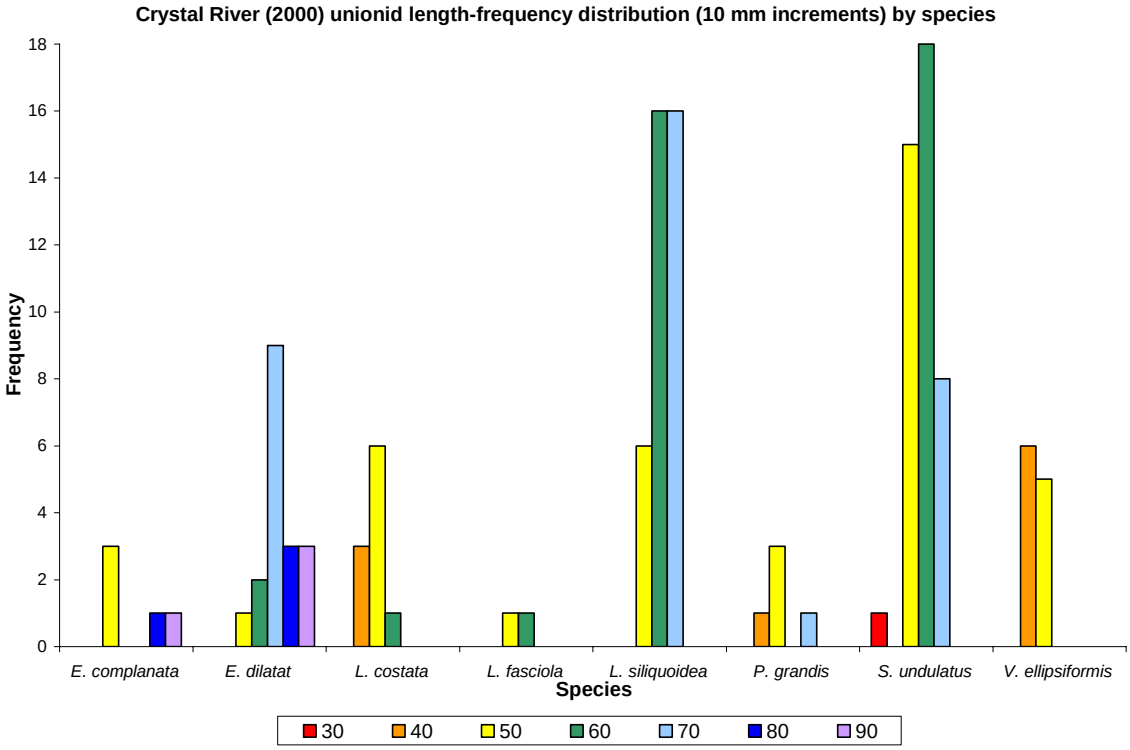


Figure 11. Length-frequency data for unionid species collected from the **Crystal River**, Sleeping Bear Dunes National Lakeshore, **2000**. Lengths were grouped into 10 mm increments.

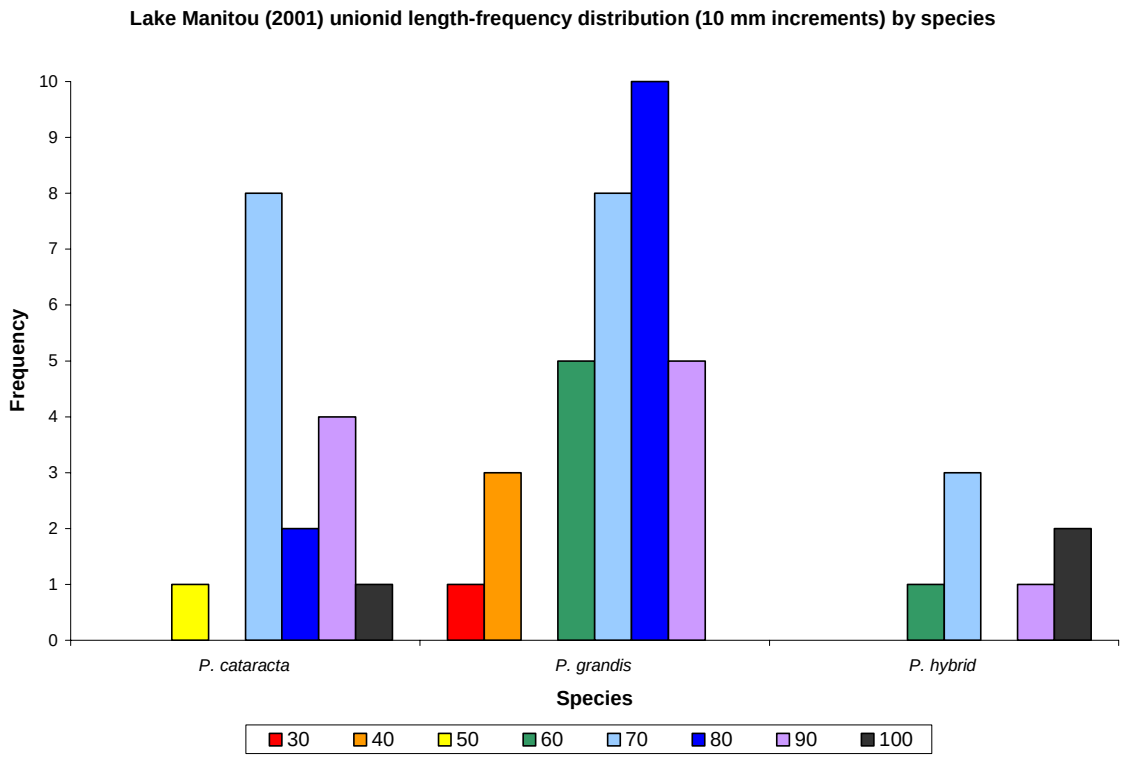


Figure 12. Length-frequency data for unionid species collected from **Lake Manitou**, Sleeping Bear Dunes National Lakeshore, **2001**. Lengths were grouped into 10 mm increments.

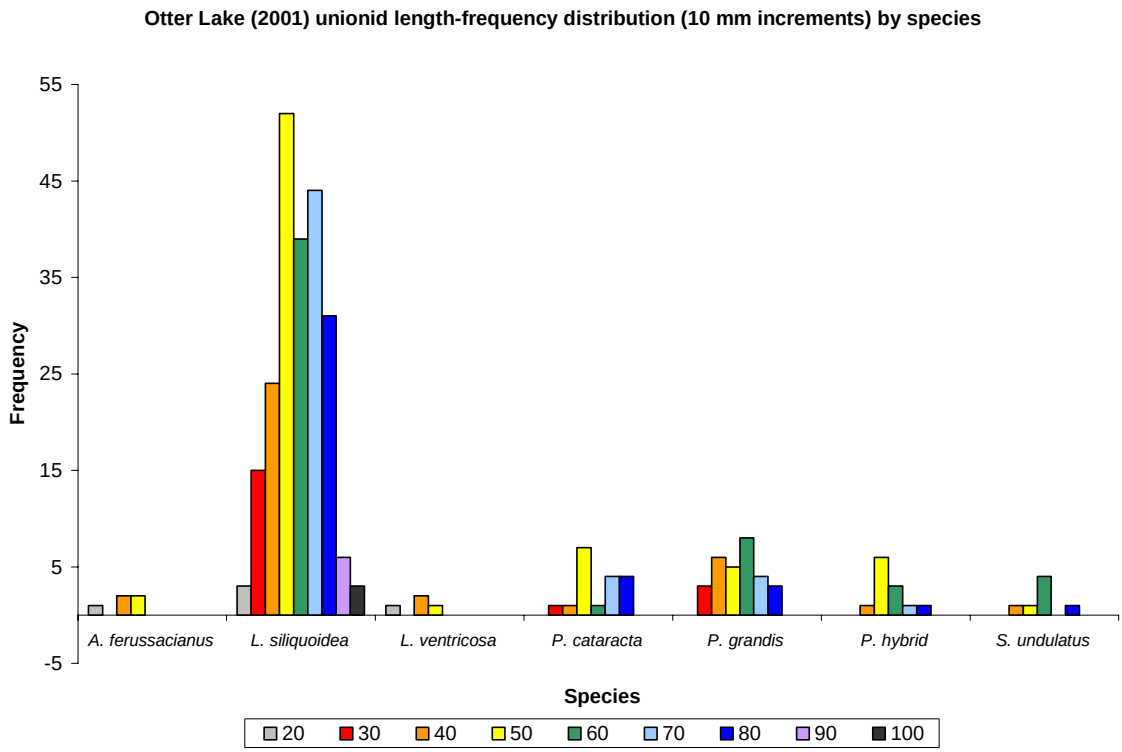


Figure 13. Length-frequency data for unionid species collected from **Otter Lake**, Sleeping Bear Dunes National Lakeshore, **2001**. Lengths were grouped into 10 mm increments.

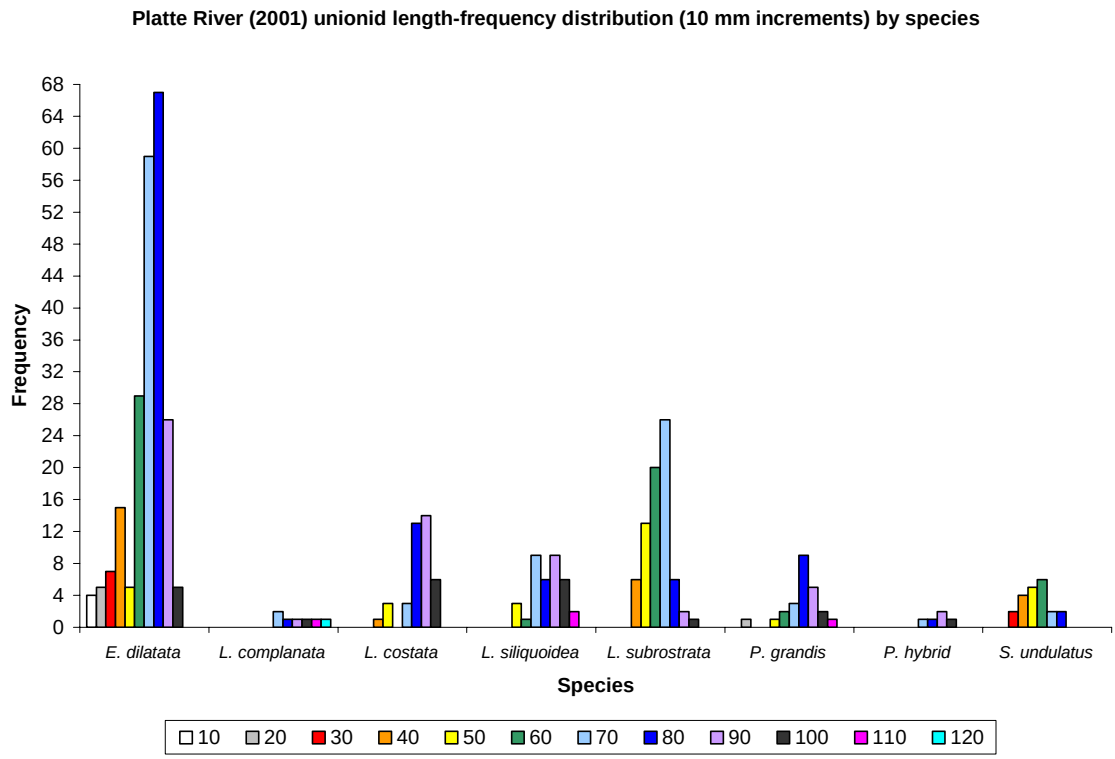


Figure 14. Length-frequency data for unionid species collected from the **Platte River**, Sleeping Bear Dunes National Lakeshore, **2001**. Lengths were grouped into 10 mm increments.

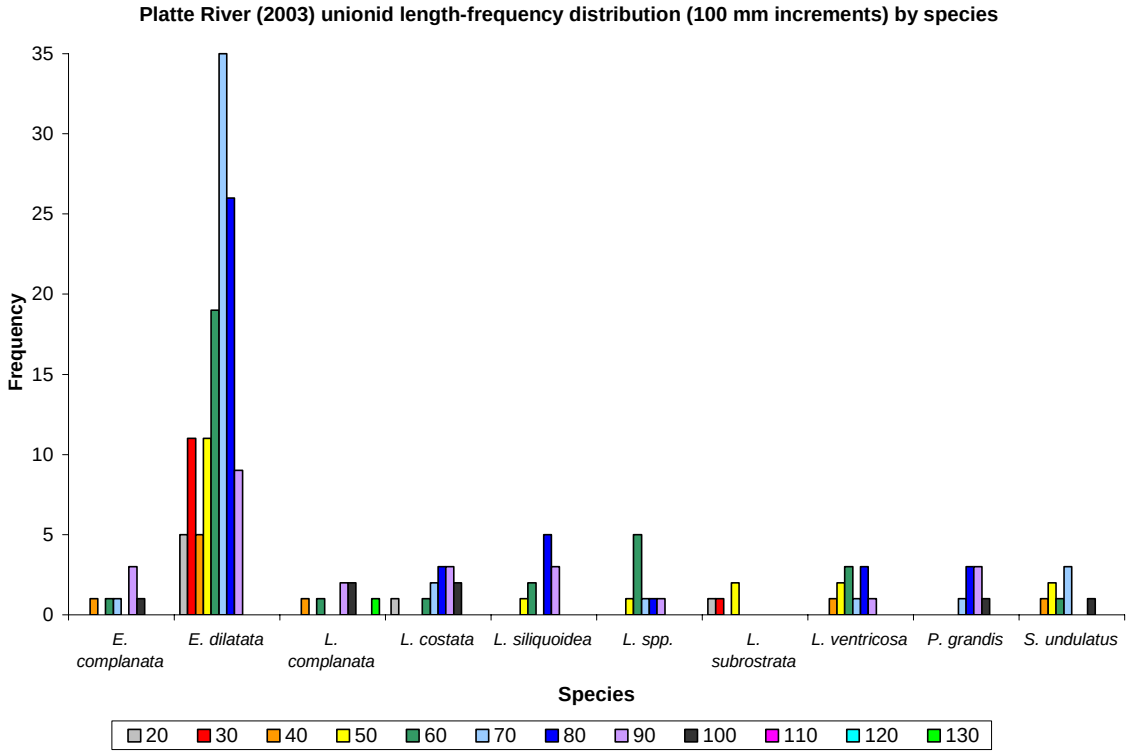


Figure 15. Length-frequency data for unionid species collected from the **Platte River**, Sleeping Bear Dunes National Lakeshore, **2003**. Lengths were grouped into 10 mm increments.

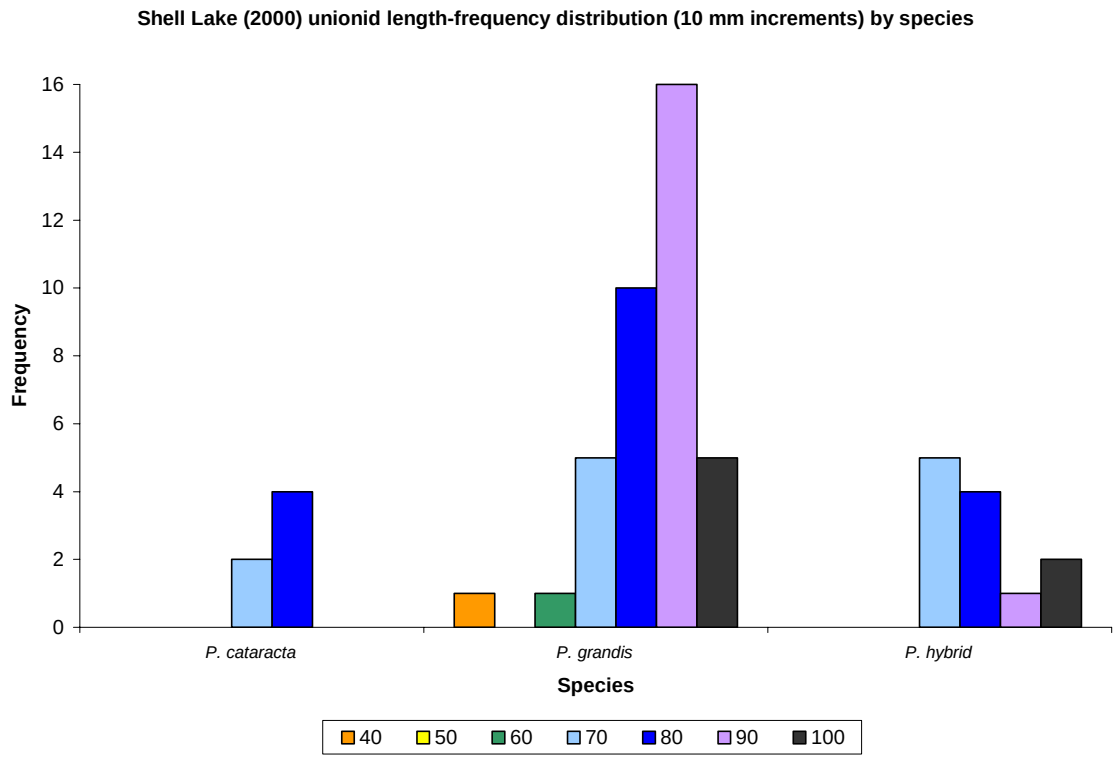


Figure 16. Length-frequency data for unionid species collected from **Shell Lake**, Sleeping Bear Dunes National Lakeshore, **2000**. Lengths were grouped into 10 mm increments.

Age-frequency and growth for *Pyganodon grandis*

In unionids, length and age are not necessarily directly related. To determine age, we first had to determine the relationship between external annuli or visible growth rings on the outside of the shell and a more accurate estimation of age as based on internal annuli in the shell cross-section. Using external annuli, if comparable, would give us a larger data set, since use of internal annuli requires killing the animal. Shell cross-sections showed that internal and external annuli were identical in *Pyganodon spp.* We used one individual *Pyganodon grandis* per water body to develop growth models (Fig. 17) which were then used to estimate age for individuals collected from one river and three lakes (Figs. 18-22). Statistical tests for differences among water bodies were not

performed due to low sample sizes, and because of the potential for growth alterations due to the presence of zebra mussels competing for the same food resources.

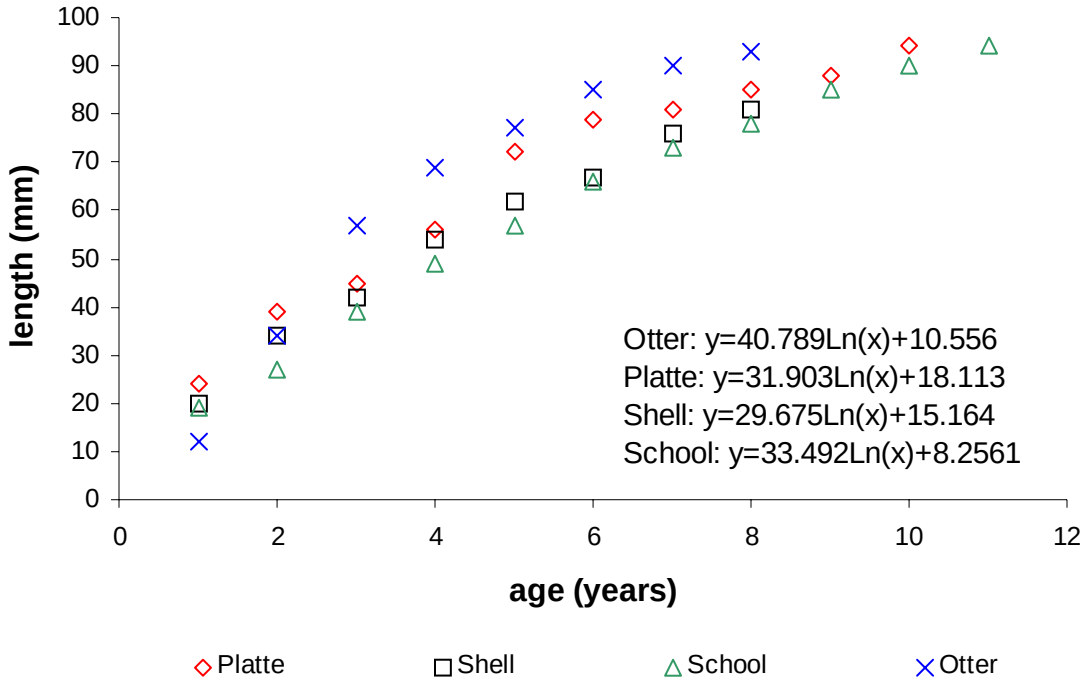


Figure 17. Growth model for one *Pyganodon grandis* from four different water bodies in Sleeping Bear Dunes National Lakeshore, sampled 2000-2003.

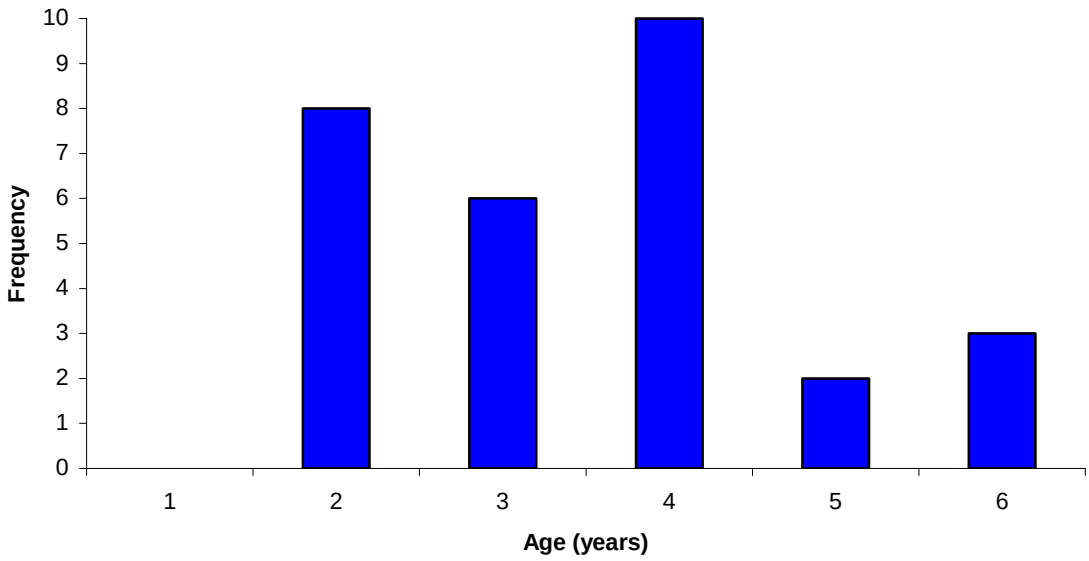


Figure 18. Age-frequency estimate for all *Pyganodon grandis* measured from **Otter Lake**, Sleeping Bear Dunes National Lakeshore, **2001**.

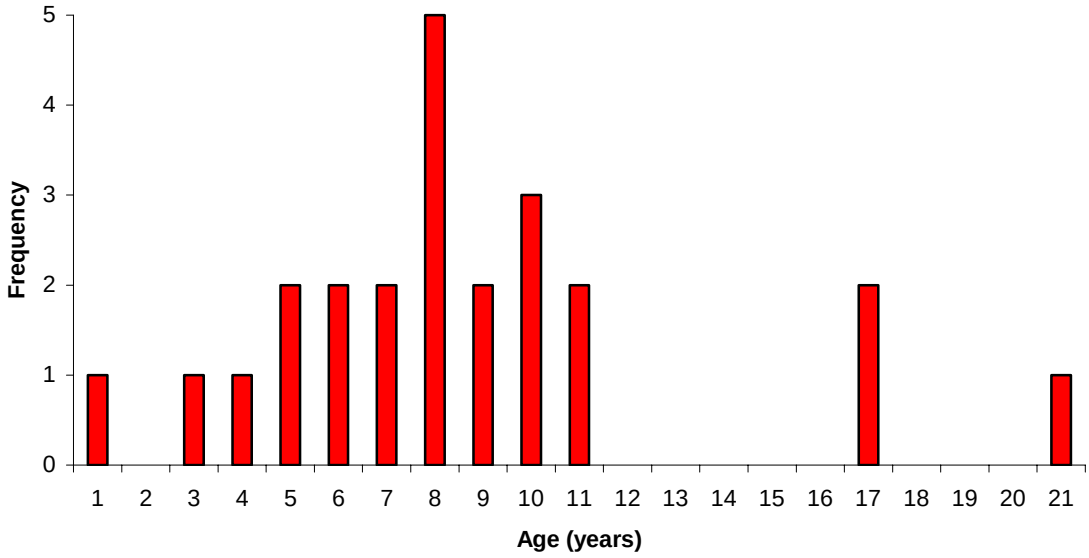


Figure 19. Age-frequency estimate for all *Pyganodon grandis* measured from **Platte River**, Sleeping Bear Dunes National Lakeshore, **2001**.

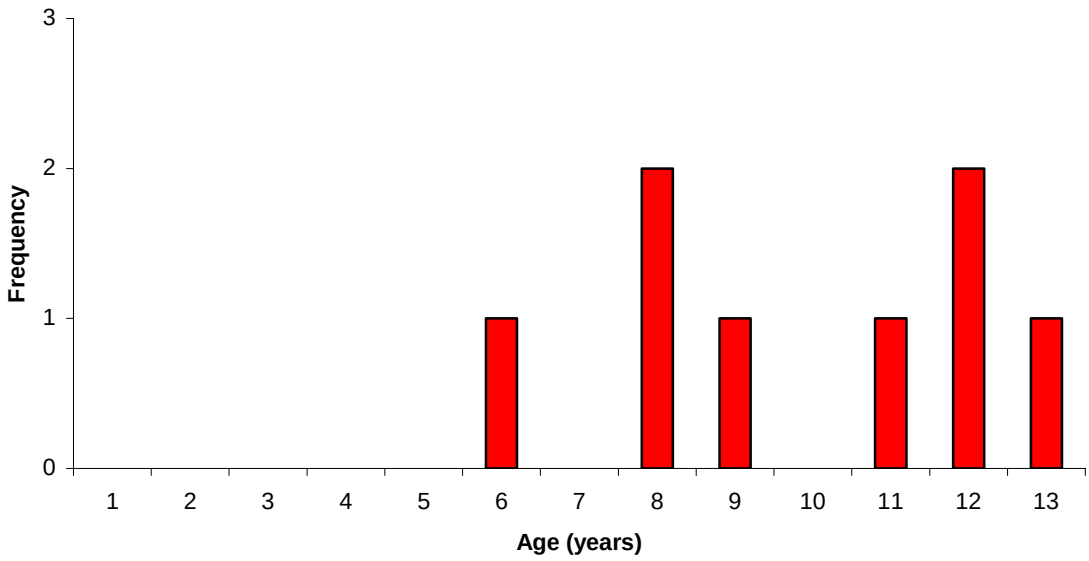


Figure 20. Age-frequency estimated for all *Pyganodon grandis* measured from **Platte River**, Sleeping Bear Dunes National Lakeshore, **2003**.

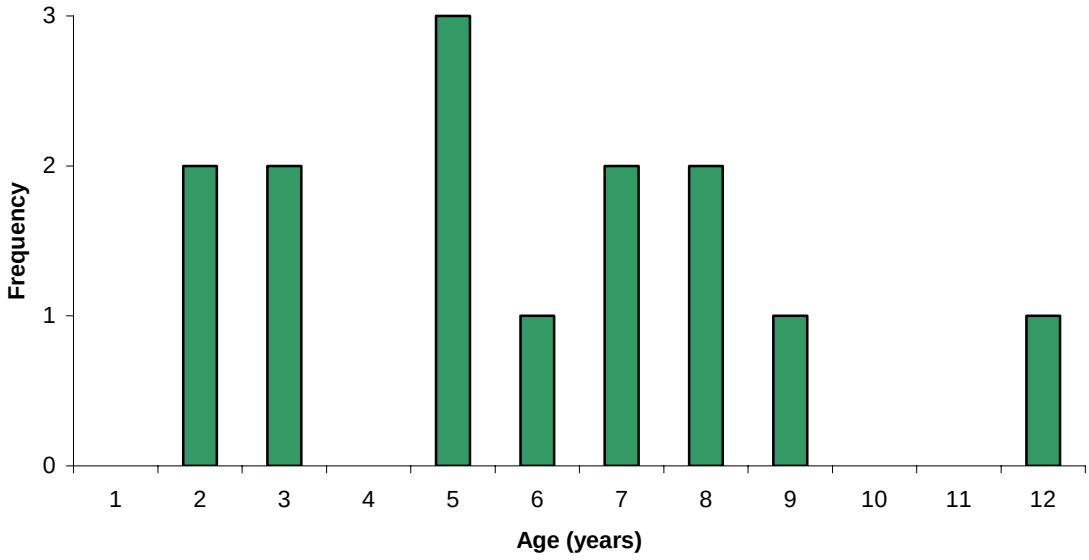


Figure 21. Age-frequency estimated for all *Pyganodon grandis* measured from **School Lake**, Sleeping Bear Dunes National Lakeshore, **2000**.

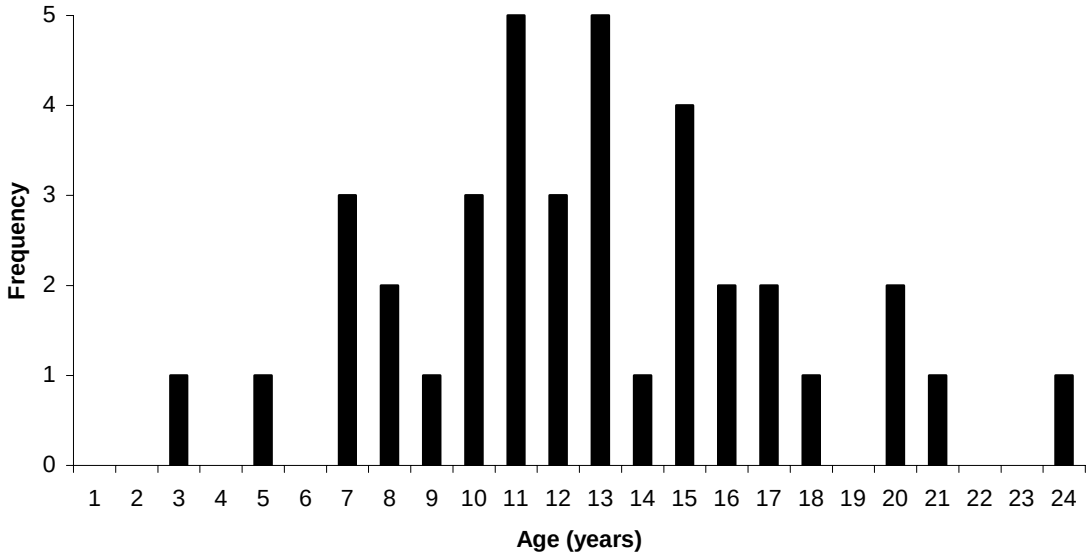


Figure 22. Age-frequency estimated for all *Pyganodon grandis* measured from **Shell Lake**, Sleeping Bear Dunes National Lakeshore, **2000**.

Contaminants

School Lake, Shell Lake, and the portion of the Crystal River downstream of Glen Arbor were sampled for soft tissue contaminants analysis. Only trace amounts of organic contaminants such as p,pDDE and a few PCB congeners were found in tissues of the clams tested (Appendix B). Though detectable, the levels found are well below any concentrations of concern. Contaminants data from Appendix B and population estimates (data not shown) were used to calculate the amount of contaminants sequestered in unionid soft tissue for the 3 water bodies tested (Table 7). Location or species differences were not detected due to a low sample size. Contaminant analysis data for Isle Royale National Park are presented in Appendix B for comparison.

Table 7. Calculated amounts of contaminants sequestered in soft tissue of unionid populations per water body, Sleeping Bear Dunes National Lakeshore, 2000.

Contaminant	School Lake	Shell Lake	Crystal River
PCBs (mg)	2.8	11.3	5.2
Toxaphenes (mg)	0	3.7	0
Pentachlorobenzene (ug)	102	81.4	136.6
Hexachlorobenzene (ug)	0	135.7	439.2
Dachtal (ug)	0	0	156.2
trans(G)-chlordane (ug)	0	0	97.6
trans(G)-nonachlor (ug)	0	0	136.6
p,p,-DDE (mg)	0	0	1.64
cis-nonachlor (ug)	0	0	380.1
Barium (g)	1827	2132	1006
Cadmium (g)	7.693	18.652	1.686
Chromium (g)	4.977	5.89	7.47
Copper (g)	7.088	20.723	35.249
Lead (g)	62.281	16.873	6.002
Mercury (g)	0.0662	0.107	0.432
Nickel (g)	2.455	12.19	6.121
Zinc (g)	563.3	1169	664.9

DISCUSSION

Unionid population diversity, distribution, and density

Sleeping Bear Dunes National Lakeshore has a rich and diverse unionid fauna though its continued survival is problematic due to human manipulations and exotic species interactions. At this time, unionids are commonly found throughout the park in most of the lakes and streams, regardless of size or productivity. Overall species composition is typical for the Great Lakes region, but higher than that found in other Great Lakes parks such as Isle Royale National Lakeshore and Picture Rocks National Lakeshore (Nichols et al. 2001a, 2001b). Most of the species found in SLBE are considered habitat-tolerant and have a widespread distribution in the Midwest. Two individuals (one live and one dead) of *Lampsilis fasciola* (wavyrayed lampmussel) were found in the tailrace area of the Crystal River. This is a species of concern and is listed as

threatened by the State of Michigan (Michigan Department of Natural Resources 1999). Overall, the number of species found (S=16) is equal to or slightly higher than what has been recorded for similar habitats in the northern part of lower Michigan (Badra and Goforth 2003). Changes in population composition and density since the park was established cannot be determined, as no historical data on this fauna has been found. However, the future of the entire SLBE unionid fauna is at risk due to influx of zebra mussels into park waters.

With one exception, the rivers had a greater number of unionid species than did the lakes, which is the typical distribution pattern in North America. Unionids are considered to be river animals, reaching their greatest species diversity and densities in flowing waters, particularly in parts of the Mississippi River watershed. Lakes generally contain fewer species and much less dense populations. Regulated streams, with their mixture of lentic and lotic habitats, fall somewhere in the middle in terms of species diversity and population densities. Rivers support higher species diversity because of the increased number of potential fish hosts that are necessary for the initial survival of larval unionids and movement into new habitats. In contrast, lakes are limited in species diversity for the same reason they are often limited in fish species, e.g. isolation from colonization events. The presence of unionids indicates that these lakes must have been historically connected to a river or one of the Great Lakes, or fish that were infected with unionid larvae were stocked into the lakes.

The three rivers surveyed (Crystal, Otter, and Platte) showed greater unionid species richness and distribution that can be directly related to river hydrology and morphology. Species richness was highest in the Platte River, with 16 live species of

unionids. This is one of the greatest number of species for any stream surveyed to date by the Michigan Natural Features Inventory in northern lower Michigan (Badra and Goforth 2003). Badra and Goforth (2003) found only nine live species in the Manistee, five in the Pere Marquette, and eight in the AuSable rivers. The population in the Platte River appeared to contain multiple length (age) classes of most species found, plus young animals, indicating that recruitment has been occurring over a number of years. Unionid populations showed a patchy, clumped distribution. This distribution pattern is a reflection of past fish host distribution. Areas where fish congregate, such as by bridges or gravel bars, tend to have greater unionid densities since increased fish residence time increases the likelihood of unionid larval release. In the Platte River, the highest population densities occurred below the fish weir.

The Crystal River fauna has the second highest species diversity found in the park (8 species). Unionid density was greatest just below the dam and then rapidly declined. This gradient distribution pattern is typical for regulated streams with low head dams (e.g., see Marangelo (1997) for a description of unionid distribution in the regulated Huron River). The clumped distribution in the tailrace below the dam is generally believed to reflect the greater number and residence times of fish hosts using this habitat. It is also indicative of greater concentration of food supplies available from the upstream lake, and lower competition for these resources. The eight species of unionids found in this river is very comparable to the number of species found by Badra and Goforth (2003) in the Manistee River. One state threatened species, *Lampsilis fasciola* (wavyrayed lampmussel), was found in the tailrace but not elsewhere in the Crystal River. The population in the tailrace area consists of multiple size (year) classes indicating

recruitment is occurring on a regular basis. However, there is no indication that recruitment is occurring regularly in the river past the first bend downstream of the dam until the area just below the second set of culverts on Hwy 675 where young *Ligumia subrostrata* were found again.

Otter Creek was one of the few water bodies surveyed in the park that was basically devoid of unionids. A few individuals of a few species were found down near the mouth of the river, but no live animals or dead shells were found upstream from Lake Michigan. Our hypothesis is that this lack of unionids is due to a heavy influx of ground water rendering year-round water temperatures too low in the river. Year-round temperature profiles do not exists for this river, and therefore, our hypothesis that the temperature regime is too low for successful reproduction for most of the year is based on visual observation. We sampled Otter Creek in early August during a hot summer and water temperatures in the river were below 13 °C. Though we did not find live animals or recent dead shell during our survey of most of Otter Creek, there was one location where historic shell of *Elliptio complanata* (eastern elliptio) was found. These old shells were within 50 meters of Otter Lake, near an old homestead, and were about a foot or so above the water level at the time. There were quite a few in the area, mostly just small fragments, but some whole shells were collected. This species did not occur in Otter Lake, nor in Otter Creek, but is a common species in Lake Michigan. This shell is old and may be a residue from historical lake shoreline shifts or from human predation.

Overall, lake populations of unionids may be limited in species diversity, but unionids have successfully colonized many different types of lakes throughout SLBE. All of the lakes surveyed at SLBE contained live unionids or dead shell even though the

lakes varied in basin morphometry, connectivity to Lake Michigan, fish community structure, ground water input, landscape development, and trophic status. The two genera which dominated lake populations (*Lampsilis* and *Pyganodon*), were also the most dominant genera found in lakes in other Great Lakes parks (e.g., Nichols et al. 2001a, 2001b). No measured environmental factor could be related to species richness, distribution, or age structure (based on length) within the lakes with the exception of water depth and thermocline development. Unionids do not colonize areas below the thermocline, usually due to temperature limitations. Only two lakes surveyed, Lake Manitou and Shell Lake, were deep enough to sustain a thermocline in the summer, and unionid distribution was limited to the shallow portions of these lakes. This is consistent with depth distribution limitations we found for these genera at Isle Royale and Pictured Rocks National Lakeshores (ISRO and PIRO, respectively).

Bass Lake (Leelanau Co.) is unique in that it contains large numbers of dead shell, but no live unionids. The condition of the shell indicates that these animals probably died within the last 10-15 years. There is no obvious data on what caused this widespread mortality, as fish and insects occur in the lake. However, many visitors and local residents use this lake for recreational purposes. Our best guess is that this lake was unofficially chemically treated to remove swimmer's itch that is endemic in this region. Swimmer's itch is a skin inflammation caused by a group of flatworms that are called schistosomes. Most schistosomes that cause swimmer's itch use bird hosts for the adult parasite and aquatic snails as intermediate hosts for the larval stages. For many decades, the application of copper sulfate as a molluscicide has been recommended on recreational lakes to break the life cycle by killing the snail intermediate hosts. Copper sulfate kills

all mollusks, including unionids. Laboratory analyses of water and sediment samples are needed to confirm this hypothesis. However, the fact that no bivalves of any kind (e.g., fingernail clams, zebra mussels, nor unionids) were found, and only a few very small snails were present, leads us to believe that a chemical treatment is the most likely explanation.

Contaminants

The unionids at SLBE contained very low levels of all the contaminants tested. These levels were well below the state and federal action levels not only for the individual animal, but also for the population as a whole. Population levels are of concern because unionids are generally long-lived animals that sequester contaminants away from ecosystem cycling for many decades. A sudden die-off in unionid fauna or replacement of unionids with shorter-lived zebra mussels would accelerate the turnover rate of contaminants in the waters of SLBE. However, the levels of the contaminants tested are so low that even a loss of the entire unionid fauna would not release a substantial amount of contaminants to the environment.

Unionid habitat restrictions

Based on our surveys and water quality parameters presented by Murphy (2004), we predict that unionids will be found in most lakes and streams regardless of size or depth in SLBE with the following restrictions: (1) The water body must not freeze solid in the winter. Even shallow lakes such as Mud Lake can contain unionids if ground water input or other conditions prevent complete freezing. Streams and rivers must either

be deep enough to escape ice scour or contain substrate deep enough to permit burrowing in winter. Bedrock streams such as at ISRO and PIRO do not support unionid fauna. (2) Water temperature regime must accommodate a summer water temperature above 55 °F so that reproduction in unionids can occur. Otherwise, unionids might be present, but reproduction will be minimal. (3) Acidic waters will not support unionids; water pH > 5.5 is generally required for populations to occur. Given our current data, there is no way to predict population size or carrying capacity in waters that have not been surveyed.

Zebra mussels as a threat to unionid populations

The future survival of the unionid fauna at SLBE is questionable due to the continued expansion of zebra mussels into the inland waters of SLBE. Zebra mussels are believed to have become established in the inland waters of SLBE in 1997 (p. Murphy, Pers. Com.) and by 2003 had colonized 50% of the water bodies we surveyed. Two sites, Otter Lake and the Platte River, were surveyed in consecutive years. In both water bodies, zebra mussels increased dramatically between years. For example, in 2001, zebra mussels found colonizing unionids in the Platte River were concentrated where Loon Lake feeds into the Platte River. By 2003, zebra mussel distribution and density was greater, with colonies found down the river from the mouth of Loon Lake to just above the fish weir. In the Platte River in 2001, only one or two zebra mussels were found biofouling unionids, whereas in 2003, the number had increased to over 25 zebra mussels per unionid and the number of unionids covered had increased exponentially. We did not see any obvious increases in mortality between 2001 and 2003, but given the track record of zebra mussel interactions with unionids (e.g., Schloesser and Nalepa 1994; Baker and

Hornbach 1996; Schloesser et al. 1996) mortality rates are expected to climb and recruitment to cease. In Otter Lake, zebra mussels are biofouling plants, unionids, and insects (Fig. 23). The unionid population is at great risk throughout the park if this trend continues.

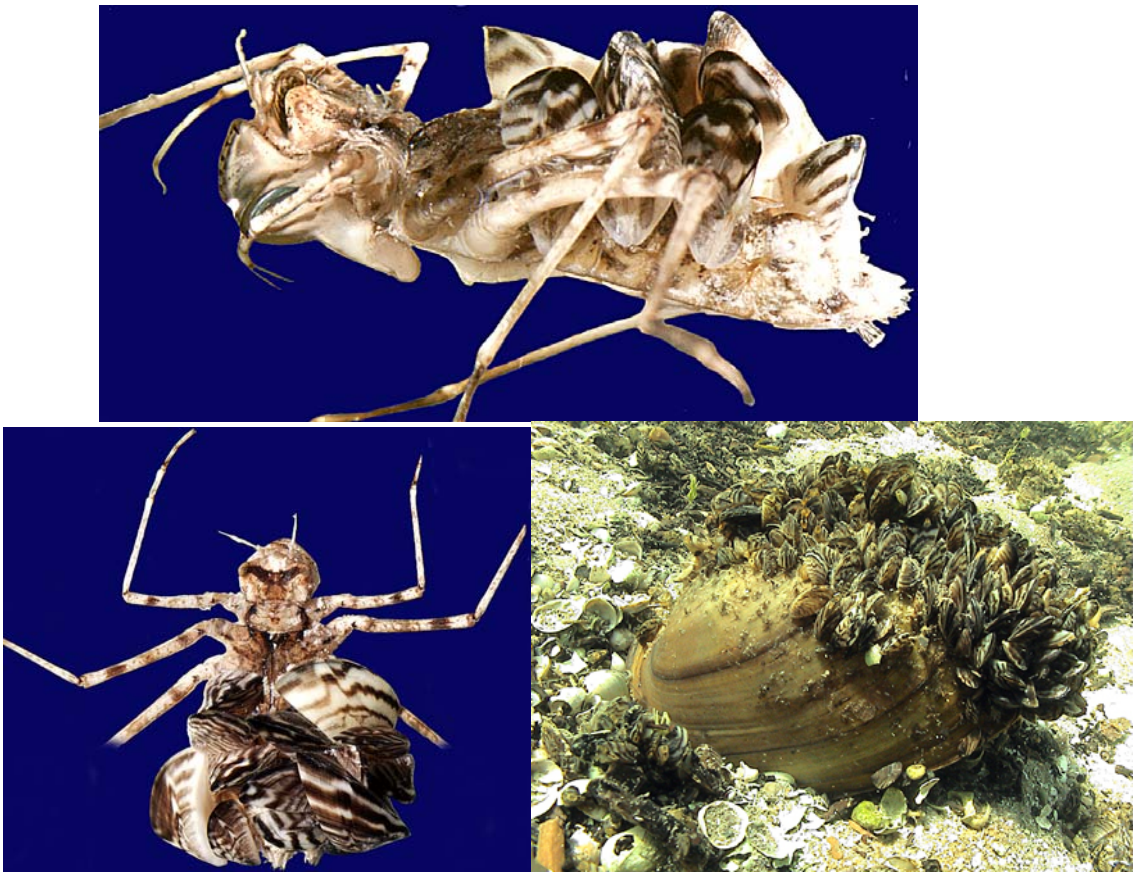


Figure 23. Zebra mussels biofouling dragonfly larvae and unionids from Otter Lake, Sleeping Bear Dunes National Lakeshore, 2002.

Mitigation and restoration

Potential techniques that the managers at SLBE could use to protect unionid populations from zebra mussels once they have become established have proven minimally successful in other parts of the country (e.g., Cope and Waller 1995). The three most common techniques are relocation of unionids into new uninfested habitats,

manually removing the biofouling zebra mussels and leaving the unionids *in situ*, or enhancing natural refugia. Relocation has been the most successful technique, but only in situations where unionids are only moved a short distance within the same water body (Cope et al. 2003). This technique is frequently used, and is successful in rivers where unionids are being moved from one point of concern, such as near a bridge construction project, into another part of the same river. Since habitat is basically the same, there are fewer potential difficulties with food supplies, fish hosts, and carrying capacity, and unionid survival is generally over 80% Relocation into other water bodies has generally resulted in mortality rates as high as 100% and long-term survival and establishment of a viable population has rarely been documented (Newton et al. 2001, Cope and Waller 1995).

The second mitigation technique, that of cleaning zebra mussels off the unionids and leaving the unionids *in situ*, is very effective in habitats where physical biofouling is the main cause of mortality. This technique is a viable option in water bodies that are shallow and can be readily reached by non-experienced personnel such as volunteers, to minimize expenses (e.g., Nichols et al. 2000; Hallac and Marsden 2001, Cope et al. 2003). Unionid survival can be greatly improved with just a once-a-year cleaning at a minimal cost per animal. This technique will not work in habitats where food competition is occurring. Zebra mussels consistently out-compete unionids for food supplies (Strayer and Smith 1996).

The third mitigation option is to identify and then enhance natural refugia. Natural refugia are small habitats within zebra mussel infested waters where unionids continue to survive. There are a few natural refugia that have been identified throughout the Great

Lakes (Nichols and Wilcox 1997, Zanatta et al. 2002, Bowers and De Szalay 2004). Such areas are often shallow, warm water sites, often with soft sediments, or in areas of high wave action, where zebra mussel larval settlement is poor. We have not been able to locate any natural refugia areas at SLBE, though they may become apparent at a later date.

In general at SLBE, two populations of unionids are most at risk from zebra mussels, those in the Platte River and in Otter Lake. These are the most species-rich and dense populations found to date at SLBE, and both are heavily biofouled with zebra mussels. Relocation and enhancing natural refugia are not techniques that will work at these two sites. Zebra mussels infest much of the Platte River, so there is no readily available upstream area to move the unionids to. As for Otter Lake, we found no sign of natural refugia anywhere in the lake, and could not identify a site where relocation out of the lake into another lake might be successful. Unionids are notoriously difficult to relocate.

In the Platte River, manually removing the zebra mussels from the unionids is the only mitigation technique that may prove successful, at least initially. This technique would be recommended for parts of the Platte River with the greatest unionid diversity, particularly around the fish weir. This site is shallow, easily worked by volunteers, and would only need to be done once a year. This technique would be successful only as long as food does not become limited. However, since there are a number of lakes along the river, there is a strong likelihood that food supplies will not decrease for some time. The question then will be whether zebra mussel populations continue increasing in numbers or subside. Manually removing the zebra mussels off the unionids in Otter Lake is a less

viable technique. In such a small lake with an increasing zebra mussel fauna, food competition will increase rapidly. Plus, much of the lake is too deep to use general volunteers and therefore SCUBA divers would be required.

REFERENCES

Baker P. and Hornbach D. 1996. Can a species be "fouled" into extinction? Zebra mussels vs. native bivalves in the upper Mississippi River. J. Shellfish Res. 15(2):524.

Badra P. and Goforth R. 2003. Freshwater Mussel Surveys of Great Lakes Tributary Rivers in Michigan. Michigan Natural Features Inventory. PO Box 30444. Lansing MI. 48909. Prepared for Michigan Dept. Environmental Quality, Coastal Zone management Unit. 44pp.

Bowers R. and De Szalay F. 2004. Effects of hydrology on Unionids (Unionidae) and zebra mussels (Dreissenidae) in a Lake Erie coastal wetland. Am. Midl. Nat. 151:286-300.

Christie W., Goddard C., Nepszy S., Collins J., MacCallum W. 1987. Problems associated with fisheries assessment methods in the Great Lakes. Can. J. Fish. Aquat. Sci. 44(S2):431-438.

Cope W. and Waller D. 1995. Evaluation of freshwater mussel relocation as a conservation and management strategy. Regul. Rivers Res. Manage. 11:147-156.

Cope W., Hove M., Waller D., Hornbach D., Bartsch M., Cunningham L., Dunn H., Kapuscincki A. 2003. Evaluation of relocation of unionid mussels to *in situ* refugia. Journal of Molluscan Studies 69(1):27-34.

Downing W., Shostell J., Downing J. 1992. Non-annual external annuli in the freshwater mussels *Anodonta grandis grandis* and *Lampsilis radiata siliquoidea*. Freshwater Biol. 28:309-317.

Evans D. and Waring P. 1987. Changes in the multispecies, winter angling fishery of Lake Simcoe, Ontario, 1961-83: Invasion by rainbow smelt, *Osmerus mordax* , and the roles of intra- and interspecific interactions. Can J. Fish. Aquat. Sci. 44(S2):182-197.

Hallac D. and Marsden J. 2001. Comparison of conservation strategies for unionids threatened by zebra mussels (*Dreissena polymorpha*): periodic cleaning vs. quarantine and translocation. J. N. Am. Benthol. Soc. 20(2):200-210.

MacDonald D., Ingersoll C., Berger T. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31.

Marangelo P. 1997. The zebra mussel (*Dreissena polymorpha*, Pallas) invasion of two rivers in southeast Michigan: Interactions with unionid bivalves and patterns of riverine dispersal and colonization. M.S. Thesis. Univ. MI. Dept. Natural Resources and Environment. 72pp.

Metcalfe-Smith J., Staton S., Mackie G., Lane N. 1998. Changes in the Biodiversity of Freshwater Mussels in the Canadian Waters of the Lower Great Lakes Drainage Basin Over the Past 140 Years. J. Great Lakes Res. 24(4):845-858.

Michigan Department of Natural Resources. 1999. Endangered and threatened species. Rule 299.1021-299.1028. Wildlife Division, Lansing, Michigan, USA.

Murphy P. 2004. Water Quality and Aquatic Ecology at Sleeping Bear Dunes National Lakeshore, 2003 Year-End Review. Prepared for Sleeping Bear Dunes National Lakeshore. Empire, MI.

Newton T., Monroe E., Kenyon R., Gutreuter S., Welke K., and Thiel P. 2001. Evaluation of relocation of unionid mussels into artificial ponds. J. N. Am. Benthol. Soc. 20(3): 468-485.

Nichols S., Black G., Allen. 2000. Use of on-site refugia to protect unionid populations from zebra mussel-induced mortality. Proc. Conservation, Captive Care, and Propagation of Freshwater Mussels Symposium. 1998. Pp 67-75.

Nichols S., Crawford E., Amberg J., Kennedy G., Black G., Allen J. 2001a. Status of freshwater Unionid populations at Pictured Rocks National Lakeshore, 1999-2000. USGS-GLSC. 1451 Green Rd. Ann Arbor MI. 48105. Prepared for U.S. National Park Service. Completion report for NPS/USGS funded work. USGS, Ann Arbor MI., 153pp.

Nichols S., Crawford E., Amberg J., Kennedy G., Black G., Allen J. 2001b. Status of freshwater Unionid populations at Isle Royale National Park, 1999-2000. USGS-GLSC. 1451 Green Rd. Ann Arbor MI. 48105. Prepared for U.S. National Park Service. Completion report for NPS/USGS funded work. USGS, Ann Arbor MI., 94pp.

Nichols S. and Wilcox D. 1997. Burrowing saves Lake Erie clams. Nature 389:921.

Schloesser D., and T. Nalepa. 1994. Dramatic decline of unionid bivalves (Bivalvia: Unionidae) in offshore waters of western lake Erie after infestation by the zebra mussel (*Dreissena polymorpha*). Can. J. Fish. Aq. Sci. 51:134-139.

Schloesser D. Nalepa T., Mackie G. 1996. Zebra mussel infestation of unionid bivalves (Unionidae) in North America. Am. Zool. 36(3):300-310.

Schmidt L. and Hesselberg R. 1992. A mass spectroscopic method for analysis of AHH-inducing and other polychlorinated biphenyl congeners and selected pesticides in fish. Arch. Environ. Contam. Toxicol. 23:37-44.

Schmidt L. 1997. Method for Analysis of Total PCBs and PCB Congeners (full suite) and Transnonachlor by Gas Chromatography/Negative Chemical Ionization Single Ion Mass Spectrometry, Vol ii of Lake Michigan Mass Balance (LMMB) Study Methods Compendium. Organic and Mercury Methods; EPA-905-R-97-012b; U.S. Environmental Protection Agency Great Lakes National Program Office. Chicago, Il.

Strayer D. and Smith L. 1996. Relationships between zebra mussels (*Dreissena polymorpha*) and unionid clams during the early stages of the zebra mussel invasion of the Hudson River. Freshwat. Biol. 36(3):771-779.

Tevesz M. and Carter J. 1980. Study of annual growth bands in unionacean bivalves. Appendix 1.4. Pp. 613-618. In D. Rhoads and R. Lutz (eds.) Skeletal growth of aquatic organisms. Biological records of environmental change. Plenum Press. New York N.Y.

Turner R. and Rabalais N. 1994. Changes in the Mississippi River nutrient supply and offshore silicate-based phytoplankton community responses. Changes In Fluxes In Estuaries: Implications From Science To Management, Olsen & Olsen, Fredensborg, Denmark, 1994. Pp. 147-150.

Vana-Miller D. 2002. Water Resources Management Plan. Sleeping Bear Dunes National Lakeshore, Michigan. Water Resources Division. National Park Service. Fort Collins, CO. 223 pp.

Wilford W., Hesselberg R., Bergman H. 1973. Versatile Combustion-Amalgamation Technique for the Photometric Determination of Mercury in Fish and Environmental Samples. Journal of the AOAC. 56(4).

Williams J., Warren Jr., M., Cummings, K., Harris, J., and Neves, R. 1993. Conservation status of freshwater mussels of the United States and Canada. American Fisheries Society 18(9): 6-22

Zanatta D., Mackie G., Metcalfe-Smith J., Woolnough D. 2002. A refuge for native freshwater mussels (Bivalvia: Unionidae) from impacts of the exotic zebra mussel (*Dreissena polymorpha*) in Lake St. Clair. J. Great Lakes Res. 28:479-489.

APPENDIX A*

Detailed Study Plan Including Quality Assurance/Quality Control Project Plan (QAPP) For:

A SURVEY OF UNIONID MUSSELS IN THE AQUATIC SYSTEMS OF TWO NATIONAL PARK SERVICE UNITS: ISLE ROYALE NATIONAL PARK AND PICTURED ROCKS NATIONAL LAKESHORE

July 7, 1999

Prepared by: Approval Signature: Date:

Susan Jerrine Nichols
Section Leader, Benthic Ecology
U.S. Geological Survey
Great Lakes Science Center
1451 Green Rd Ann Arbor, MI 48105
Phone: 734-214-7218
Fax: 734-994-8780
E mail: S_Jerrine_Nichols@USGS.GOV

With assistance from other members of the small group QAPP planning group, including (see titles and addresses on distribution list, below):

Jack Oelfke, ISRO, NPS

Brian Kenner, PIRO, NPS

Roy Irwin, WRD, NPS

* This QAPP was developed for Isle Royale National Park and Pictured Rocks National Lakeshore, and is applicable to all National Parks.

Table of Contents

1. Title and Approval Page.
2. Table of Contents.
3. Distribution List
4. Project/Task Organization
5. Problem Definition and Questions to be answered.
6. Management, regulatory or additional study decisions or actions that might depend on the results of the study.
7. Background Information and Previous data
8. Project task description/Implementation plan details, including outlined schedule and standard operating procedures (SOPs).
9. Data Quality Objectives (DQOs).
10. Statistics to be used
11. Documentation and Records; Data Handling QA/QC Standard Operating Procedures.
12. Reconciliation of Data Collected with Data Quality Objectives (DQOs).
13. Deliverables

Distribution List:

Susan Jerrine Nichols
Section Leader, Benthic Ecology
U.S. Geological Survey
Great Lakes Science Center
1451 Green Rd Ann Arbor, MI 48105
Phone: 734-214-7218
Fax: 734-994-8780
E mail: S_Jerrine_Nichols@USGS.GOV

Jack Oelfke
Isle Royale National Park (ISRO)
800 East Lakeshore Drive,
Houghton, MI 49931

Jerry Belant,
Pictured Rocks National Lakeshore (PIRO)
P.O. Box 40,
Munising, MI 49862

Roy Irwin, Senior Contaminants Specialist and
Biomonitoring Coordinator
Water Resources Division, NPS
1201 Oakridge Drive,
Fort Collins, CO 80525

Project/Task Organization:

Key personnel and organizations that are involved in the project include:

Principal Investigator and Project Leader
Susan Jerrine Nichols, USGS, BRD

The principal investigator will be assisted by other BRD staff including, but not limited to: Michael Stewart, USGS, BRD, Indiana Dunes National Lakeshore (general project assistance); Mike Schloesser, USGS, BRD, Ann Arbor (general and malacological assistance); and Mike Hoff, USGS, BRD, Ann Arbor (statistical assistance)

Park Service Representatives involved in the project include:

Lead Contact/Project Coordinator for Isle Royale National Park
Jack Oelfke

Lead Contact/Project Coordinator for Pictured Rocks National Lakeshore
Brian Kenner

Technical Contact for the National Park Service Water Resources Division
Roy Irwin, NPS, WASO, Fort Collins, CO.

Data users will include the Park Service Staff, USGS staff, others doing bivalve studies in the region, and the general public.

Problem Definition and Questions to be answered:

The first six questions are qualitative and semi-quantitative questions. Questions 7-10 are quantitative questions related to establishing baseline condition status for later comparison with subsequent changes and possible determination of long-term trends:

1. What unionid and other easily identified species of bivalves are present in representative lakes and streams on ISRO and PIRO?

2. At all sites sampled, what is the abundance classification of each species (rare, common, or very abundant)?

3. At these same sites, which species fall into quickly ascertainable age classifications (i.e., juvenile, adult) based on size? Which species are actively recruiting?

4. What is the overall status of the population- stable, marginal, or at-risk?

5. With certain caveats, at these same sites, which of the unionid and other bivalve species fall into classifications such as native, non-native, pollution/disturbance tolerant or intolerant, rare, ecological sentinel species, or undesirable species?

6. What are the key environmental variables at each habitat sampled and are specific unionid communities associated with certain variables? Variables to be considered will be such things as which fish are and other aquatic organisms are present in the same area, type of substrate, dissolved oxygen, total calcium, pH, secchi depth, water depth, and water velocity,

7. What is the quantity of each species present based on randomized quadrats or transects?

8. What is the annual incremental increase in shell length, or growth rate, for each species (based on dead shell- may not be possible for all species or for any endangered species)?

9. What proportion of the population sampled is composed of individual unionids <5years of age?

10. What is the amount and type of chemical contaminant present per gm of soft body tissue for each species sampled?

Management. regulatory or additional study decisions or potential actions that might hinge on the results of the study include deciding:

a. if unionid and other bivalve populations in various Park lakes are in good shape, appear to be under stress, or are at risk based on current status.
b. what type of long term monitoring of unionids and other bivalves is needed (if any) to keep an eye on trends. In the final report, the Parks would like the principle investigator to make specific recommendations on the frequency of monitoring needed (in any), where/what to monitor, and specific monitoring protocols, etc. The recommendations should be very specific so that any Park Service natural resource manager in the future could understand what needed to be done to adequately document trends
c. whether or not to try to eradicate or otherwise manage non-native bivalve species, hosts, or other biota that might be threatening native bivalve species.
d. what other management actions (if any) should be taken to see that unionids and other bivalves in ISRO and PIRO are protected according to NPS mandates.

Background Information and Previous Data:

The only background mollusk work available from ISRO was a report on the mollusks, mainly gastropods, found on the island (Walker, 1909). There is no existing unionid work available from the streams and lakes of PIRO. Probable mussel species that may be found at Isle Royale National Park and Pictured Rocks National Lakeshore are listed (Table 1, Dave Heath, WI DNR. A request to the Ohio State and Michigan State Mollusc Collections is ongoing to determine if unionids from these sites are present in their databases.

Previously collected data bases on environmental parameters (chlorophyll *a*, pH, secchi depth etc.) and fish communities for waters sampled will be examined and compiled for comparison with the unionid data collected by our survey.

Some initial "range-finding" and exploratory sampling will be done at PIRO to try the proposed methods and determine data variability (which can drive the number of samples needed). At this time, an effort will be made do fine tune optimum field methods and other study details. The QAPP may be modified based on the results of these exploratory efforts or the discovery of additional previous information or newly identified expert opinion.

Data Quality Objectives (DQOs):

General Introduction and Discussion of DQOs for Qualitative Questions (1-6):

The questions being asked are general ones. The information being collected is not being collected to respond to litigated issues or other issues expected to be especially contentious or otherwise be subject to any unusual scrutiny. The data is not being collected in response to Superfund (CERCLA) or Natural Resource Damage Assessment laws or other rigid processes that require particular protocols to be followed. So the guiding principal for DQOs in this project is simply scientific and general common sense (for example, does it pass the common sense and being able to say it with a straight face tests?) credibility. The questions being asked (see listing above) were divided into questions requiring qualitative versus quantitative answers to provide scientific credibility. For this modestly funded project, the QA/QC measures detailed in this plan should be adequate to insure that data collected will be of sufficient quality to answer the identified question(s) in a defensible manner. Precision, Accuracy, Representativeness, Completeness and Comparability (PARCC) terms are defined for qualitative and semi-quantitative questions as follows:

Precision: The variability of each set of repeat measurements will be quantified to give a simple indication of the precision (or lack thereof) of each method used. Precision is a measure of scatter among independent repeated observations of the same property. Using standardized protocols, optimal standard methods developed by an advisory team of experts, and trained teams, as specified herein, will all help minimize precision errors. In cases where many trial replicates are made, precision will be expressed as a standard deviation or relative standard deviation for normally distributed data or as some other measure of variability when the data is not normally distributed. In the case of the qualitative questions 1-6, reasonable quantitative DQOs are difficult to predict before the study is done. Also, the modest funding makes a high number of replicate trials impractical. Therefore, the professional judgment precision QC step taken for questions 1-6 will be that the principal investigator will present the results to at least one other malacologist and have that other person independently classify the results. The precision of the classifications made will be expressed as relative percent difference (RPD). The RPD is the larger value minus the smaller times 100 divided by the larger minus the smaller divided by two. The data quality objective is that the classifications will represent the best professional opinion of the principal investigator after getting an independent opinion of another malacologist and explaining the relative percent difference of opinions. The initial DQO for precision in the qualitative and semi-quantitative measurements is a relative percent difference (RPD) of 25% or less. In addition to this "professional judgment DQO", the following additional DQOs will be met to help insure adequate precision:

Precision will be estimated from repeated measurements. The investigators will ensure that 5% of the samples are resampled during the study by another team. In the case where use of a different team is impossible, such as dive samples in remote areas, the same team will repeat the sample immediately after the first sample is collected. Some of the samples will require cleaning and picking of young mussels from the sediment

collected. Each sample collected in this manner will be checked for completeness. Repeat samples will be handled the same as the original sample. The 5% of samples collected to check repeatability by the same team (or reproducibility among different teams) will meet a precision DQO of a relative standard deviation of 10% or less for repeatability (within team variation) and a precision DQO of 20% or less for reproducibility (between team variation).

Accuracy is a measure of confidence in a measurement. *Precision* and bias contribute random and systematic error in a measurement that together can negatively impact accuracy. Measurement accuracy can be determined by comparing a sample that has a known value, such as a standard reference material to the measurement result for that sample. Accuracy = average value minus the true value. For qualitative parameters such as secchi depth and macroinvertebrate abundance, however, no standard reference or performance evaluation exists. In these cases, the trainer's results will be considered the reference value and to which the trainees' results are compared. The DQO for accuracy in the qualitative and semi-quantitative measurements is a relative percent difference (RPD) of 25% or less.

Representativeness: The representativeness assessment is being done to insure that the data will be "representative" of the actual condition measured. Representativeness is defined as the degree to which the data represents a population parameter. This is affected by problems in any, or all, of the other attributes of data quality. Representativeness is also affected by the selection of sites to be sampled, the location of sites in a reach, and the time period when samples are collected. The random-stratified sample design is intended to maximize representativeness. The final study design will be reviewed by statisticians and study design experts to assure that the results are as representative as possible. The DQO for representativeness is to insure that the data is as representative as practicable by carefully following the randomization and other study design details (documented herein) that insure probability samples will be collected. If this is done, the data quality objectives for representativeness for the qualitative questions will be considered to have been 100% met.

Completeness: In a simple sense, completeness is a measure of the number of samples taken compared to the number originally judged to be needed to use the information. Valid data must be acquired from a minimum number of sites in order to make population estimates with a specified level of confidence. To calculate percent completeness (%C), we will divide the number off measurements that have been judged valid by the total number of measurements originally agreed upon as being needed and then multiply by 100. The DQO for completeness in the qualitative and semi-quantitative information is a percent completeness of 80%.

Comparability: Comparability is the extent to which data from one study can be directly compared to either past data from the current project or (better yet, and often absolutely necessary to examine trends or regional significance) to data from another study. It is difficult to interpret the meaning of data if the methods used are so unique that there is no comparison data available. Therefore, our "comparability" QC will insure that lab and field methods are similar enough to those used by other investigators to insure that data

will be "comparable" to high-quality data from other studies. The use of QA data, uniform training of field crews, and incorporation of team duplicate sample sites into the study, will all help insure comparability. Before study methods are finalized, an effort will be made to standardize our methods with those used in other studies in the state (the Michigan Mussel Committee), so that new data is comparable. The DQO for comparability in the qualitative questions is to insure that the data is as comparable as practicable by carefully following study design details documented herein. If this is done, and the data is therefore at least 95% compatible (RPD of 5% or less) with at least one other important data set in the region, the DQO for qualitative questions will be considered to have been 100% met.

Taxonomic accuracy is critical to all the questions being considered in this project. Standard operating procedures used to help insure taxonomic accuracy include the specification of the taxon level (species), the specification of appropriate taxonomic reference material, and voucher specimen collections. The DQOs for precision and accuracy in taxonomic identification are:
1) a relative percent difference of 5% or less between the identifications of the principal investigator and a museum taxonomic expert at the University of Michigan or other institution of equal or better reputation in the identification of bivalves, and 2) a relative percent differences of 10% or less between the identifications of the principal investigator and any others who help identify the bivalves in this project.

DQOs for Quantitative Questions (7-10):

DQOs for question 7 (What is the quantity of each species present based on randomized quadrats or transects.

> Data collection for this question will involve destructive sampling, so precision and accuracy DQOs are difficult to develop. However, for this modestly funded project, the QA/QC measures for training, representativeness, comparability, and other PARCC parameters detailed elsewhere in this plan should be adequate to insure that data collected will be of sufficient quality to answer the identified question(s) in a defensible manner. During the initial stages of field sampling, the principle investigator will see if any practical quantitative DQOs for this type of data can be developed.

DQO for Question 8 (What is the annual incremental increase in shell length, or growth rate, for each species?):

> The SOPs call for each shell section to be aged independently by two different people. The expert trainer will be considered to produce the correct value. The comparison results of the all the others doing this procedure (after training is complete) shall have a precision DQO of a relative standard deviation of 10% or less.

Each trainee shall also have an accuracy DQO of a relative percent difference (RPD) of 10% or less compared to the results of the expert.

DQOs for Question 9 (What proportion of the population sampled is composed of individual unionids <5years of age.

The SOPs call for each shell section to be aged independently by two different people. The expert trainer will be considered to produce the correct value. The comparison results of the all the others doing this procedure (after training is complete) shall have a precision DQO of a relative standard deviation of 10% or less. Each trainee's results shall also have an accuracy DQO of a relative percent difference of 10% or less compared to the results of the expert.

DQOs for Question 10 (What is the amount and type of chemical contaminant present per gm of soft body tissue for each species sampled?):

Analysis techniques and QA/QC protocols to be used are described in Schmidt (1997), Schmidt and Hesselberg (1992), and Wilford et al. (1973). See Table 2 for detection limits.

QC samples used to help measure precision will include field and laboratory splits and duplicates. When more than two replicate measurements of the same sample are made, they are will be referred to as field (measuring both analytical and field precision) or lab (measuring precision of the lab analysis only) splits. As simple descriptive measures of variability, the relative standard deviation will be used to express the precision of repeated measurements of the same thing. When only two replicates are used, they will be referred to as duplicates and precision will be measured as the relative percent difference (RPD). The precision DQO for duplicate chemical analyses is 25% (or less) RPD. The precision DQO for spits chemical analyses is a 25% (or less) relative standard deviation. If the data seems to be from a non-normal distribution, quartiles will be used rather than 25% relative standard deviations.

Accuracy is a measure of confidence in a measurement. Measurement accuracy will be determined by comparing a sample that has a known value, such as a standard reference material to the measurement result for that sample. In the chemical analyses, QC samples will be used to help measure accuracy. The QC samples will include spikes (samples where the concentration of the chemical are known exactly. Percent recovery of the spiked material will be used to calculate analytical accuracy. The DQO for accuracy will be percent recovery of the laboratory control sample of 75-125%.

Representativeness: The representativeness assessment should insure that the data will be "representative" of the actual condition measured. Samples will be randomly selected to insure probability sampling. Precautions will instituted to make sure that samples neither add nor lose the contaminants being measured in

transit from the point of collection to lab analysis, so that the concentration measured is actually representative of the concentration which was present in the field. QC chemical samples used to help measure representativeness will include field blanks, equipment blanks, and rinsate blanks. The DQO for representativeness of chemical samples is a relative percent difference of 5% or less for each comparison of the sample blanks versus the controls.

To make sure the data is representative by avoiding false negatives, the following additional representativeness DQO will be used: 95% of all chemical analyses shall meet the following detection limits:

> Hexachlorobenzene, α- and γ-BHC, aldrin, dieldrin, endrin, α- and β-heptachlor epoxide, cis- and trans- nonachlors, p,p'-(DDE, DDD, and DDT), mirex (including 8-monohydro mirex), α- and γ-chlordanes, oxychlordane, toxaphenes (Cl 6 to Cl 10), and all other organochlorines not specified otherwise. Detection limits should be as low as state of the art permits and in no case higher than comparison benchmarks or higher than 0.01 ppm wet weight PQLs in tissues.
>
> Mercury: PQL detection limits 0.01 ppm (or lower) dry weight in tissues.
>
> Pentachlorobenzene, octachlorostryene, dacthal, and pentachlorophenyl methyl ether: Detection limits should be as low as state of the art permits and in no case higher than comparison benchmarks or higher than a PQL of 0.01 ppm wet weight in tissues.
>
> PCBs : Detection limits should be below the comparison benchmarks, by a factor of 10 whenever possible. Tissue detection limits in the ppb range are now possible (ATSDR. 1999. Toxicological Profile for Polychlorinated Biphyenyls). In no case should the PQL detection limits be above 0.05 ppm.

Completeness is defined as the percentage of measurements made that are judged to be valid according to specific validation criteria and entered into the data management system. Every effort will be made to avoid sample or data loss through accidents or inadvertence**.** The DQO for completeness in the chemical quantitative data is a percent completeness of 90%.

Comparability is addressed by utilizing standard EPA protocols from SW-846 guidance or the USGS Denver Water lab. When better methods are used, for example clean lab mercury methods with lower detection limits, only those methods which have already been used widely and gained scientific acceptance will be utilized. The (meta data) method details will be provided in the final report, along with a rationale explaining why the alternative methods are superior to standard SW-846 or Denver USGS water lab methods. The DQO for

comparability for chemical data is that 95% must meet the criteria specified in this paragraph.

The initial DQOs specified above may be modified by the principal investigator with the approval of Park Service contacts if the results of the initial investigations at Pictured Rocks National Lakeshore indicate that modifications are necessary.

Implementation plan details. A summarization of project tasks and standard operating procedures (SOPs):

Approach and Methods

Although species richness in qualitative timed searches and in quantitative quadrat searches are correlated, more mussel species can be found in timed searches than in quadrat searches (Vaughn et al. 1997). Timed searches tend to overestimate obvious species and underestimate the less easily seen species. Quadrats will underestimate rare species and the total number of species, unless a very large number of samples are collected. A previous study required. 368 quadrats at a site to achieve a 95% confidence level (Vaughn et al., 1997). Therefore, we intend to use a combination of these methods as suggested by Vaughn et al. (1997). Finding the unionid beds in each river or lake and then concentrating quadrat sampling in these locations is a method that combines both qualitative and quantitative methodology.

SOPs for Site selection and Overall Study Design:

For qualitative sampling, the location of sampling sites chosen to survey within each habitat and park will be based on (1) A minimum of three sample sites (lentic, lotic and littoral zones) within each habitat type in each park, selected from literature and reconnaissance searches, and (2) a minimum of three sites within each habitat type will be surveyed by qualitative techniques. Qualitative sampling is faster and cheaper than quantitative and thus more sites will be covered.

For quantitative sampling, a minimum of three sites within each habitat type will be selected for quantitative sampling. This will be based on resource management recommendations and on both random and non-random lake stratification parameters.

Initially, sites will be chosen non-randomly to maximize our ability to locate unionid populations. The selection criteria to be used are as follows: first, waters known to contain unionids based on shell found in the area by either park personnel or other research teams. If a number of such sites are present, those waters connected to one of the Great Lakes or suspected of being infested with zebra mussels will be sampled first (sites at maximum risk). The second selective criteria will be to sample waters with previously collected information on habitat, fish communities, and water quality information.

However, since one of the goals of this unionid survey is to provide a data base that can be used to test developing national unionid-specific IBI and ICI strategies, we will overlay these non-random site selection criteria with a random site stratification and selection system. The selection system entails grouping lakes and streams into functional classes based on habitat characteristics obtained from previously collected data provided by the parks. These characteristics include habitat such as water depth, clarity, chlorophyll a, pH, temperature regimes, hydrology patterns, fish populations, etc. We will overlay the waters we have sampled with these groupings and ensure that

representatives of each group have been sampled. We will then use principal component analyses to compare populations/ habitat, or use a non-parametric statistics if unionid populations are minimal. This type of information should provide baseline information for predicting unionid communities in park waters that we were not able to sample, but for which habitat data is available.

The divers will be placed on a line across the stream or lake and will float as much of the water body as possible searching for unionids. Once unionid beds are located, a square meter grid will be set-up across the entire bed, if possible, or at least 100 square meters of the bed (chosen randomly if bed is larger than this). The divers searching for unionids within the grid will sample the entire grid on timed surveys (15 min/diver for a maximum of 30 min/100 sq. meter grid). Species type, shell length, sex (if shell dimorphic) gravidity, and any other characteristics will be noted for every animal found.

A further 10% of the grids will be excavated. A grid will be selected, then a ¼ m quadrat frame placed randomly in it, and the entire substrate down to a depth of 15 cm removed, sieved and replaced if possible in the quadrat. All unionids will be identified and any juveniles that cannot be identified will be photographed and returned to the substrate. Once the unionid beds in each water body have been sampled, an equal number of 100 square meter grids will be placed randomly in areas where no unionid beds are found, and sampled as described above.

If no concentrated unionid populations are found in the water body, then 10-10x10 m^2 will be randomly placed in the water body, across various depths, and 100% of each 10x10 m^2 grids will be examined as described above, and a further 10% excavated.

Once water bodies are clustered into groups, we will randomly choose examples from each group, and compare and contrast unionid populations from each group. This system will be field tested at Pictured Rocks, where access to sampling sites is easier. This dual sampling regime will provide a model for estimating potential unionid communities in waters that cannot be sampled directly.

Initial sampling techniques focus on finding the unionid beds in each river or lake and then concentrating quadrat random sampling within these strata.

<u>SOPs for sampling in large water bodies:</u>

Random ‘statistical’ sampling techniques will be used in water bodies too large for a total and complete float by the SCUBA divers. We will use transect lines to cut across potential longitudinal aggregations of unionids. This method involves sending the diver on randomly selected compass headings from one side of the water body to the other, or from the center of the water body to one shoreline. Five transects per 90° on the compass rose will be chosen randomly. Quadrat locations along this transect line will be chosen randomly, but one within every ten meters. Each quadrat will be fully excavated to at least a depth of 15 cm and all substrate material sieved. All unionids will be handled as described above.

These two sampling methods will be compared and contrasted for sampling bias at one lake and one stream in PIRO, which is more easily accessible and if possible at ISRO. This should enable us to predict the probability of finding unionid populations using statistical sampling at both parks.

Sampling methods will be modified according to the habitat that is surveyed and will include both stratified random sampling techniques and statistical sampling techniques using SCUBA divers or snorkelers (when water depth is <1.5 m). The dive team manager retains the final authority to alter sites sampled when safety concerns arise.

SOPs for Training:

Training: Field crews will be trained in the methods to be used for collecting mussels by unionid experts from the GLSC. Field crews will consist of at least on person highly experienced at sampling unionid populations (GLSC crew) along with additional less experienced personnel.

SOPs for Taxonomic Accuracy

Prior to any fieldwork, the principal investigators will examine museum collections to become familiar with mussel fauna found in the region (see Table 1). The PI (Nichols) has a collection permit (# 99-1055) from the Michigan Department of Natural Resources for collecting unionids including endangered species. Appropriate personnel from the permitting branch will be notified regarding new sampling locations. Historic information on mussel communities within the parks and surrounding areas will be obtained through a search and review of the literature, examination of museum collections, and contact with regional malacologists.

Taxonomic accuracy will be evaluated by conducting independent identifications of voucher specimens by an experienced taxonomist. Species identification will be based on live shell and collected dead shell. In the field, the divers will collect any dead shell found and record where it was collected. This shell will be sent to the University of Michigan Mollusc Collection for verification of identification and be used to prepare a field guide for each site. We will take pictures and video of each type of live shell found in the field. Shell vouchers for each type of live shell found will be collected. Using voucher shells, the randomly collected dead shell from each site, plus pictures of live individuals and array shots at each clam bed, we can correct all field ID problems later. Taxonomic keys will be distributed to each team along with a photograph of each mussel that is expected in the area. Training will be provided by the GLSC team on how to set transects or grids, clear quadrats, do excavations, determine gravidity and measure environmental parameters. SOPs include the following:

Photographic records: All crews will carry a 35-mm camera, a digital camera, and if possible, an underwater video camera. A picture of habitat and specimens collected will be taken at the site. More than one mussel can be photographed per slide.

Specimen record: A representative of each mussel species will be collected from each site (excluding endangered species). These will be preserved and returned to the laboratory. Voucher specimens will be deposited with ISRO and PIRO managers, plus at the University of Michigan Mollusc Collection.

Collection confirmations by experts: The voucher collection will be sent to mussel experts at the University of Michigan Mollusc Collection, and/or any other expert preferred by Park managers for taxonomic confirmations.

All mussels collected (except for a voucher collection and animals needed for contaminant analysis) will be identified, photographed, and returned to the wild. Voucher specimens of each species will be retained and mussels of questionable identification will be kept for positive identification. All freshly dead shells collected will be stored in a bag containing a field label including stream or lake name, location, date, and collector. Voucher specimens will be narcotized and fixed by using menthol crystals until immobilized, then placed into 70% ethanol. A labeled reference collection will be made for each park for deposit with the park collection manager or the state museum. Pictures will be provided of any rare or endangered mussels for which no shell was collected.

SOPs for Quantitative Questions:

Question: What is the annual incremental increase in shell length, or growth rate, for each species (based on dead shell- may not be possible for all species or for any endangered species)?
Standard Operating Procedures to be used: The shell will be sectioned on a perpendicular line from the umbo to the ventral margin of the shell. The cut sections will be sanded using fine grade, coated in glycerin, and examined under a 10X power dissecting scope. Internal annular rings will be determined using techniques described in Tevesz and Carter (1980). Each shell section will be aged independently by two different people. Length and age frequencies will be plotted using a modified Walford plot (regression). Comparisons between internal and external annuli (examination for non-annular external rings) will be done according to the techniques described in Downing et al. (1992).

Question: What proportion of the population sampled is composed of individual unionids <5years of age?
SOP: The relationship between length and age will be determined through shell sections. Differences in age and length between sites will be determined as described above.

Question: What is the amount and type of chemical contaminant present per gm of soft body tissue for each species sampled?
SOP: Live individuals of two species of unionids, preferably P. grandis and L. radiata (if present), will be collected from two sites per park and placed on ice as quickly as possible and sent to the Great Lakes Science Center. There, soft

tissues from each individual will be frozen at –40°F and processed individually. The following contaminant array will be surveyed: pesticides including hexachlorobenzene, pentachlorobenzene, octachlorostryene, α- and γ-BHC, aldrin, dieldrin, endrin, α- and β-heptachlor epoxide, cis- and trans- nonachlors, p,p'-(DDE, DDD, and DDT), mirex (including 8-monohydro mirex), α- and γ-chlordanes, oxychlordane, toxaphenes (Cl 6 to Cl 10), dacthal, and pentachlorophenyl methyl ether; PCBs (80 congeners, including most of the planar dangerous ones) and mercury. Analysis techniques and QA/QC protocols are described in Schmidt (1997), Schmidt and Hesselberg (1992), and Wilford et al. (1973). Field and lab methods shall follow recommendations of EPA (SW-846) or published USGS protocol and shall be detailed as meta data in the revised QAPP submitted with the first annual report.

Question: With certain caveats, at these same sites, which of the unionid and other bivalve species fall into classifications such as native, non-native, pollution/disturbance tolerant or intolerant, rare, ecological sentinel species, or undesirable species?
SOP: The following caveats will be factored into to these designations: There are no non-native unionids presently found in the continental United States. There are no undesirable unionid species. While three species (Lampsilis radiata/siliquoidea, Leptodea fragilis, and Pyganodon grandis) are commonly found in all types of habitats, the term "undesirable" is probably inappropriate as it implies something that must be eradicated rather than just a very adaptable species. Although not unionids, zebra mussels, asian clams, and various fingernail clams will be documented and reported. Taxonomic identification of fingernail clams is difficult, but an attempt will be made to identify them to the lowest level practicable.

SOPs for Documentation of habitat. With each qualitative and quantitative sample, we will also collect habitat data. These will include composition of substrate, water depth, and presence or absence of zebra mussels. These include scoring for stream and lake habitat variables (see field forms in the appendix).

Schedule of activities

June 1999	Methods/Site selection discussion
July 1999.....	Reconnaissance/Sampling (PIRO)
August-early September 1999.....	Reconnaissance/Sampling at ISRO
Fall……	Data entry
EOY	Report
June	Reconnaissance/Sampling at PIRO
August-early September 2000.....	Reconnaissance/Sampling at ISRO
Fall	Data entry
EOY	Report
June	Final report

Sampling dates will be scheduled after discussion with park managers and modified as needed. We have anticipated a total 28 days field sampling/park for the two-year period. If sampling is completed sooner in one park, the remaining days will be spent at the other.

Statistics to be used:

General Approach**:**

We will use both general statistics (median, range, etc.) as well as multivariate statistical methods to analyze the abundance data (number of mussels/taxon/transect), comparisons between populations within a water body and water bodies and potential relationships to habitats.
In addition to the basic statistics described above, we will use multivariate statistical methods to analyze abundance data (number of mussels/taxon/transect/grid). Hierarchical cluster analysis (Afifi and Clark 1990) will be used to reveal groups and patterns in abundance data across habitats. Principal component analysis will be used to reduce the dimensionality of the data by obtaining linear transformations of the mussel taxa variables and to summarize the major sources of variation in the abundance data (Jackson 1991). Raw data will be provided along with statistically manipulated data.

Statistics Related to Specific Questions:

Question: What is the quantity of each species present based on randomized quadrats or transects?
Statistics to be used: Simple descriptive statistics will be provided for each quadrat/transect sampled and for each 100 sq. m plot sampled. We will provide the raw data on the actual number and species of unionids collected in each type of quadrat, the median and range for each specie, plus the calculated #/m^2. The type of statistics used to test differences between quadrats will be determined once we determine if the distribution patterns of these animals across the 100 sq m plot/transect are normal or skewed. If the distribution is normal, tests such as ANOVAs and standard deviations will be used to further characterize the population in this plot/transect. Non-normal distribution patterns will be initially analyzed using more descriptive statistics such as the average deviation from the mean (AVEDEV), median, quartile, quantiles, etc. If necessary the data will be transformed either using a log or arcsign transformation. Non-parametric statistics will be used only as a last resort. Different 100 sq m plots or transects within the same water body will be initially compared using the techniques described above, with the statistical tests dependent on the distribution of the data. We will use multivariate statistical methods to analyze the abundance data (number of mussels/taxon/transect/plot).

Question: What is the annual incremental increase in shell length, or growth rate, for each species (based on dead shell- may not be possible for all species or for any endangered species)?
Statistics to be used: A probability chart indicating the accuracy of estimating age through the use of external annuli (usable on live animals) will be prepared. Differences in growth rates for a single species within a 100 sq. m plot or transect as well as between different plots or transects will be determined using ANOVA or Tukey's t-test depending on the sample size.

Question: What proportion of the population sampled is composed of individual unionids <5years of age?
Statistics to be used: Length frequency histogram will be prepared for every species, every water body, and every 100 sq. m plot or transect.

Question: What is the amount and type of chemical contaminant present per gm of soft body tissue for each species sampled?
Statistics to be used: Simple nonparametric descriptive statistics (median, interquartile ranges, etc.) will be used to summarize the results.

Documentation and Records; Summarization of data handling QA/QC SOPs.

High quality, defensible data is required for all National Park Service projects, Data will be entered into an Excel spreadsheet and checked by the principal investigator. These data, at the completion of the project, will be transferred to the park for eventual entry into EPA's STORET database. Meta-data will be provided for all sampling protocols and data analyses. The following steps will be done to insure that data meets the quality necessary for the purposes of the project: All grid plots, unionid beds, etc., will be entered as meta-data into EPA Storet system. Locations of grids and unionid beds will be further delineated by GPS locations and maps provided to park managers.

Data handling QA/QC steps include making sure that: (1) transcription or data transfer efforts are minimized, (2) information is not lost, (3) chain-of-custody is followed where appropriate, and (4) appropriate decision makers get the results in a form they can understand. All water-related data, including physical, chemical, substrate type, and biological data, will be reported to the parks for eventual placement into EPA's newly expanded STORET database by national park service personnel.

Data will be entered into standardized forms with all blanks filled out, At each site, the site leader will check all forms for completeness. A photocopy of the sheet will be made prior to mailing. Data will be entered into Excel format and checked by the principal investigator. At the end of the project, the Excel database will be presented to the park.

The basics of guidance for data entry, data verification, data validation, data documentation, data archiving, data backup, and version control, will all follow the NPS I&M guidance (www.nature.nps.gov/im/dmproto/joe4OOOl.htm) as closely as possible within the practicalities of funding levels available. For example:

Data verification will include the verification of the accuracy of all entries by their comparison with the original source to identify and correct errors. This will include checking the accuracy of the computerized records against the original source.

Data validation will include reviewing field and computerized data for range and logic efforts (the pH can't be 25). Unlike data entry and data verification, data validation requires in-depth knowledge about the data. Corrections or deletions of logical or range efforts in a data set will be done with notations in the original paper field records about how and why the data were changed. Modifications of the field data should be clear and concise but preserve the original data entries or notes (i.e., no erasing!).

Site identification by GPS. Site information will be recorded on a GPS unit or marked on a topographic map for later identification. These units, plus instruction on their use, will be made available to the field crews. Otherwise, the field crews will mark their sampling locations on topographic maps provided to them.

Data will be collected using the following data sheets (located at end of document):

Sheets 1&2. Stratified Random Field Sheet

Sheets 3&4. Statistical Sampling Sheet

Study Plan and QAPP Revisions

Provisions for the unexpected or alterations that need to be made in the final QAPP need to be anticipated. Unexpected situations often come up during the course of investigations and any major changes will need to be authorized by the Park representatives and WRD technical lead before being implemented. If changes are necessary, the QAPP will be revised accordingly as the study progresses.

The final QAPP will be attached (as an appendix) to the final report submitted to the Park Service. The QAPP plan thereby becomes an important part of post-project "meta-data" (data about data). The meta-data in the QAPP plan provides the detailed information reviewers need to understand exactly how the data was generated. Thus, the details of what was done must be available to those desiring to repeat the investigation exactly as it was done before. Access to these details is also critical to reviewers trying to understand data comparability, data representativeness, and other perspective on "what the data means." In peer-reviewed articles where attaching the entire QAPP is not allowed, an alternative way to include meta-data details of exactly what is done both in the field and the lab will be found.

Deliverables and other Reporting Requirements:

A. **Interim Report -** An interim progress report (EOY) win be due as an end-of-year report to the parks.

B. Final Report - Due EOY 2000 will be a draft final report to the parks. The final report is due June 2001 and will consist of the following parts:

1). Title page - listing the investigators and affiliations.

2). Abstract (suitable for an abstract journal).

3). Executive summary, management implications, and information needs.

4). Introduction

5). Methods (Brief)

6). Results

7). Discussion

8). Summary

9). Appendix I - species lists and abundance estimates per area sampled. Detailed maps of all areas sampled and where each species is to be found will be provided.

10). Appendix 2: Final Detailed Study Plan and QAPP including all SOPS, Detailed
Methods and metadata.

References cited

Afifi, A., and V. Clark. 1990. Computer-aided multivariate analysis. Van Nostrand Reinhold, New York.

Downing W., J. Shostell, and J. Downing. 1992. Non-annual external annuli in the freshwater mussels *Anadonta grandis grandis* and *Lampsilis radiata siliquoidea*. Freshwater Biol. 28:309-317.

Jackson, J. 1991. A User's Guide to Principal Components. John Wiley and Sons, New York.

Schmidt, L., and R. Hesselberg. 1992. A Mass Spectroscopic Method for Analysis of AHH-Inducing and Other Polychlorinated Biphenyl Congeners and Selected Pesticides in Fish. Archives of Environmental Contamination and Toxicology. 23:37-44.

Schmidt, L. 1997. Method for Analysis of Total PCBs and PCB Congeners (full suite) and Transnonachlor by Gas Chromatography/Negative Chemical Ionization Single Ion Mass Spectrometry, Vol II of Lake Michigan Mass Balance (LMMB) Study Methods Compendium. Organic and Mercury Methods; EPA-905-R-97-012b; U.S. Environmental Protection Agency Great Lakes National Program Office: Chicago, IL.

Tevesz M., and J. Carter. 1980. Study of annual growth bands in unionacean bivalves. Appendix 1.4. Pp 613-618. In D. Rhoads and R. Lutz (eds.) Skeletal growth of aquatic organisms. Biological records of environmental change. Plenum Press. New York N.Y.

Vaughn, CC., CM. Taylor, and K. J. Eberhard. 1997. A comparison of the effectiveness of timed search vs. quadrat sampling in mussel surveys. Pps. 157-162 in K. S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo (eds.), Conservation & Management of Freshwater Mussels 11, Proceedings of a Upper Mississippi River Conservation Committee Symposium, 12-14 October, St. Louis, Missouri.

Walker, B. 1909. Annotated list of the Mollusca of Isle Royale, Michigan.
Pps. 282-298 in C. C. Adams (ed.), An Ecological Survey of Isle Royale, Lake Superior. University of Michigan Museum, State Biological Survey, Report of the Board of the Geological Survey for 1908. Wynkoop, Hallenbeck Crawford, Co., State Printers, Lansing, Michigan. 468 pp.

Willford, W., R. Hesselberg, R., and H. Bergman. 1973. Versatile Combustion-Amalgamation Technique for the Photometric Determination of Mercury in Fish and Environmental Samples. Journal of the AOAC. Vol. 56, No. 4.

Table 1. Unionid mussels that may be found in Isle Royale National Park and Pictured Rocks National Lakeshore (list compiled by David J. Heath, Wisconsin DNR).

Phylum Mollusca
Class Bivalvia
Order Unionoida
Family Unionidae

Subfamily Anodontinae
Anodonta cataracta cataracta (Eastern floater)
Anodonta cataracta marginata
Anodontoides ferussacianus (Cylindrical papershell)
Lasmigona complanata (White heelsplitter)
Lasmigona costata (fluted-shell)
Lasmigona compressa (Creek heelsplitter)
Pyganadon grandis f. grandis (Giant Floater)
Strophitus undulatus (Squawfoot)

Subfamily Ambleminae
Elliptio complanata (Eastern elliptio)

Subfamily Lampsilinae
Lampsilis cardium (=ventricosa) (Plain pocketbook)
Lampsilis siliquoidea (= radiata luteola) (Fatmucket)
Ligumia recta (Black sandshell)
Obovaria olivarioa (Hickorynut)

Table 2. PCB Congeners/trans nonachlor to be Determined by GC/NCI/SIM. Detection Limits for PCB Congeners and Trans Nonachlor for EPA Contract IAG DW14947842-01 (Remaining Pesticides to be Completed Before Analyses Begin)

Compound	Inst. Det. Lim. using 1 g sample (**ng/g** or parts/billion/gram dry tissue)
1. PCB Congener #31+#28	9
2. PCB Congener #33	4
3. PCB Congener #22	4
4. PCB Congener #52	12
5. PCB Congener #49	18
6. PCB Congener #47+#48	6
7. PCB Congener #44	25
8. PCB Congener #42	4
9. PCB Congener #41+#71	18
10. PCB Congener #64	4
11. PCB Congener #40	7
12. PCB Congener #63	0.4
13. PCB Congener #74	2
14 PCB Congener#70 + #76	1
15. PCB Congener #66	2
16. PCB Congener #95	6
17. PCB Congener #91	7
18. PCB Congener #56+#60	1
19. PCB Congener #84+#92+#89	1
20. PCB Congener #101	0.2
21. PCB Congener #99	0.4
22. Trans-nonachlor	0.08
23. PCB Congener #119	0.1
24. PCB Congener #83	0.6
25. PCB Congener #97	0.9
26. PCB Congener #81+#87	0.6
27. PCB Congener #85	0.3
28. PCB Congener #77	0.2
29. PCB Congener #110	0.5
30. PCB Congener #82	1
31. PCB Congener #151	0.02
32. PCB Congener #144+#135	0.03
33. PCB Congener #107	0.3
34. PCB Congener #123	0.1
35. PCB Congener #149	0.04
36. PCB Congener #118	0.3
37. PCB Congener #134	0.02
38. PCB Congener #114	0.4

39. PCB Congener #131	0.01
40. PCB Congener #146	0.01
41. PCB Congener #132+#153	0.02
42. PCB Congener #105	0.02
43. PCB Congener #141	0.1
44. PCB Congener #137+#176	0.08
45. PCB Congener #138+#163	0.04
46. PCB Congener #158	0.03
47. PCB Congener #129	0.01
48 . PCB Congener #126	0.03
49. PCB Congener #178	0.1
50. PCB Congener #175	0.1
51. PCB Congener #187+#182	0.08
52. PCB Congener #183	0.06
53. PCB Congener #128	0.02
54. PCB Congener #167	0.03
55. PCB Congener #185	0.04
56. PCB Congener #174	0.09
57. PCB Congener #177	0.1
58. PCB Congener #202	0.2
59. PCB Congener #171	0.1
60. PCB Congener #156	0.04
61. PCB Congener #173	0.06
62. PCB Congener #157	0.03
63. PCB Congener #200	0.2
64. PCB Congener #172	0.04
65. PCB Congener #197	0.04
66. PCB Congener #180	0.07
67. PCB Congener #193	0.08
68. PCB Congener #191	0.1
69. PCB Congener #199	0.2
70. PCB Congener #170+#190	0.09
71. PCB Congener #198	0.1
72. PCB Congener #201	0.3
73. PCB Congener #203+#196	0.4
74. PCB Congener #189	0.1
75. PCB Congener #195	0.1
76. PCB Congener #208	0.07
77. PCB Congener #207	0.1
78. PCB Congener #194	0.1
79. PCB Congener #205	0.2
80. PCB Congener #206	0.2
81. PCB Congener #209	0.07

82. Pentachlorobenzene	0.15
83. Hexachlorobenzene	0.6

84. Octachlorostyrene	0.5
85. p,p'-DDT	40.0
86. p,p'-DDE	10.0
87. p,p'-DDD	70.0
88. β-Heptachlor epoxide	2.0
89. Oxychlordane	1.0
90. Pentachlorophenyl methyl ether	0.5
91. Deildrin	0.5
92. Endrin	0.5
93. Aldrin	3.5
94. Lindane	1.0
95. Alpha BHC	4.0
96. Alpha Chlordane	0.2
97. γ-Chlordane	0.2
98. trans-Nonachlor	0.2
99. cis-Nonachlor	0.1
100. Tot. taxaphene	120.0
101. Dacthal	1.0
102. Photomirex	25.0
103. Mirex	2.0
104. Mercury	20.0

Internal QA/QC samples will include a blank, spike, duplicate, and reference unionid tissue samples (check) analyzed with each set of monitoring unionid samples. Additionally when each subject sample or QA sample is analyzed, internal standards of PCB congeners #136 and 204 will be added just prior to the analysis step to monitor sample injection and adjust instrument calibration for every sample analyzed. Also, each sample will be spiked with surrogates. The Great Lakes Science Center's current procedure requires that each sample is spiked (at least 50 times the measured background concentration) with PCB congeners #65 and 166 and octachloronaphthalene for the pesticides just prior to extracting contaminants from tissues. The relative response from these congeners is then compared to that obtained during the calibration step of the GC/MS and a recovery is then calculated. Results from the collected unionids are not usually corrected for recovery based on spiked samples. The purpose of the surrogate spike is to check each sample for different errors that may occur during sample preparation. Results from the surrogates are especially useful in determining extent of the problem and corrective action when spike or check results are outside the acceptance criteria.

Mercury content in unionid tissues is determined by using LECO High Frequency Induction Furnace. Reference samples are SPEC reference Plasma Standards. Blanks, replicates, and reference samples will be run with each set of unionid tissue samples.

A complete in-depth QA/QC and sampling handling protocol will be provided with the final report.

Susan Jerrine Nichols

Section Leader, Benthic Ecology **Phone: 734-214-7218**
U.S. Geological Survey **Fax: 734-994-8780** **Great Lakes Science Center** **Email:**
1451 Green Rd **S_Jerrine_Nichols@USGS.GOV**
Ann Arbor, MI 48105

SCIENTIFIC AND PROFESSIONAL ORGANIZATIONS
Michigan Unionid Committee, National Shellfish Association, National Unionid Conservation Society

PERTINENT GRANTS AND CONTRACTS
U.S. EPA: Reestablishing the Unionid Population in Metzger Marsh, Sept 1998- Sept 1999; $100,000.
U.S. National Biological Survey: 1) Development of refugia to protect Unionidae from zebra mussels and, 2) food web dynamics and nutritional requirements of Unionidae Aug. 1998- $100,000

MAJOR PUBLICATIONS:
Nichols S. and Amburg J. Coexistence of Zebra Mussels and Unionids: Population Dynamics of Leptodea fragilis in a Zebra-mussel Infested Coastal Wetland. Can. J. Zool. In Press.

Nichols S. and Garling D. Food Web Dynamics and Trophic Level Interactions in a Multi-species Community of Unionidae. Can. J. Zool. In Press.

Nichols S., Black G., and Allen J. Use of Refugia to Protect Unionid Populations from Zebra Mussel-Induced Mortality. Proc. Confer. Unionid Conservation. March, 1998. Columbus Ohio IN PRESS.

Nichols S. 1997. Burrowing Saves Lake Erie Clams. Nature. Vol. 389.

Nichols S. 1996. Review of The Reproductive Cycle of The Zebra Mussel (Dreissena polymorpha): Europe, Russia, And North America. American Society of Zoologists

Nichols S. and Black G. 1994. Identification of Larvae: Zebra Mussel (Dreissena polymorpha), Quagga Mussel (Dreissenia bugensis), And The Asian Clam (Corbicula fluminea). Canadian J. Zoology 72:406-417.

Nichols S. 1993. Laboratory Culture of Dreissena polymorpha. In Dreissena: Biology, Impact And Control. D.W. Schloesser and T. Nalepa Eds. Lewis Publishers. Chelsea, Mi. Pp 733-748.

Nichols S. 1993. Spawning And Rearing of Dreissena polymorpha Under Laboratory Conditions. Dreissena: Biology, Impact And Control. D.W. Schloesser and T. Nalepa Eds. Lewis Publishers. Chelsea, Mi. Pp 315-329.

Ram J. and S. Nichols. 1991. Approaches to Zebra Mussel Control Through Intervention in Reproduction. Journal of Shellfish Research 10:254.

Nichols S. and Kollar B. 1992. Reproductive Cycle of Zebra Mussels (Dreissena polymorpha) in Western Lake Erie at Monroe, Michigan. Journal of Shellfish Research 11:235

Nichols S., Manny B., Schloesser D., and Edsall T. 1991. Heavy Metal Contamination of The Sediments in The Upper Great Lakes Connecting Channels. Hydrobiologia 29:307-316.

Hudson P., Davis B., Nichols S., and Tomcko C. 1986. Environmental Studies of Macrozoobenthos, Aquatic Macrophytes, And Juvenile Fishes in The St. Clair-Detroit River System, 1983-1984. Final Report Prepared by the U. S. Fish And Wildlife Service, Great Lakes Fishery Laboratory For The Detroit- District, U. S. Army Corps of Engineers. FWS-NFC-GL/AR-86-7. 303 PP.

APPENDIX B

CONTAMINANTS ANALYSIS IN SOFT TISSUE OF NATIVE CLAMS SAMPLED FROM ISLE ROYALE NATIONAL PARK AND SLEEPING BEAR DUNES NATIONAL LAKESHORE, 2000.

ORGANIC CONTAMINANT LEVELS FOUND IN SOFT TISSUES OF NATIVE CLAMS- 2000.

ISRO	PCB#81#87	PCB#85	PCB#110	PCB#177	PCB#202	PCB#171	PCB#156	PCB#173	PCB#157
McCargoe Cove	12.55	1.16	3.68	0.00	0.07	0.13	0.00	0.15	0.08
Lake Livermore	3.25	2.86	4.02	0.00	0.26	0.00	0.00	0.00	0.08
LeSage Lake	13.65	1.39	1.46	0.00	0.20	0.00	0.00	0.16	0.11
Lake Ritchie	0.00	0.00	2.42	0.00	0.21	0.00	0.00	1.00	0.00
Lake Whittlesey	3.13	3.25	2.57	0.00	0.21	0.00	0.00	0.00	0.00
Chickenbone Lake	0.00	2.60	0.00	0.00	0.13	0.00	0.00	0.00	0.00
Intermediate Lake	6.35	2.68	0.00	0.25	0.20	0.00	0.13	0.13	0.00
Wood Lake	3.20	2.09	3.96	0.00	0.19	0.00	0.00	0.20	0.00
Siskiwit Lake	4.24	2.26	3.49	0.00	0.18	0.00	0.00	0.00	0.19
Sargent Lake	2.83	0.00	3.51	0.00	0.26	0.00	0.00	0.00	0.00
SLBE									
School Lake	5.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shell Lake	3.72	2.45	0.00	0.00	0.30	0.30	0.00	0.00	0.00
Crystal River (below town)	3.70	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ISRO	Pentachlorobenzene	Alpha-HCH	Hexachlorobenzene	PCPME	Lindane	Aldrin	Dachtal	Octachlorostyrene	B-heptachlorepoxyde
McCargoe Cove	0.2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lake Livermore	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LeSage Lake	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lake Ritchie	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lake Whittlesey	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chickenbone Lake	0.23	0	0.29	0.00	0.00	0.00	0.00	0.00	0.00
Intermediate Lake	0	0	0.45	0.00	0.00	0.00	0.00	0.00	0.00
Wood Lake	0.16	0	0.21	0.00	0.00	0.00	0.00	0.00	0.00
Siskiwit Lake	0.18	0	0.00	0.00		0.00	0.00	0.00	0.00
Sargent Lake	0.15	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SLBE									
School Lake	0.21	0	0.35	0.00	0.00	0.00	0.00	0.00	0.00
Shell Lake	0.12	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crystal River (below town)	0.28	0	0.90	0.00	0.00	0.00	0.35	0.00	0.00

ISRO	PCB#200	PCB#172	PCB#197	PCB#180	PCB#118	PCB#114	PCB#132#153	PCB#138#163	PCB#175
McCargoe Cove	0.06	2.54	0.25	0.32	0.00	0.00	0.33	0.35	0.00
Lake Livermore	0.00	2.68	0.00	0.26	0.00	0.83	0.00	0.25	0.00
LeSage Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.41	0.00
Lake Ritchie	0.00	2.14	0.12	0.00	0.00	0.81	0.24	0.00	0.23
Lake Whittlesey	0.18	2.20	0.37	0.00	0.00	0.70	0.34	0.00	0.00
Chickenbone Lake	0.00	0.10	0.00	0.13	0.00	0.00	0.25	0.00	0.00
Intermediate Lake	0.16	0.21	0.00	0.16	0.00	0.96	0.30	0.55	0.26
Wood Lake	0.18	0.30	0.00	0.00	0.00	1.09	0.34	0.42	0.41
Siskiwit Lake	0.18	0.00	0.00	0.00	0.41	0.00	0.00	0.72	0.55
Sargent Lake	0.17	1.59	0.36	0.00	0.00	0.00	0.43	0.00	0.66
SLBE									
School Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00
Shell Lake	0.00	0.40	0.61	0.43	1.16	0.81	0.49	1.17	0.70
Crystal River (below town)	0.00	0.77	0.00	0.00	1.12	0.00	0.87	0.00	0.00

ISRO	Oxychlordane	trans(G)-Chlordane	cis(A)-Chlordane	trans(G)-Nonachlor	Dieldrin	p,p,-DDE	endrin	cis-Nonachlor	p,p-DDD
McCargoe Cove	0.00	0.18	0.21	0.17	0.00	0.00	0.00	0.00	0.00
Lake Livermore	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
LeSage Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lake Ritchie	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lake Whittlesey	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chickenbone Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Intermediate Lake	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
Wood Lake	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Siskiwit Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sargent Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SLBE									
School Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shell Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crystal River (below town)	0.00	0.20	0.00	0.28	0.00	3.36	0.00	0.78	0.00

ORGANIC CONTAMINANT LEVELS FOUND IN SOFT TISSUES OF NATIVE CLAMS-
2000.

ISRO	PCB#187#182	PCB#183	PCB#167	PCB#185	PCB#199	PCB#198	PCB#201	PCB#208	PCB#205	PCB#206	PCB#209	**Total PCB**
McCargoe Cove	0.07	0.19	0.00	0.06	0.00	0.00	0.17	0.00	0.00	0.44	0.06	**22.65**
Lake Livermore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.84	0.00	**15.42**
LeSage Lake	0.17	0.00	0.22	0.00	0.00	0.10	0.00	0.08	0.00	0.59	0.00	**18.90**
Lake Ritchie	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	1.01	0.00	**8.30**
Lake Whittlesey	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.23	0.00	**13.96**
Chickenbone Lake	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.28	0.00	**3.55**
Intermediate Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.66	0.00	**13.06**
Wood Lake	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	**13.31**
Siskiwit Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.87	0.00	**13.09**
Sargent Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	**10.50**
SLBE												
School Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	0.00	**7.32**
Shell Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00	**13.24**
Crystal River (below town)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.65	0.00	**10.56**

ISRO	p,p,-DDT	Photo-mirex	Mirex
McCargoe Cove	0.00	0.00	0.00
Lake Livermore	0.00	0.00	0.00
LeSage Lake	0.00	0.00	0.00
Lake Ritchie	0.00	0.00	0.00
Lake Whittlesey	0.00	0.00	0.00
Chickenbone Lake	0.00	0.00	0.00
Intermediate Lake	0.00	0.00	0.00
Wood Lake	0.00	0.00	0.00
Siskiwit Lake	0.00	0.00	0.00
Sargent Lake	0.00	0.00	0.00
SLBE			
School Lake	0.00	0.00	0.00
Shell Lake	0.00	0.00	0.00
Crystal River (below town)	0.00	0.00	0.00

ORGANIC CONTAMINANT LEVELS FOUND IN SOFT TISSUES OF NATIVE CLAMS- 2000.

TOXAPHENES

ISRO	cl-6 #1	cl-6 #2	cl-6 #3	cl-6 #4	cl-6 #5	cl-6 #6	cl-6 #7	cl-7 #1	cl-7 #2
McCargoe Cove	0	0	0	0.00	0.00	0.00	0.00	0.77	0.00
Lake Livermore	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
LeSage Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Lake Ritchie	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Lake Whittlesey	0	0	0	4.17	0.00	0.00	0.00	0.00	0.00
Chickenbone Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Intermediate Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Wood Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Siskiwit Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Sargent Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
SLBE									
School Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Shell Lake	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Crystal River (below town)	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00

ORGANIC CONTAMINANT LEVELS FOUND IN SOFT TISSUES OF NATIVE CLAMS- 2000.

TOXAPHENES

ISRO	cl-7 #3	cl-7 #4	cl-8 #1	cl-8 #2	cl-8 #5	cl-8 #6	cl-8 #7	cl-8 #8	cl-8 #9
McCargoe Cove	0.00	0.00	0.40	0.00	1.14	1.17	0.00	0.00	0.00
Lake Livermore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LeSage Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lake Ritchie	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lake Whittlesey	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chickenbone Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Intermediate Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wood Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Siskiwit Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sargent Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SLBE									
School Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shell Lake	0.00	0.00	0.00	0.00	0.00	1.57	2.75	0.00	0.00
Crystal River (below town)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ORGANIC CONTAMINANT LEVELS FOUND IN SOFT TISSUES OF NATIVE CLAMS-
2000.

	TOXAPHENE											
ISRO	cl-9 #2	cl-9 #3	cl-9 #4	cl-9 # 5	cl-10 #1	cl-10 #3	cl-10 #4	**CL-6**	**CL-7**	**CL-8**	**CL 9&10**	**Total Toxaphenes**
McCargoe Cove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	2.71	0.00	**3.48**
Lake Livermore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
LeSage Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Lake Ritchie	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Lake Whittlesey	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	**4.17**
Chickenbone Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Intermediate Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Wood Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Siskiwit Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Sargent Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
SLBE												
School Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Shell Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.32	0.00	**4.32**
Crystal River (below town)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**

APPENDIX C

Background on the Unionid Genera and Species Found at Sleeping Bear Dunes National Lakeshore

Taxonomic Authority

The genera designations are not in taxonomic dispute, and are easily identified in the field (Figure 10). However, the species identifications for the *Lampsilis* group and the *Pyganadon* group are in major taxonomic dispute, and have undergone many name changes during the last 50 years, with more changes likely in the future. Furthermore, the two main taxonomic authorities for the midwest (the Ohio State University Museum of Biological Diversity, The Bivalve Mollusk Collection (OSU), Drs. Stansbury and Watters, and the University of Michigan Mollusk Collection (UM), Drs. Burch, Sherman, and Graf) do not always agree on species designations for these genera. Since we expect the names to shift in the next decade, and because it is easier to combine data that to try to split past collections and reports, we have chosen to use the OSU nomenclature (splitters rather than clumpers) where necessary. Figure 24 shows pictures of unionid species found at SLBE.

1. *Elliptio*

We identified two species of *Elliptio* at SLBE. *Elliptio complanata*, the eastern elliptio, is a thick shelled, slow-growing mussel that reaches a maximum length of 13 cm. The shell is dark brown in color, with no distinguishing stripes or rays and the nacre is usually white or light pink. The shells do not show sexual dimorphism. This species tolerates a wide variety of habitats and is widely distributed in the Great Lakes drainage basin. This mussel uses a number of fish hosts such as banded killifish, green sunfish, largemouth bass, white crappie, and yellow perch.

Elliptio dilatata, the spike or lady finger, is about the same size as the eastern elliptio (maximum recorded length 13 cm) but is more widely distributed throughout the Great Lakes drainage system. It can easily be distinguished from other mussels by its elongated shape, ventral indentation (full adult) and purple nacre. Young mussels (< 6 cm) tend to be lighter brown in color, with a strong posterior wing, while older animals become very dark brown. No

shell stripes or bars are visible, nor are there any external sexual differences. These mussels are usually found in rivers and are tolerant of any type of substrate except shifting sand. As with the eastern elliptio, this is a heavy-shelled, slow-growing, long-lived species. This species of mussel uses black crappie, flathead catfish, gizzard shad, sauger, white crappie, and yellow perch as its fish hosts.

2. *Lampsilis*

In general, the group of *Lampsilis* species are widely distributed throughout the Great Lakes drainage system. Three species are found at SLBE: *fasciola, siliquoidea,* and *ventricosa*. In general, the maximum size of these animals is about 13.5 cm. The shell varies from extremely dark reddish brown, with no stripes, to pale tan with green stripes. These Lampsilis species are one of the few unionids to have sexually dimorphic shells. Females have a posterior inflation to the shell and use a mantle lure to attract fish hosts. These mussels prefer quieter waters and have no limitations with regards to substrate. These are heavy-shelled, slow-growing, long-lived animals. These *Lampsilis* species use a wide variety of fish as hosts for their larvae, including black crappie, bluegill, common shiner, largemouth bass, pumpkinseed, rock bass, sauger, smallmouth bass, walleye, white bass, white crappie, and white perch.

Taxonomy in this group is in dispute, especially for *siliquoidea* and *ventricosa*. Name changes have occurred frequently over the last 20 years, with subspecies first being raised to species status and now, clumped into general groups. Synonyms that have been found in the literature for *L. siliquoidea* are *luteola, radiata,* and *superiorensis*, to name a few. There are strong physical differences between these animals at many sites, with multiple morphs found living together, but genetic differences are minimal, due in part to the recent divergence on the evolutionary timeline. We were able to distinguish separate and substantial color/morph types at both PIRO and ISRO and accordingly split the samples into *L. luteola* and *L. radiata* on the premise that it is easier to clump than split the data at a later date. At SLBE the *L. siliquoidea* group showed no strong morph differences as seen at the other parks and as such was merely called *L. siliquoidea. Lampsilis ventricosa* has also undergone some name changes, though to a

lesser extent, including *L. cardium, ovata,* and *ventricosa. Lampsilis ventricosa* is the species designation most used for this group in this part of the Great Lakes at this time.

3. *Pyganodon (Anodonta)*

Identification of *Pyganodon* species is difficult not only due to poor taxonomic revision, but also because of extensive shell variability within the different species, natural erosion of key shell characteristics, and the observation that hybridization between species is a common occurrence. We have identified two species, *P. grandis* and *P. cataracta*, plus intergrades or hybrids. These species and hybrids are not as readily differentiated in the field, as are the *Lampsilis* species. Identifications are based on shell shape, which is often subjective, and the whorls located on the umbo of the shell (beak structure), which are often eroded even in very young animals. The hybrids are so designated because they combine physical characteristics of both *P. cataracta* and *P. grandis*.

Pyganodon grandis, or the giant floater, is the most adaptable and widespread unionid in North America. It is a fast-growing, thin-shelled mussel, with no proven external sexual characteristics and can easily reach 26 cm in length. The shell is light-to-medium brown, usually without stripes, and inflated rounded ventral edge; the nacre is white. This mussel is found in most habitats except fast flowing areas, and at all temperature extremes. *P. grandis* can use a wide variety of fish hosts such as black crappie, bluegill, bullhead, carp, common shiner, darters, freshwater drum, gar, killifish, largemouth bass, pumpkinseed, rock bass, sauger, smallmouth bass, stickleback, walleye, white bass, white crappie, white sucker, and yellow perch. In some localities, populations may not always require a fish host to complete the life cycle.

Pyganodon cataracta cataracta, the lake floater, is more commonly found on the Atlantic slope. As with all *Pyganadon* spp., this is a fast-growing, thin-shelled mussel, with no proven external sexual characteristics, but usually is less than 20 cm in length. The shell is elongated, medium-dark brown, usually without stripes, and has white nacre. This mussel is also found in most habitats, except fast-flowing areas. This mussel can use a wide variety of fish hosts.

Pyganodon lacustris is a recently described species, very similar in shape to *P. cataracta* but with differences in umbonal growth lines. Otherwise, the two species are very similar. Nothing is known about host specificity, but it is assumed to be similar to *P. grandis*.

4. *Anodontoides*

The cylindrical papershell, *Anadontoides ferussacianus,* is a small mussel (~6 cm) with a very thin shell, bright iridescent nacre, and without hinge teeth. It is locally abundant throughout the Great lakes, living in sandy areas of small streams and rivers. There is a slight sexual dimorphism of the shells, with females being more inflated posteriorly. A number of fish hosts such as largemouth bass and darters are used.

5. *Lasmigona*

Two species, *L. complanata* and *L. costata* were found at SLBE. *Lasmigona complanata*, the white heelsplitter, is the larger of the two , reaching lengths of up to 20 cm. This species has a relatively thick dark-brown shell with white nacre. It is very adaptable to various types of habitats and fish hosts and is common in the Great Lakes watershed.

Lasmigona costata, or the fluted shell, is a smaller animal (~17 cm) that can be easily distinguished by the crinkling of the shell on the posterior margin. This species is widespread throughout the Great Lakes region, but rarely in large numbers. Fish hosts include carp and bowfin.

6. *Ligumia*

Two species of *Ligumia* were found at SLBE. *Ligumia recta*, the black sandshell, is the larger of the two, often up to 15 cm in shell length. The outside of the shell is black or very dark green and the inside nacre is usually purple or white. This species is typically found only in rivers, and is widely distributed, but usually in low population numbers. Fish hosts include largemouth bass and walleye. The second species, *Ligumia subrostrata*, or the pond mussel, is much smaller, usually less than 8 cm in length. The shell is elongated, pate tan with darker rays,

and often blunted at the posterior end. This is a stream species, occasionally found in small lakes. It uses the same host fish as *L. recta*.

7. *Strophitus*

Strophitus undulatus, or the creeper or strange floater, is a small mussel (10 cm) that colonizes both lake and river habitats. It can use a variety of fish as hosts, including creek chubs and walleye. Metamorphosis of *Strophitus spp*. larvae may take place without the use of a fish host (Clarke A.H. 1973. The freshwater molluscs of the Canadian Interior Basin. Malacologia 13:1-509).

8. *Venustaconcha*

Venustaconcha ellipsiformis, or the ellipse, is a small mussel <8 cm in length that can be easily confused with *Lampsilis fasciola*. The ellipse tends to be more elongated and the internal anatomy of the shell shows distinct internal teeth differences. This mussel is usually found in low numbers in small streams. A number of fish hosts are used, mostly darter and sculpin.

Figure 24. Pictures of unionid species found at Sleeping Bear Dunes National Lakeshore.

Anodontoides ferussacianus

Elliptio complanata

Elliptio dilatata

Lampsilis fasciola

Lampsilis siliquoidea - ♀

Lampsilis ventricosa - ♀

Lasmigona complanata

Lasmigona costata

Ligumia recta

Ligumia subrostrata

Pyganadon grandis

Pyganodon cataracta

Strophitus undulates

Venustaconcha ellipsiformis