Great Lakes Sea Grant Fisheries Leadership Institute

Fisheries Habitat Module

by
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Photo credits: NOAA

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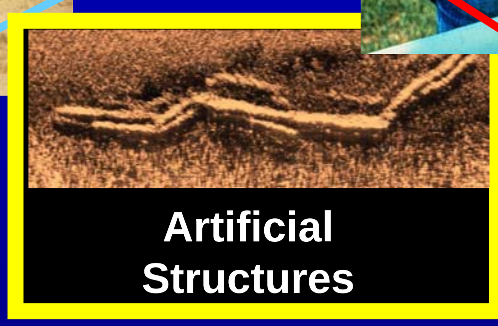
TABLE OF CONTENTS

Types of Great Lakes Habitat



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INTRODUCTION

Types of Great Lakes Habitat

Fish within the Great Lakes basin utilize many different types of habitats. Types range from something as simple as water (i.e., fish require water to live in) to habitats as complex as an organism itself (i.e., one organism may use another as habitat). Moreover, humans are responsible for constructing artificial structures that often serve as fish habitat. Fish may utilize unique habitats during different seasons throughout the year or to complete various stages of their life-cycle. Fish are not only directly influenced by changes to Great Lakes aquatic habitat, but also indirectly by changes to terrestrial habitats that fall within the Great Lakes basin. Changes to habitat can result via natural processes, but more often, are due to human-induced degradation or impacts.

Great Lakes Habitat Types

WATER

- Fish need water to live (intuitive, but very important)
- Fish need suitable water quality
  - Temperature
    - Warmwater fish (preferred summer temp 27-31º C)
      - Channel catfish, largemouth bass, bluegill
    - Coolwater fish (preferred summer temp 21-25º C)
      - Yellow perch, walleye, northern pike
    - Coldwater fish (preferred summer temp <15º C)
      - Trout, salmon, whitefish, deepwater sculpin

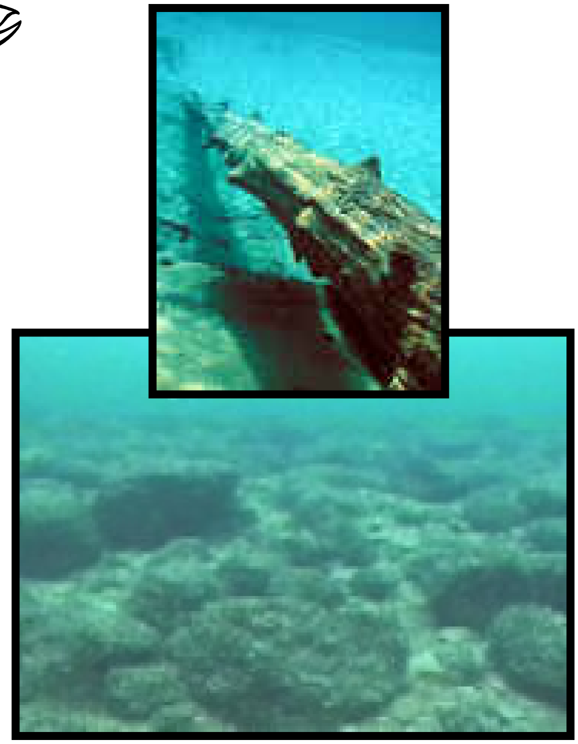
Photo credit: NOAA

  - Dissolved oxygen (D.O.)
    - Some fish are more tolerant of low levels
    - Coldwater holds more D.O.
    - Warmwater holds less D.O.
  - Pollutants
    - Nutrients
      - Fish require a balance of nutrients (nitrogen and phosphorous)
      - Can cause problems in excess or shortage
    - Contaminants or toxins
      - Fish are intolerant of the presence of contaminants
        - Can accumulate, magnify, and cause harm or death to fish as well as aquatic life, and even humans
    - Sediment
      - Can cause turbid (cloudy) water
      - Many freshwater fish and aquatic plants are intolerant of high turbidity (e.g., sight feeders may have difficulty w/ prey capture; primary production is slowed)

Photo credit: Unknown

• Acidity

▫ Many freshwater fish are intolerant of highly acidic (pH < 7) or basic (pH >7) environments, but are more suited to neutral (pH = 7) conditions



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SUBSTRATE & NATURAL STRUCUTURE

● Silt, clay, sand, gravel, cobble, boulder, logs, trees, limbs, leaves

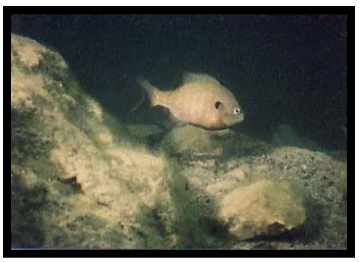


Photo credit: Michael Eversmier

▪ Fish use as refuge, feeding grounds (different substrates often support diverse communities of invertebrates), or spawning grounds

BIOTA

● One species may serve as habitat for another

Photo credit: USFWS

▪ Lake trout serve as hosts for sea lamprey

▪ Microscopic parasites, bacteria, and fungi colonize fish hosts

▪ Zebra mussels foul freshwater snails and native mussels

▪ Zebra mussels create interstitial spaces for macroinvertebrates to colonize

▪ Native mussel larvae attach to fish hosts (i.e., on gills or body), rely on fish for population replenishment, distribution, range expansion

NEARSHORE WATERS (littoral zone)

● Shallower, warmer waters are more enriched by streams and tributaries

Photo credit: NOAA

▪ All Great Lakes fish use for one or more critical life stages

▪ Permanent residence for some species

▪ Feeding or nursery grounds for offshore species

▪ Fish species diversity and production is greater in nearshore waters than offshore waters (i.e., more light penetration in shallow waters)

OFFSHORE WATERS (pelagic areas)

- Deeper, cooler, open waters

Photo credit: NOAA

- Less diverse than nearshore waters
- Often vertical stratification of temperature
- Great Lakes fish inhabitants include whitefish, trout, salmon, deepwater sculpin

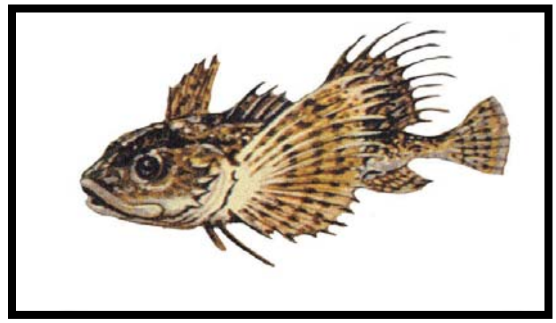


Photo credit: NOAA

WETLANDS

- Coastal wetlands

Photo credit: USFWS

- Open shoreline; unrestricted bays; shallow, sloping beach; restricted riverine; lake-connected inland; and protected-barrier beach

Photo credit: USGS

- Functions include flood water transport, flood storage, shoreline protection (act as barrier), water quality improvement (remove excess nutrients and pollutants), food chain production and export, habitat for flora and fauna
- Collect nutrients that are washed off land and into tributaries
- Support both the aquatic food web and habitat for birds, mammals, reptiles, amphibians, fish, and invertebrates (all depend on wetlands for at least one life stage)
- Shaped by waves, wind, tides, and water-level fluctuations

- Inland wetlands

- Fens, bogs, wet meadows, and wet forests

Photo credit: USFWS

- Function as reservoirs for water in the Great Lakes drainage basin
- Help regulate sediment and certain pollutant loads
- Store nutrients and serve as vehicle for nutrient exchange for the diverse species that use wetlands
- Breeding area for basin's wetland and upland species

COASTAL SHORE SYSTEMS

- Sand dunes

Photo credit: NOAA

- ▪ Dunes along Lake Michigan shoreline are up to 300 feet in height
- ▪ Buffer coastal wetlands (fish habitat) from waves, wind, and ice
- ▪ Rich in species diversity
- ▪ Greatly affected by natural processes such as weather, wind, erosion, and lake-level fluctuations

Photo credit: NOAA

- Sand beaches

Photo credit: NOAA

- ▪ Shoals, sandbars, and sand spits (fish habitat)
- ▪ Protect lagoons and coastal marshes from wind and wave action

Photo credit: MPP

LAKE PLAIN SYSTEMS (lakeplain prairies and savannas)

- Occupies the area of the ancestral lakebed formed as the last glaciers receded

Photo credit: USEPA

- ▪ Provided a refuge during severe weather events
- ▪ Flood water retention
- ▪ Found in southern Lake Michigan basin
- ▪ Only fragmented areas survive after European settlement
- ▪ No longer viable to sustain historically significant communities

Photo credit: INHS

INLAND TERRESTRIAL SYSTEMS

- Includes numerous types of forests, barrens (oak and pine in northern basin), prairies

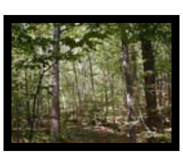


Photo credit: INHS, Unknown

- ▪ Input of materials into aquatic systems which decompose and release nutrients
- ▪ Results of glaciation and climatic effects
- ▪ Support globally significant and rare ecological communities
  - • Rare land snails inhabit thin layered rocks and soils

ARTIFICIAL STRUCTURES

- Reefs, break walls, rip-rap shoreline, concrete piers, intake and outflow pipes, harbors
    - Fish use as refuge, feeding areas, spawning areas

Photo credit: NOAA

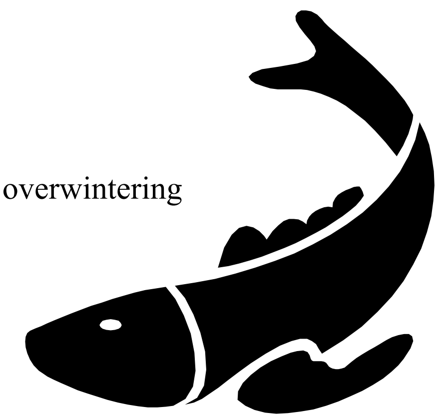
Photo credit: INHS

ARTIFICIAL REEF

Photo credit: NOAA

TRIBUTARIES

- River and streams
    - Fish utilize lotic (i.e., flowing water) areas at different times in their life cycle
        - Spawning
        - Nursery areas
        - Feeding
        - May utilize river backwaters for overwintering



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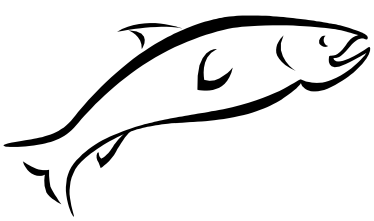


Photo credit: USFWS

SUMMARY

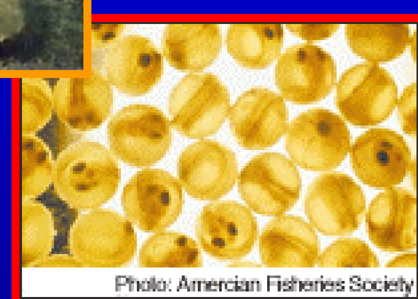
Types of Great Lakes Habitat

Many different aquatic and terrestrial habitat types exist throughout the Great Lakes basin. Examples include water, substrate/other natural structure, biota, nearshore waters, offshore waters, wetlands, coastal shore systems, lakeplain systems, tributaries, and artificial structures. Different habitat types function uniquely to benefit individual organisms as well as the ecology of the Great Lakes as a whole. Degradation or removal of a particular habitat may directly or indirectly alter lake ecology. For example, an impacted coastal wetland may no longer be viable to serve as a spawning or nursery area for the fish community. Similarly, the removal of lakeplain habitat may alter lake hydrology as it typically serves as a flood retention area. Such changes in hydrology may lead to the restructuring of plankton, macrophyte, invertebrate, and fish communities.

Great Lakes Habitat Uses

Feeding

CoVER



Spawning

Photo credits: AFS, GLFC, Michael Eversmier, Nick Giles, Unknown

INTRODUCTION

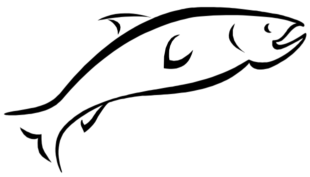
Great Lakes Fish Habitat Uses

Fish use aquatic habitat for many different purposes, and such uses are often dictated by conditions needed for survival or production of offspring. Habitats may only be accessible to fishes during a particular season or critical to only a specific life-stage of a species. Moreover, fishes may have completely separate habitat requirements or have minor to major overlap in the utilization of one or many habitats. Some fishes may use a single habitat for multiple purposes. Undisturbed or minimally impacted habitat is critical to the survival of Great Lakes fishes.

Great Lakes FISH Habitat uses

COVER

- Fish orient to physical structure



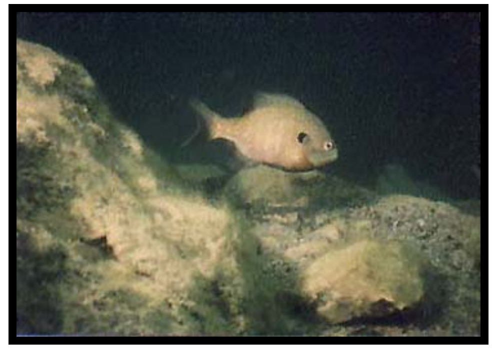


Photo credit: Michael Eversmier

  - Rocks, sand, gravel
  - Logs, limbs, sticks
  - Macrophytes, algae
  - Reefs, gravel bars

- Fish use physical structure for many purposes

Photo credit: MPP

Photo credit: Unknown

  - Predator avoidance
  - Shelter from storms
  - Temperature regulation
    - Physical structure can provide shade
    - Shallow bays warm quickest in Spring
  - Escape of high flow conditions
  - Ambush of prey
  - Egg deposition

Photo credit: NOAA

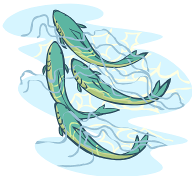
FEEDING

- Fish have preferred feeding habitats

Photo credit: Michael Eversmier

  - Benthic (bottom-feeding) fishes often found over sand, silt, and mud
    - Macroinvertebrates inhabit softer sediments
    - Mussels utilize softer sediments as habitat
  - Planktivorous (plankton-feeding) species may inhabit open water
    - Zooplankton and phytoplankton often found in pelagic (deep) waters
  - Ambush predators may be found in areas of high structural complexity
  - Open water predators may feed on schooling prey species

SPAWNING



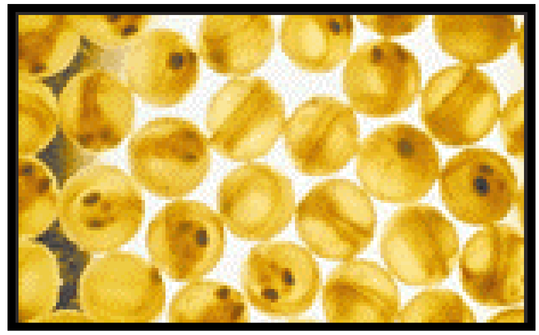
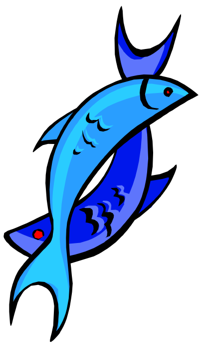


Photo credit: AFS

- Fish spawn in different habitats
  - Nearshore/littoral areas
  - Wetlands
  - Rivers and streams
  - Offshore areas
    - Deep reefs
- Fish spawn over different substrate types
  - Sand
    - Eggs may travel w/ current along sandy bottom



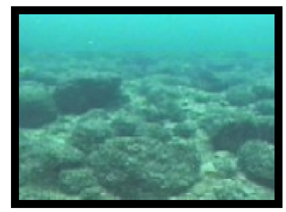
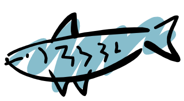


Photo credit: NOAA

  - Gravel
    - Deposition of eggs in interstitial spaces
    - Eggs mimic gravel in color, size, and shape
      - Eggs are camouflaged

Photo credit: NOAA

  - Rocks
    - Deposition of eggs on or under rocks
    - Deposition of eggs in interstitial spaces
- Fish spawn in different temperature conditions



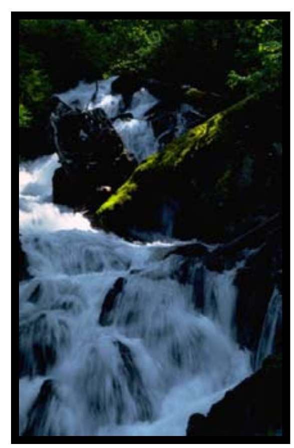


Photo credit: MPP

  - High flow
    - High gradient rivers and streams
  - Intermediate flow
    - Lower gradient rivers and streams
  - Low flow
    - Littoral areas, backwaters, wetlands, harbors
- Fish spawn near aquatic plants or woody structure

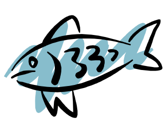


Photo credit: Michael Eversmier

  - Logs, limbs, sticks
    - Deposit eggs on structure
    - Broadcast eggs over interstitial spaces
  - Aquatic macrophytes
    - Deposit eggs
      - On undersides of leaves
      - Within plant or algal masses

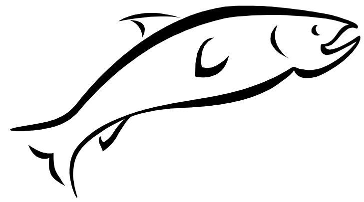
Photo credit: MPP

NURSERY

Photo credit: NOAA

- Fish may deposit eggs in areas that promote a high chance of survival for offspring
    - Nearshore/littoral areas
        - Highly productive areas
            - Produce more abundant food items
        - Areas inaccessible to large predators
        - Warmer, more constant water temperature
        - High structural complexity
            - Provides shelter
            - Minimizes predation of eggs, larvae, and juveniles
        - Food source
            - These areas also produce aquatic food items lower on the food chain

Photo credit: Unknown



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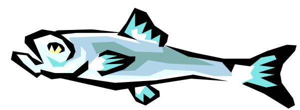
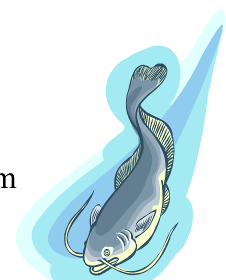


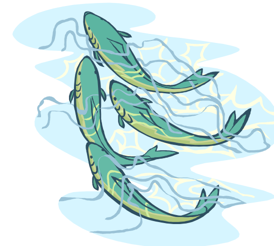
- Coastal wetlands
    - Still water
        - Usually surrounded by trees and vegetation
            - Provides shade
            - Reduces impact of storm events
        - High structural complexity
            - Provides shelter
                - Between reeds, grasses, tree roots, etc.
            - Minimizes predation of eggs, larvae, and juveniles
        - Food source
            - These areas also produce aquatic food items lower on the food chain

Photo credit: Nick Giles

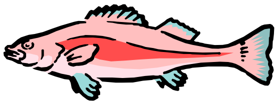
Photo credit: INHS

Photo credit: Michael Eversmier





▪ Inland wetlands



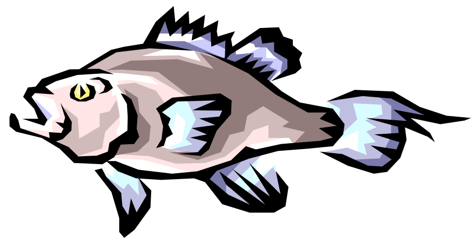
• Adults access this habitat during flood events

• High structural complexity

▫ Provides shelter from weather

▫ Minimizes predation of eggs, larvae, and juveniles

Photo credit: Nick Giles



▪ Logs, limbs, sticks, aquatic plants, algae

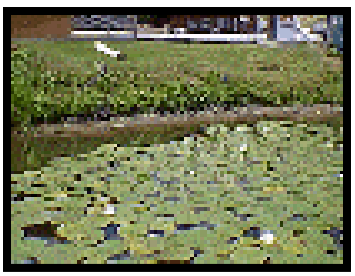


Photo credit: Unknown

• Provide structural complexity

• Minimizes predation of eggs, larvae, and juveniles

• Provides shelter from storm events

• Source of food

▫ Other organisms such as macroinvertebrates may be produced on or near structure

Photo credit: Unknown

▪ Rocks, gravel, sand

• Gravel-riffle areas in high flowing streams

▫ Sediment deposition on eggs is minimized by flowing water

▫ Interstitial spaces in gravel may insure eggs remain where desposited

Photo credit: NOAA

Photo credit: IDNR

• Rock reefs

▫ Provide deep interstitial spaces

· Minimizes predation of eggs, larvae, and juveniles

Photo credit: NOAA

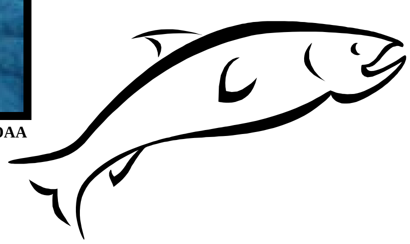
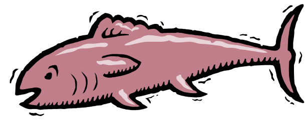
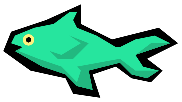


Photo credit: GLFC

MIGRATION



- Fish use many different habitats for migratory purposes
  - Fish may spawn in different places than they feed or reside
    - Rivers, streams, deep areas of a lake



  - May overwinter in an area far removed from their summer residence
  - Use open water, channels, littoral areas, etc., as a highway to travel from one habitat to another

OVERWINTERING/OTHER SEASONAL USES

- Fish utilize different habitats seasonally
  - Spring utilization
    - Migration
    - Spawning
    - Feeding

Photo credit: Sea Grant, Shedd Aquarium

  - Summer utilization
    - Some spawning
    - Nursery
    - Feeding

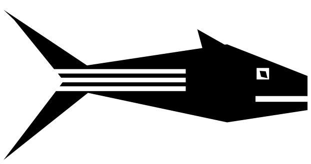
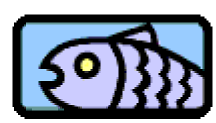


Photo credit: NOAA

  - Fall utilization
    - Feeding
    - Spawning
      - Fall spawners
        - Lake trout
    - Migration

Photo credit: Sea Grant, Shedd Aquarium

  - Winter utilization
    - Overwintering
      - Deeper open water
        - Maintain slightly higher temperatures than shallow areas
          - Rarely ice over



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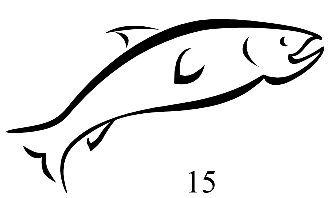
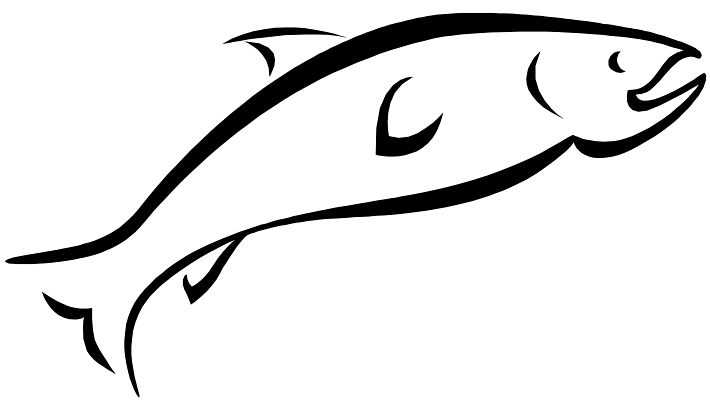


- Deeper backwater areas
  - Escape winter storm events
    - Areas surrounding backwaters are often heavily wooded
    - Maintain slightly higher temps than other areas

Photo credit: NOAA

Photo credit: NOAA



SUMMARY

Great Lakes Fish Habitat Uses

Fish use various aquatic habitats for many different purposes such as cover, feeding, spawning, nursery areas, migration, and over-wintering/other seasonal uses. Cover habitat is often used for refuge, and includes rocks, sand, gravel, logs, limbs, aquatic plants, and artificial reefs. Feeding habitats consist of littoral areas (ambush predators), open water (piscivorous or planktivorous predators), or lake/river/stream bottoms (benthic predators). Spawning may occur in different habitats (e.g., littoral areas, streams, wetlands) or habitat conditions (e.g., temperature, flow). Exceptional nursery habitat often promotes the greatest chance of survival for offspring. Fish may use different habitats for migrating from one location to another. Habitats can be utilized seasonally. For example, acceptable over-wintering habitat for fishes may be that which maintains slightly higher water temperatures than shallower areas.

Degradation of Great Lakes Habitat

Industrial processes

AGRICULTURE

Photo credits: Unknown, NOAA

CANAL building

URBANIZATION

INTRODUCTION

Degradation of Great Lakes Habitat

Habitat degradation began with the onset of European settlement in the Great Lakes basin in the mid-1800s. Multiple stressors such as logging, farming, fishing, industry, and urbanization have all impacted terrestrial and aquatic habitat. Examples of habitats that have been degraded are water, substrate or natural structure, wetlands, coastal shore systems, lakeplain systems, inland terrestrials systems, and tributaries. Biota that have been affected as a result of habitat degradation are lake trout, blue pike, lake sturgeon, and ciscos. Prportions of some habitats (e.g., wetlands) have been severely reduced, but recently efforts aimed at protecting or restoring aquatic and terrestrial habitats have slowed degradation. Pollution and nonnative species are two major causes of habitat degradation that developed as a result of urbanization and the increased number of vectors for world travel.

DEGRADATION OF GREAT LAKES HABITAT

IMPACTS TO GREAT LAKES BASIN (historical)

Photo credit: NOAA

- Human settlement in the mid-1800s led to the development of the region
  - Multiple stressors developed
    - Exploitation of resources
      - Logging (forests were clear cut)
        - Erosion increased sediment loads to aquatic systems
        - Protective shade was removed from rivers and streams
        - Sawmills left streams and embayments clogged with sawdust
      - Farming
        - Prairies were plowed
        - Exposed soils washed away more readily
        - Valuable stream and river habitat were buried under sediment
      - Fishing
        - Fish stocks were harvested indiscriminately
        - Seemingly endless abundance of fish was reduced
        - Whole populations of fish began to disappear
          - Blue pike
          - Lake trout
    - Industry and advances in agriculture
      - Untreated wastes led to degradation of one water body after another
      - New chemical substances came into use
        - PCBs and DDTs

Photo credits: YMDLD, ISM, Unknown

- Non-organic fertilizers were applied to agricultural fields

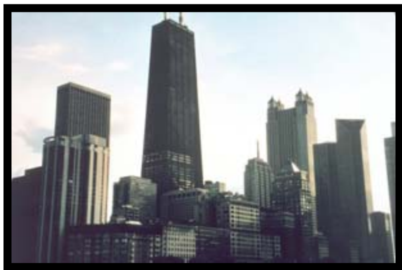
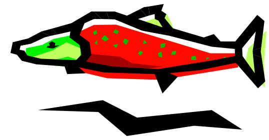
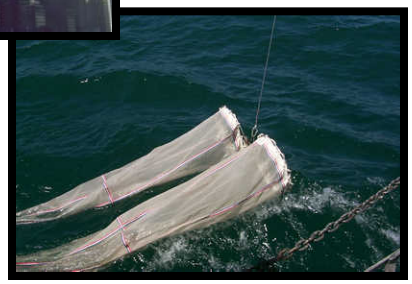


Photo credit: NOAA

- Urbanization



  - Cities developed
  - Untreated human wastes became a problem
    - Bacterial contamination
    - Resulted in floating debris in nearshore areas
    - Waterborne diseases developed
    - Nutrient levels (resulting from wastes) exceeded what water bodies could handle



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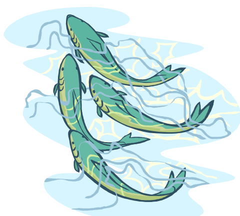


- Currently (today) the ecosystem is heavily dependent on human management
  - Fish stocking or control of exotic species such as the sea lamprey and zebra mussel
  - Efforts to improve water quality
  - Major reductions were made in pollutant discharges in the 1970s
    - Floating debris and oil slicks disappeared
    - D.O. levels improved
    - Many beaches reopened due to sewage control
    - Algal mats disappeared as nutrient levels declined

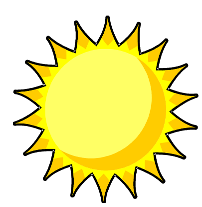
Photo credit: NOAA

Photo credit: MPP

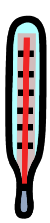
Photo credit: NOAA

Photo credit: MPP

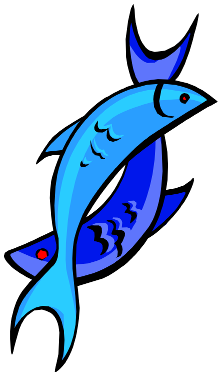
IMPACTS TO WATER (nearshore and offshore waters)



- Destruction of riparian areas (terrestrial plant life that borders nearshore water)



  - Water body is no longer shaded
  - Water temp increases
  - Aquatic plant life increases due to increased light, photosynthesis, and primary production



▪ Aquatic plant life dies

• D.O. is used up in decomposition of dead organic matter

▪ Fish community structure/population dynamics change

• Lose species intolerant to higher temperatures and low D.O.

• More tolerant species may increase in number (e.g., carp, bowfin)

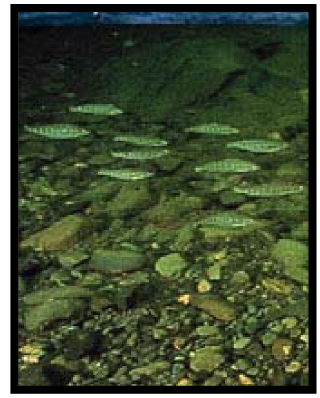


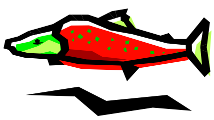
Photo credit: GLFC

● Hardening and straightening of shoreline

▪ Eliminates the migration of the nearshore with changing water levels

▪ Such modifications are meant to eliminate this migration

Photo credit: NOAA



• Effect is the reduction of the amount of fish habitat available in high water years

▪ Removes the irregularities in the shoreline that cause local variation in current

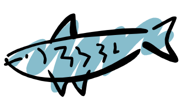
• In turn, removes local variation in substrate

▪ Results in loss of habitat diversity in nearshore waters

Photo credit: NOAA

● Interactions of exotics with native species in nearshore and offshore habitat

▪ Competitition of native fishes with exotics for food and habitat has restructured the nearshore and offshore fish communities



▪ Predation of exotics on native fishes has caused disturbances

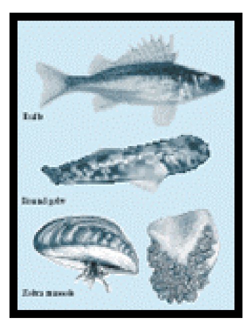
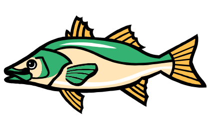


Photo credits: GLFC

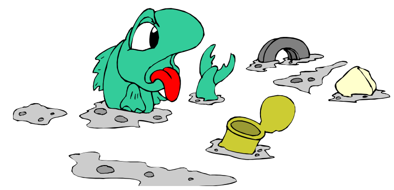
● Overexploitation of nearshore and offshore fishes

▪ Harvesting of too many fish of a particular species has eliminated populations from the community entirely



▪ Caused restructuring of the fish community

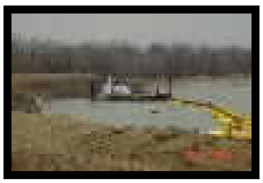
- Water quality degradation of nearshore and offshore water
    - See *Effects of Pollution on Great Lakes Habitat*



IMPACTS TO SUBSTRATE AND NATURAL STRUCTURE

- Dredging
    - Deepening areas of the Great Lakes to allow passage of ships

Photo credits: USACE



- Done by removing sediment from lake bottoms
- Sediment was often deposited on land or used to fill in wetlands
    - Disturbance of terrestrial or wetland habitat
- Resulted in redistribution of trapped nutrients or contaminants
- Changed flow regimes and water quality
    - Fish community structure and population dynamics changed

- Shoreline development
    - Construction of impervious surfaces (cement)
        - Cement is relatively impermeable and heats quickly in the sun
            - Increased surface run-off
            - Warmed run-off waters
                - Increased temperature of shallower waters

Photo credit: USDOT

Photo credit: USDOT

- Rivers and streams diverted
    - Flow regimes changed
    - Altered water temperatures

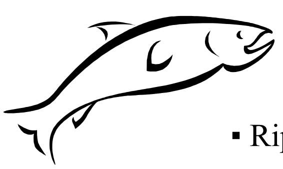


Photo credit: IDNR

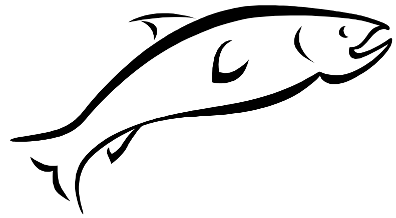
- Rip-rap shorelines
    - Replaced natural vegetation
    - Size of interstitial spaces differed from natural rock
        - Predators may have easier access to eggs and larvae
        - Fish maybe unsuccessful in using habitat or may not utilize artificial habitat at all
        - Fish populations may crash (e.g., lake trout)

Photo credit: NOAA

- Building of harbors

Photo credit: NOAA

  - Dredging of main harbor and channels
  - Redistribution of nutrients and pollutants
  - Introduction of chemicals from boat traffic
  - Changed flow regimes
  - Resulted in changes to fish community composition



- Clear-cutting and plowing to create agricultural fields

Photo credit: Unknown

  - Sediment run-off to water bodies
    - Light penetration is decreased
    - Primary production is slowed or altered
    - Aquatic plant and animal life die
  - Sediment embeds more structurally complex substrate (gravel, rocks)
    - Renders substrate habitat unusable to many fish species (e.g., darters, sculpins)

- Building of canals

Photo credit: Unknown

  - Built to allow passage of ships
  - Disturbance of bottom sediment
    - Redistribution of nutrients and contaminants
  - Creation of impervious surfaces

Photo credit: NOAA

    - Decreases absorption of nutrients and chemicals
      - Overfertilization
      - Accumulation of contaminants
    - Also created passage for nonnatives
    - Resulted in changes to fish community and populations

- Building of artificial reefs
  - Reefs may attract or concentrate fish

Photo credit: INHS

    - Fish may be easier to catch
    - Low recruitment coupled with abundant harvest may cause changes to the community or population

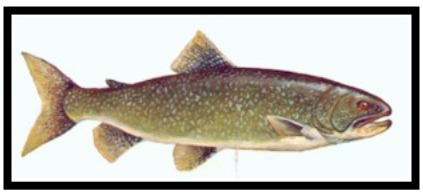
- May not necessarily increase production

Photo credit: NOAA

  - Size of interstitial spaces may not be adequate
    - Predators may have easier access to prey
  - Reefs may not be placed in the right areas
    - Adaptions of fish over evolutionary time may prevent adequate use of reefs that were built in human time

IMPACTS TO BIOTA ENDEMIC TO THE GREAT LAKES REGION (examples)

- Lake Trout



  - Commercial fishing
    - Little to no regulations in the 19th Century
    - Abundant fish were harvested
    - Stocks were reduced in the Great Lakes
  - Sea Lamprey

    - Entered the Great Lakes via the Welland and Erie canals
    - Preyed on lake trout (used them as habitat)
    - Reduced lake trout populations to critical levels
    - Natural populations were essentially eliminated from most of the Great Lakes

  - Current status
    - Lakes Ontario, Huron, Erie, and Michigan
      - Lake trout populations are supported by aggressive stocking programs
      - Stocking programs have been relatively unsuccessful in establishing breeding populations
    - Lake Superior
      - Lake trout populations were not as severely impacted
      - High degree of natural reproduction
      - Populations supplemented with some stocking

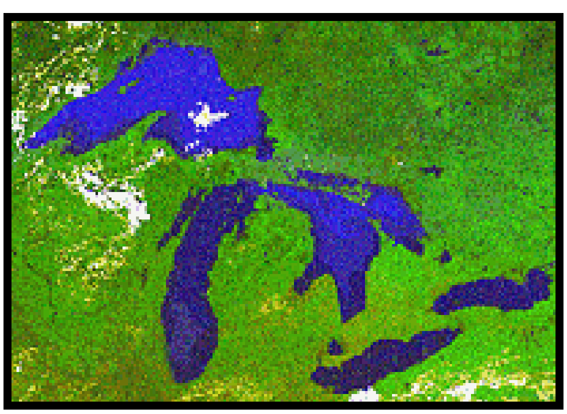


Photo credit: Sea Grant, GLFC, USFWS, NOAA, Unknown

- Blue pike (sub-species of walleye)
  - Commercial and recreational fishermen


Photo credit: NOAA

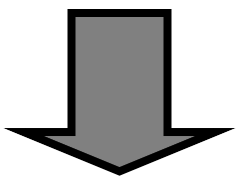
    - Landed a billion pounds of fish between 1885 and 1962
    - At times, blue pike made up half of the commercial catch in Lake Erie
    - Population of blue pike declined
  - Urbanization and agriculture


Photo credit: Unknown

    - Marshes and wetlands were drained
    - Dams were built in tributaries and rivers
    - Pollution and sediment in the Great Lakes increased
    - Clear, cool water habitat needed by blue pike deteriorated
  - Introduction of non-natives


Photo credit: Sea Grant

    - Sea lamprey, rainbow smelt, alewife
      - Competition with blue pike for food
      - Predation on blue pike eggs and larvae
  - Current status



EXTINCTION

    - Population crash
      - Crashed in 1958
      - Blue pike lingered until extinction in 1970
- Lake sturgeon
  - Pre-1900 commercial fishermen
    - Pre-1850 fishermen regarded lake sturgeon as a nuisance because of fishing gear destruction
      - Led to their widespread slaughter
    - Economic importance (e.g., caviar) was recognized by the mid- to late 1800s
      - Harvest intensified

Photo credit: Sea Grant, Shedd Aquarium

Photo credit: ISM

- ▫ About 1879-1900, commercial catch averaged over 1,814 metric tons
- ▫ In 1885, 4,901 metric tons were harvested
  - · Of which 2.359 tons (5.2 million pounds came from Lake Erie)

• Post 1900 commercial fishermen

- ▫ From 1900 to the 1970s little is known about lake sturgeon populations
  - · Continued to decline
  - · By the 1900s, 80% of lake sturgeon were removed from Lake Erie
  - · Commercial harvest was reported until 1977 but in very low numbers after 1956
  - · Canadian fishing operations in Lake Erie reported catches of 1.36 to 2.27 metric tons (3 to 5 thousand pounds)
    - - Much reduced from previous century

Photo credit: DFO

Photo credit: NOAA

• Factors affecting lake sturgeon decline

- ▫ Commercial overexploitation
- ▫ Habitat loss and degradation
- ▫ Damming of tributaries
  - · Prevented access to historical spawning grounds
- ▫ Destruction of spawning areas
  - · Siltation
    - - Via deforestation, agriculture, and dredging

• Hindrance of reproductive success

- ▫ Due to pollution from nutrient and contaminants loads

Photo credit: USACE

Photo credit: Unknown

Photo credit: USFWS

- Long reproductive cycle complicates recruitment (i.e., the process of adding new individuals to the population) in the presence of other problems
    - Takes 24-26 years (but up to 33 years) for females to sexually mature
    - Takes 8-12 years (but up to 22 years) for males to sexually mature

- Current status (1987-present)

Photo credit: USFWS

- Only remnant populations remain in most Great Lakes areas
- Recognized by the American Fisheries Society (AFS) as threatened in North America
- Listed as threatened, endangered, or of special concern in 19 of 20 states throughout its range
- Protected in Canadian waters
    - Closed seasons, size limits, creel limits, and gear restrictions
- Recently restoration efforts have increased
    - Lake sturgeon appear to be on the rebound
        - Energy flow is shifting to benthos with the addition of nonnative mussels
        - May be benefiting the benthic feeding lake sturgeon
        - Natural reproduction is occurring
        - Still impaired relative to historical abundance
        - High contaminant loads are still a problem

Photo credit: USFWS

- Ciscos

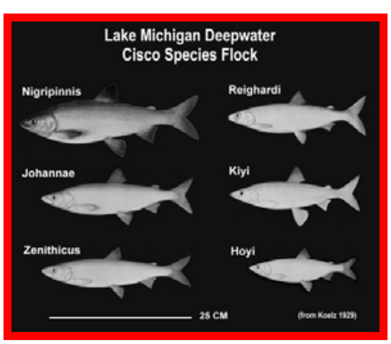


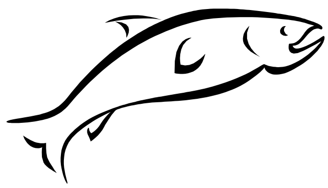
Photo credit: DFO

- Deepwater cisco
    - Native to Lakes Huron and Michigan
    - Became extinct in the 1950s
- Blackfin cisco
    - Native to all of the Great Lakes except Lake Erie
    - Disappeared in the 1960s

Photo credit: Sea Grant, Shedd Aquarium

- Longjaw cisco
  - ▫ Native to Lakes Erie, Huron, and Michigan
  - ▫ Reached extinction in the 1970s
- Factors affecting extinction
  - ▫ Overexploitation by fishermen
  - ▫ Pollution
  - ▫ Siltation
  - ▫ Other forms of habitat degradation
    - · Due to development
    - · Predation and competition from nonnative species

Photo credit: Sea Grant, Shedd Aquarium



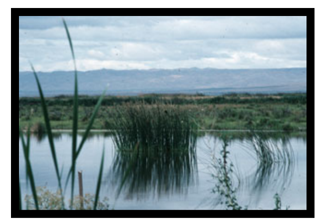


Photo credit: USFWS

IMPACTS TO WETLANDS

- ● Coastal Wetlands
  - ▪ Stressors

Photo credit: USGS

- Nonnative species such as purple loosestrife
- Changes in sediment composition and deposition
  - ▫ Affected habitat types, productivity, and diversity
- Shoreline modification is increasing

Photo credit: USGS

- ▪ Fragmentation
  - Most coastal wetlands have been filled in or paved over
  - Only fragments of coastal wetlands remain

Photo credit: USFWS

- ▪ Protection or restoration
  - No coordinated stewardship activities to protect or restore the remaining fragments

- ● Inland wetlands
  - ▪ Stressors
    - Agriculture
    - Industry
    - Urban development

Photo credit: USFWS

Photo credit: NOAA

▪ Loss

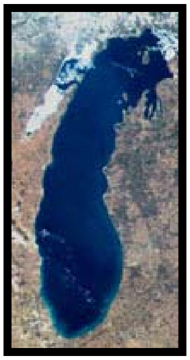


Photo credit: NOAA

• Over the last two centuries wetland losses within the fours states at least partially within the Lake Michigan basin have been disproportionately greater than in other U.S. regions

• Since the 1780s, have lost 21.9 million acres (62.9%) out of an original 34.8 million wetland acres

• Only 12.9 million acres remain

▫ Represents 12.3% of the wetlands within the lower 48 states

▪ Protection or restoration

• The Supreme Court ruled that the federal government, namely the Army Corps of Engineers, has no jurisdiction over wetlands

• The responsibility for protecting isolated wetlands is in the hands of the states and local authorities

• Wisconsin Wetland Law

▫ Those who have not filled or drained their wetlands must wait for approval from the Wisconsin Department of Natural Resources

• Antrim County, Michigan, Wetland Protection Ordinance

▫ The county will have local control over the protection of wetlands as a valuable resource

▫ Gives authority over wetlands contiguous to lakes and streams, and also, those that are not connected to a water body

IMPACTS TO COASTAL SHORE SYSTEMS

Photo credit: NOAA

● Sand Dunes

▪ Stressors

• Residential development

• Mining practices

• Nonnative species

▫ Baby's breath

Photo credit: NOAA

Photo credit: NOAA

- Blowouts
  - Occur in foredune area
  - Vegetation is disrupted
  - Wind quickly erodes the sand leaving a saucer-shaped depression
  - Result from human activity

▪ Sand beaches

Photo credit: NOAA

Photo credit: NOAA

- Stressors
  - Building of artificial structures
  - Hardening of shoreline
- Problem
  - Interruption of long-term sediment transport
    - Natural erosion and replenishment of beaches is altered
  - Beach closures
    - Due to excessive levels of pathogens
- Protection or restoration
  - Tons of sand brought in each year to artificially replenish beaches

IMPACTS TO LAKEPLAIN SYSTEMS

Photo credit: USEPA

Photo credit: NOAA

- Stressors
  - Human development
  - Invasive species
- Fragmentation
  - Only small fragments remain
  - No longer viable to establish diverse plant and animal communities
- Protection or restoration
  - Areas only remain because they are protected
  - Some of these areas contain or did contain federally endangered species

IMPACTS TO INLAND TERRESTRIAL SYSTEMS

- Stressors
  - Tourism (via disturbance of natural areas)
  - Development
  - Deforestation

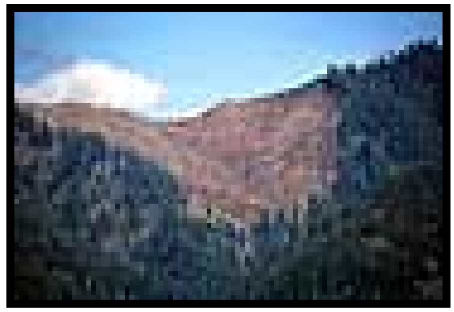


Photo credit: WK & P

IMPACTS TO TRIBUTARIES (rivers and streams)

- Stressors
  - Channelization
  - Dredging
  - Damming
  - Sedimentation
  - Bankside vegetation loss
  - Eutrophication
  - Increased flooding in the Spring
  - Toxic contamination

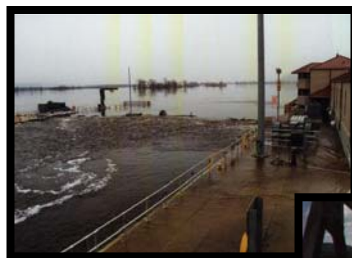


Photo credit: Uknown

Photo credit: USACE

- Problems
  - Tributaries carry increased pollutant and sediment loads to lakes
  - The suitability of tributaries as fish spawning habitats has been seriously impaired
  - Habitat degradation has been most severe in urban areas
  - Pollution from agriculture, industry, and urban development has contaminates rivers, streams, and bottom sediment
  - Also killed or contaminated fish and wildlife
  - Beneficial uses of rivers and streams have been impaired

Photo credit: LFC

- Protection or restoration
  - Progress is being made in improving and protecting tributary rivers and streams
  - Watershed management efforts by private organizations and remedial actions by government agencies has resulted in improvement

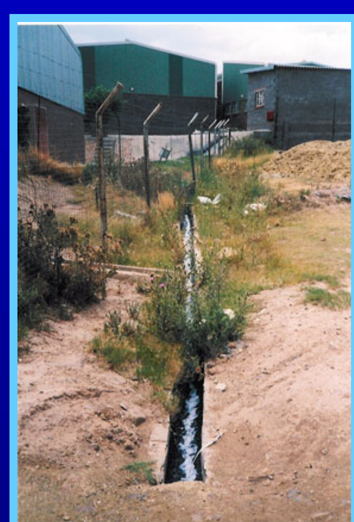
Photo credit: Unknown

SUMMARY

Degradation of Great Lakes Habitat

Riparian cover has been removed from shorelines and stream banks, resulting in water temp increases and increased primary production. Dissolved oxygen (D.O.) can be depleted resulting in fish kills. Shorelines are often straightened, developed, and hardened with impervious materials. Irregularities that provide shelter for fish are removed. Temperature increases of run-off water may lead to temperatures increases in littoral areas. The building of canals has provided a pathway for non-native species to invade the Great Lakes. These species often alter habitat utilized by native species through competition for food and space. Over-fertilization due to high nutrient input from the landscape (due to agriculture and urban run-off) can have serious consequences. Populations of Great Lakes fishes have completely disappeared or their numbers have been greatly reduced because habitat is eliminated or rendered unsuitable for completing life histories. Wetlands, coastal shores, lake plains, and inland terrestrials areas are disappearing. Great Lakes tributaries have been severely degraded, or carry excess pollutant loads to nearshore areas and open water. Currently, the Great Lakes ecosystem is heavily dependent upon human management.

Impacts of Pollution On Great Lakes Habitat



Water pollution

Photo credits: LFC, Unknown

INTRODUCTION

Impacts of Pollution on Great Lakes Habitat

Pollution is any chemical, biological, or physical change to air and water quality that has harmful effects on living organisms or makes water unsuitable for desired uses. Pollution can be from a point source (e.g., industrial pipe) or non-point source (e.g., terrestrial run-off). Industry, agriculture practices, and urbanization have are all sources of pollutants. Pollutants can be toxic to organisms, accumulate in animal or plant tissue, result in the eutrophication of a water body, or contaminant soils. Examples of pollutants include nitrogen, phosphorous, copper, nickel, oil, gas, excess sediment, etc. Pollutants can render habitat unsuitable to support life, and in some instances, may result in deformities or death in aquatic and terrestrial species. Legislation has been passed to help reduce pollutant loads in the Great Lakes basin.

IMPACTS OF pollution on habitat

POLLUTION

- Air and water
  - Any chemical, biological, or physical change to air and water quality that has harmful effects on living organisms or makes water unsuitable for desired uses

TYPES OF POLLUTION

- Point source pollution
  - Origins can be traced back to a specific entry point such a drainpipe
    - Medical, municipal, and industrial facilities
      - By-products or wastes of production processes
      - Biohazardous/biochemical wastes
      - Water from oil and gas operations
    - Bypasses and overflows from sewage systems
      - Septic system effluent
    - Unpermitted or illegal discharges
      - Dumping of paints, varnishes, and household cleaners

Photo credit: Unknown

- Nonpoint source pollution
  - Origins are many different sources that are difficult to regulate and control
    - Atmospheric deposition and subsequent washoff from impervious surfaces
      - Sources of airborne pollutants include street dust, automobiles, and natural sources such as pollen
      - Burning of fossil fuels is a major source of nitrogen
      - Acid rain is the most well-known atmospheric pollutant
      - PCBs, phosphorous, and mercury are all transported by air
      - Reaches waterways such as streams, river, and lakes
      - Airborne pollutants are a more significant source of pollutants in urban watersheds due to high impervious cover (rooftops, roads, sidewalks, and other pavement)

Photo credit: Unknown

Photo credit: GEB

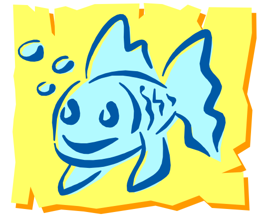

Photo credit: Unknown

• Agricultural practices

▫ Crop fertilizers

▫ Insecticides or other pesticides

▫ Sediment from eroded fields



• Urbanization

▫ Cities

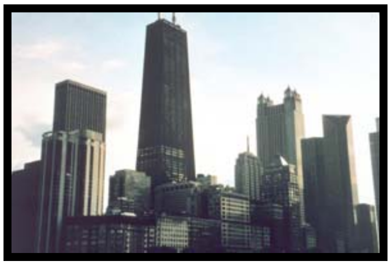


Photo credit: NOAA

· Population growth (more human waste)

· Expansion of infrastructure/impervious surfaces

▫ Construction sites

· Sediment inputs via erosion

· Chemicals used in construction practices (e.g., acids)

· Petroleum products (e.g., gas, oil)


Photo credit: YMDLD

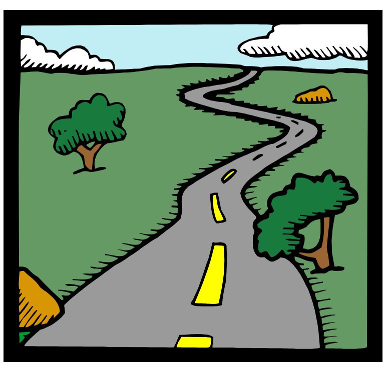
▫ Home owners

· Lawn fertilizers

· Paints, varnishes, household cleaners

▫ Highways

· Grease, oil, chemicals from automobiles



▫ Landfills

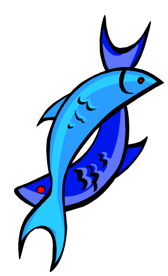
· Leaking toxins leach into groundwater

▫ Unstable shorelines

· Sediment inputs from erosion

· Sediment from shoreline development

CLASSES OF POLLUTION (point and nonpoint sources)



● Inorganic plant nutrients (i.e., nutrients not arising from natural growth)

▪ Nitrogen (N)

• Essential constituent of protein, a building block of all living material

• Fixation is the conversion of N_2 (gaseous nitrogen) to a useable form

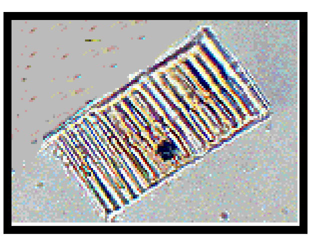

Photo credit: Unknown

- Mineralization or ammonification is the conversion of protein and nucleic acids in dead plant or animal material into amino acids which are oxidized to CO_2 (carbon dioxide), H_2O (water), and NH_3 (ammonia)
- Nitrification is the process in which ammonia is oxidized to nitrate and nitrite, yielding energy
- Denitrification is the process in which nitrates are reduced to gaseous nitrogen by certain organisms to obtain oxygen
- Ammonia (NH_3), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-)


Photo credit: Unknown

  - NH_3 and NH_4^+ are essential to plants, but toxic to fish
  - NH_3 is used in fertilizers, and surface run-off can pollute water
  - NO_2^- is toxic, but less so than NH_3 and NH_4^+
  - NO_2^- readily leaches through soils, in excess cannot be taken up by plants alone, and can pollute water
  - NO_3^- is not toxic, but high concentrations may cause algal blooms

▪ Phosphorous (P)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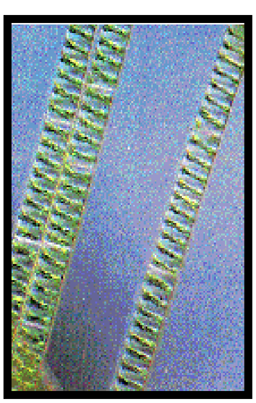
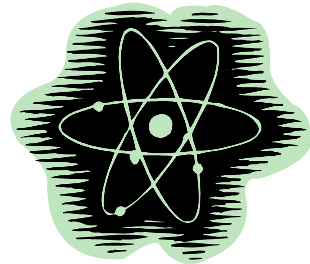


Photo credit: Unknown

- Particulate phophorous
  - Dead particulate matter and phytoplankton
- Inorganic phosphates (PO_4^{-3})
- Inorganic and organic phosphorous is excreted by zooplankton which feed on phytoplankton
- Soluble colloidal phosphorous is derived from organic phosphorous
- Both organic and colloidal phosphorous release phosphate to the inorganic fraction
- Inorganics are utilized by phytoplankton
- Organics are utilized by bacteria which are eaten by microbial grazers
- Microbial grazers excrete the phosphates they ingest
- Phosphates are present in sewage effluent, and this pathway accounts for nearly all the phosphorous that reaches rivers and lakes

- Inorganic chemicals
    - Heavy metals
        - Cadmium, chromium, copper, lead, mercury, and nickel
    - Radioactive isotopes
        - Released by industries and power plants
    - Acids
    - Salts



- Organic Chemicals (i.e., derived from living organisms)
    - Oil, gas, and solvents
        - Decomposed over time, but decomposition rate is much longer
    - Toxins or contaminants
        - PCBs, chlorinated and flourinated hydrocarbons, dioxins, furans, DDT, mirex, dieldrin, TCDD

- Oxygen demanding wastes
    - Organic wastes decomposed by biological or chemical processes that consume oxygen from water (can lead to winterkill of fish)
- Sediments
    - Increases turbidity (cloudiness of water), decreasing photosynthesis
    - Fish have different tolerances for turbid water
        - Some tolerant
        - Some intolerant
    - High turbidity limits light penetration, aquatic macrophytes die, decomposition of plant matter causes declines in oxygen levels
    - Mortality of aquatic life (plants and animals) occurs
    - Absence of aquatic macrophytes decreases complexity of available fish habitat
    - Disturbance of aquatic sediments by dredging, shipping, and storms resuspends pollutants and contaminants in the water column

Photo credit: IDNR

Photo credit: NOAA

● Thermal pollution

- Heat absorbed by water while cooling industrial and power generating plants
- Water is withdrawn from a nearby body of surface water, passed through an electric power plant, and the heated water is returned to the same body of water

Photo credit: Unknown

● Pathogens

- Often result from untreated sewage effluent
- Fecal coliform bacteria in animal human wastes
- Cause waterborne diseases
    - Bacterial, viral, and parasitic
- Treatment of sewage effluent with chlorine has drastically reduced waterborne diseases

OTHER CLASSES OF POLLUTION

● Genetic pollution

- Disruption of an aquatic system by the deliberate or accidental introduction of nonnative species (e.g, intro. of white perch resulted in white perch X white bass hybrids)

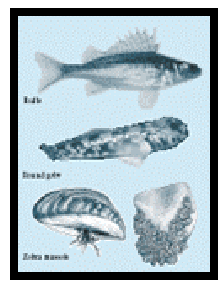


Photo credit: GLFC

ECOSYSTEMS AND ORGANISMS IMPACTED

- The waterways themselves
- Organisms living in and around the waterway
- Humans that live in the Great Lakes basin

Photo credit: INHS, Unknown

EFFECTS OF POLLUTION

● Eutrophication

- Input of sediment, silts, and nutrients to lakes, causing enrichment or fertilization, allowing life to grow
- The Great lakes were mainly oligotrophic meaning they contained little plant nutrients and were continuously cool and clear due to their immense size and depth
- Oligotrophic lakes can support high levels of animal life and receive high amounts of nutrients, from natural sources, such as decomposing plant matter

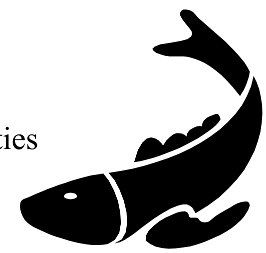
Photo credit: IDNR

- Urbanization and agriculture has increased in the Great Lakes basin, and thus, has increased the input of nutrients in to the Great Lakes

- Cultural eutrophication
  - Nutrients that enter the lake or waterway are from anthropogenic (human) sources
  - Input of more nutrients than a water body can handle results in over-fertilization
  - Nutrient loading stimulates excessive plant growth
  - Plants die, decomposition decreases the amount of oxygen in the water
  - Kills certain species of animal life
  - Other pollution tolerant species such as carp grow more rapidly, significantly altering the balance of the lake

Photo credits: YMDLD, IDNR, Sea Grant, Shedd Aquarium

- Dead zones
  - Areas within water body that are devoid of oxygen due to decomposition of dead organic matter
  - Common in the shallow, nutrient enriched Lake Erie in the 1960s
    - Problems were due to chemical pollution from phosphorous in sewage, detergent, and fertilizer
    - Legislation led to upgraded sewage treatment facilities largely solved the problem of chemical pollution



  - Dead zones returned to Lake Erie’s central basin in the 1990s
    - Causes
      - Biological
        - Zebra mussels (exotic species) remove organic matter from the lake
        - Expel the phosphorous their food contained into the bottom of the lake
        - Algae begin to grow, and as they die, they drain oxygen from the water

Photo credit: Sea Grant

      - Nonpoint source pollution
        - Cities continue to grow
        - More impervious surfaces that allow effluents from sewers and lawns to reach the lake

Photo credit: NOAA

· Has led to declines in fish populations such as yellow perch and walleye

▫ Climate change/increases in water use

· Water levels have dropped 3-4 feet since 1997

· Resulted in the reduction of the oxygen reservoir

● Bioaccumulation/biomagnification

Photo credits: Sea Grant, IDNR, Unknown

▪ Heavy metals and organic pollutants such as pesticides may be present in low concentrations in the water

▪ These pollutants are absorbed by simple organisms in much higher concentrations

▪ Fish feed on simple organisms and accumulate the pollutants

▪ More pollutants accumulate in fish as they feed on more simple organisms (biomagnification)

▪ Fish are caught and eaten by humans

● Aquatic diseases, extreme deformities, and death

▪ Tumors and death in lake trout, herring gulls, and even humans

▪ Cross-billed syndrome in cormorants 42% higher than natural occurrence in the presence of elevated levels of heavy metals and organic chemicals

▪ Terns exhibit birth defects from dioxin, PCBs, and furan at 31 times the normal level

▪ Tumors in large fish

▪ Three-legged frogs

▪ Sickness and disease in humans

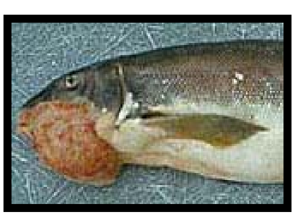


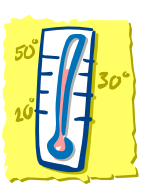
Photo credit: Unknown

• Reproductive problems, cancer, neurological disorders, skin infection caused by bacterial contamination

• Those at risk are those with weakened immune systems, including pregnant women and the elderly

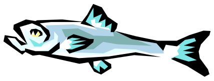
• 1,000 consumption advisories in the Great Lakes

● Heated water (thermal pollution)



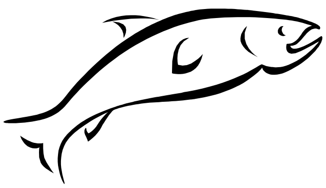
▪ Warm water holds less oxygen than cool water (solubility of oxygen is decreased)

▪ Warm water may increase nitrogen levels so as to seriously affect fish life



- Some fish species are not very efficient at extracting oxygen from water containing low concentrations and must move or die
- Rate of respiration increases and fish consume oxygen faster
- Susceptibility of fish to disease, parasites, and toxic chemicals increases
- Rate of metabolic processes (chemical reactions) in fish increases
- A fish’s physiology may prevent it from meeting increased demands causing death

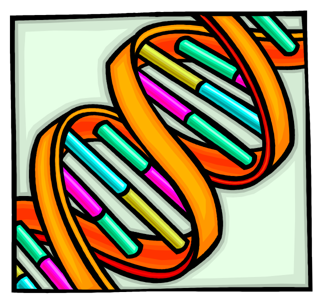
Photo credits: Sea Grant, Shedd Aquarium



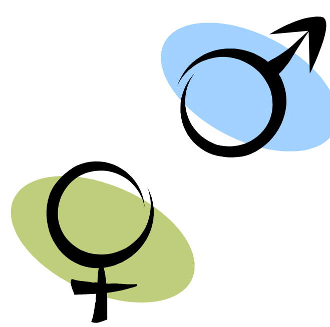
  - Enzymes may be rendered inactive
  - Coagulation of cell proteins
  - Reduction in permeability of cell membranes
  - Production of toxic products

- Disinfection action is increased, coagulant dosages are contradictory, increase slime and algae, taste and odor are increased
- Incubation of eggs and fry at high temperatures may be altered

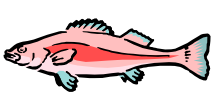
- May kill prey such as macroinvertebrates
- High temps often eliminate desirable species of algae and produce undesirable species
- Bacterial levels increase, problem if pathogens



- Genetic mutations
  - Changes in the DNA sequence of an organism
  - Most are harmful, some neutral, a few are beneficial
  - Contaminants may cause a fish to grow a small air bladder
    - The fish will succumb to natural selection because it is less fit than its counterparts



- Reproductive failure/feminization
  - Can alter sexual characteristics and hormonal function
  - DDT was shown to thin the shells of bird eggs



  - DDT and TCDD (a dioxin) mimic estrogen and may cause feminization of sex organs or development of female sexual characteristics in males

● Behavioral changes


Photo credit: Unknown

- Altered feeding habits
- Changes in migration patterns
- Changes in habitat use
- Caused potentially by damage to sensory organs (lateral line)

● Reduction in genetic diversity


Photo credit: Nick Giles

- Cultured fish are produced from the same parental stock; thus, have like genes
- These fish reproduce with wild stock leading to reduction in genetic variation
- May cause lack of fitness in offspring

WATER QUALITY LEGISLATION

● Boundary Waters Treaty (1909)


Photo credit: MPP

- It provided the principles and mechanisms to help resolve disputes, and to prevent future ones, primarily those concerning water quantity and quality along the boundary between Canada and the United States
- Provided for the creation of the International Joint Commission (IJC)
- In 1919, the IJC concluded that serious water quality problems in the Great Lakes required a new treaty to control pollution
- In the 1940s, IJC recommended water quality objectives be established
- Work of IJC led to the Great Lakes Water Quality Agreement in 1972


Photo credit: Unknown

● National Environmental Protection Act (NEPA; 1969)

- Declared a national policy which encouraged productive and enjoyable harmony between man and his environment
- Promoted efforts which prevented or eliminated damage to the environment and biosphere and stimulated the health and welfare of man
- Enriched the understanding of the ecological systems and natural resources important to the nation
- Established a Council on Environmental Quality

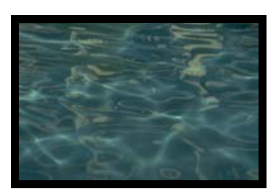


Photo credit: MPP

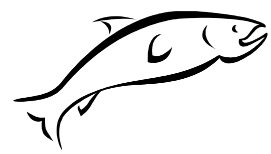
● Canada Water Act (1970)

- Provided the framework for cooperation with provinces and territories, in the conservation, development, and utilization of Canada's water resources

● Great Lakes Water Quality Agreement (GLWQA; 1972)

- Established pollution control measures
  - Mainly to reduce phosphorous levels in Lake Ontario and Erie
  - Paved way for bi-national water quality research and monitoring efforts
- Agreement renewed in 1978 to reduce phosphorous levels in all of the Great Lakes
  - Called for elimination of all persistent organic pollutants discharging into the Great Lakes
  - Objective was to restore and maintain the chemical, physical, and biological integrity of the Great Lakes basin ecosystem

- U.S. and Canada renewed the GLWQA in 1987



  - Now the focus was on nonpoint source pollution, contaminated sediments, and airborne pollutants
  - New management approaches were established
    - Remedial action plans (RAPs)
      - Focus on 42 geographic areas of concerns
    - Lakewide management plans (LaMPs)
      - Designed to improve the environmental quality of the open waters of each of the Great Lakes with a focus on critical pollutants

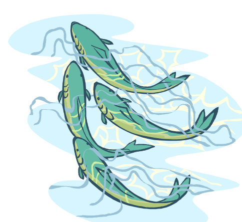


Photo credit: USEPA

● Clean Water Act (1972, 1977)

- Established the basic structure for regulating discharges and pollutants into U.S. waters
- Gave the EPA authority to implement pollution control programs such as wastewater standards for industry
- Continued requirements to set water quality standards for all contaminants in surface waters
- Made it unlawful for any person to discharge any pollutant from a point source into navigable waters
- Funded the construction of sewage treatment plants
- Recognized the need for planning to address nonpoint source pollution

● Great Lakes Toxic Substances Control Agreement (1986)

- Coordinated regional action to control toxic pollutants to the Great Lakes

● Canada Environmental Protection Act (1988)

- Is part of the government of Canada's framework to protect the environment and human health from the release of potentially toxic substances

Canada

COMMUNITY INVOLVEMENT IN CONTROLLING POLLUTION

● Reduction or stoppage of the use of lawn pesticides and fertilizers

● Disposal of oil, paint, varnishes at a recycle center

● Control soil erosion by replacing sections (or all) of a yard with native plants

● Keeping litter and leaves out of street gutters and storm drains

● Community policing (i.e., civilians can report offenders)

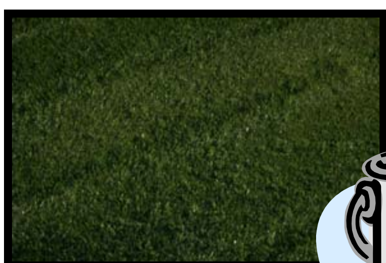


Photo credit: MPP

SUMMARY

Impacts of Pollution on Great Lakes Habitat

Pollutants can raise the acidity of water, lead to eutrophication, cause fish kills, bioaccumulate/biomagnify, and cause deformities or death in aquatic and terrestrial organisms. The origin of point source pollution includes medical, municipal, industrial facilities, septic systems, and illegal discharges. Non-point source pollution results from the run-off of fertilizers and contaminants over the landscape or via atmospheric pollution from industries. Overfertilization of aquatic systems can lead to excess oxygen consumption in decomposition processes (i.e., the development of dead zones). If oxygen levels become critical, biota (e.g., fish) may die. Pathogens may lead to diseases or behavioral changes in fish and humans. Fish populations in polluted waters have been severely reduced. Legislation, such as the Clean Water Act, has greatly reduced the effects of point source pollution resulting in the recovery of some fishes. However, select species (e.g., blackfin cisco) were eliminated from the community permanently. Efforts are now aimed at addressing problems which stem from non-point source pollution.

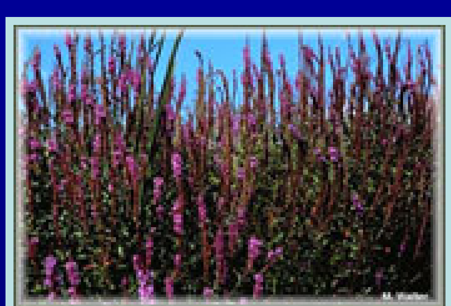
Impacts of exotics on Great Lakes Habitat

Sea lamprey

Round Goby

Common Carp

Eurasian Ruffe



Purple loosestrife

Photo credits: Sea Grant, USGS

INTRODUCTION

Impacts of Exotics on Great Lakes Habitat

Exotic species are becoming more prevalent in the Great Lakes as the number of vectors that promote species movement increases with advances in technology. The presence of exotics provides signals about the integrity of natural systems. Great Lakes aquatic and terrestrial habitats currently support a diverse community of exotic invertebrates, fishes, and plants. Examples of Great Lakes exotics include the common carp, round goby, Eurasian ruffe, sea lamprey, alewife, Pacific salmon, zebra mussel, spiny water flea, fish hook water flea, Eurasian water milfoil, and purple loosestrife. Exotics have been introduced to the Great Lakes basin accidentally as well as intentionally. They can cause major disruptions of the Great Lakes ecosystem by outcompeting native species for food and space. Control of exotics is attempted via chemical, mechanical, and biological means as well as by the implementation of environmental laws. Education is an important tool in combating further exotic introductions.

IMPACTS OF exotics on habitat

EXOTICS PROVIDE SIGNALS ABOUT THE INTEGRITY OF NATURAL SYSTEMS (both terrestrial and aquatic)

- Presence suggests habitat alteration or degradation

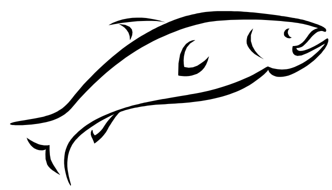
TWO GLOBAL TRENDS THAT CONSISTENTLY AND STRONGLY ENCOURAGE INVASIONS

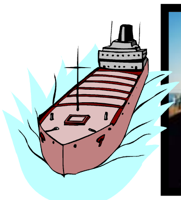
- Land-use changes which replace, fragment, and degrade natural systems
  - Urbanization and agriculture
    - Natural forests are cut or burned
    - Meadows are plowed or paved
    - Wetlands drained and filled
    - Roads are cut through wild ecosystems
    - Removal of shoreline vegetation (destruction of riparian zones)
    - Exotics may be more tolerant of degraded habitat

Photo credit: NOAA

Photo credit: Unknown

- Increase in number of vectors that promote species movement
  - Growth worldwide in trade
    - Most remote regions are connected to global markets by truck, train, ship, and airplane
      - Shipping canals are built that allow exotics to spread
      - Transport in ship ballast water leads to aquatic invasions
  - Pet trade and aquaculture import exotics
  - Deliberate stocking of non-native fishes into rivers and lakes
  - Anglers dump live bait into waterways
  - Trailering of boats from one waterway to another
  - Use of exotic plants in marsh restoration projects, backyard ponds, and retention basins
  - Nursery/water garden industry
  - Live fish market





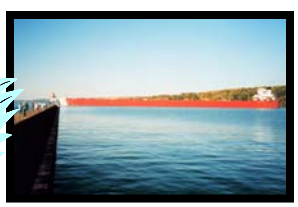


Photo credit: NOAA

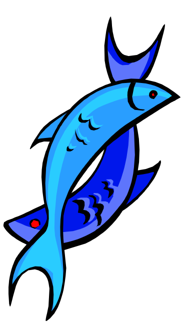
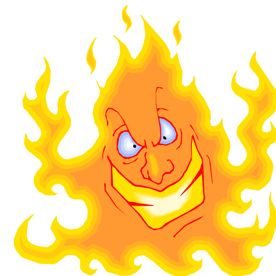


Photo credit: Unknown

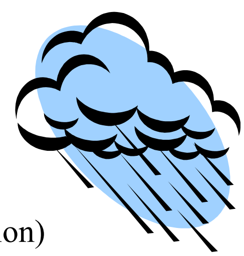
LESS CONSISTENT TRENDS THAT PROMOTE INVASION



- Global temperature changes
  - Changes in water temperature may favor exotics over natives
  - Cause shifts in primary productivity that alter water quality and foodwebs
  - Extend or reduce length or timing of reproductive or growing seasons
  - Leads to range expansion of a species
- Increase in the frequency of large scale disturbances such as fire
  - Open habitat niches for colonization by non-native plant life
  - Exotic plant life can enhance fire by altering amount, distribution, and rate of accumulation of fuel

Photo credit: USDA FS

- Rising atmospheric carbon dioxide levels
  - Some non-native plants have been shown to respond well to increases in carbon dioxide levels
- Heavy nitrogen deposition resulting from air pollution and fertilizer use
  - Conditions may promote high growth rate of exotic plants
  - Waters suitable for those fishes (e.g., exotics) tolerant of acidic conditions only
- Potential rainfall changes



GREAT LAKES EXOTICS AND IMPACTS ON HABITAT

- Fish
  - Round goby *Neogobius melanostomus* (ballast water introduction)
    - Displaces native sculpin from interstitial habitat
    - Alters quality of reproductive habitat of lake trout by consuming eggs
    - Alters quality of feeding habitat for native sculpins
    - Provides new pathway for toxins to move up food chain (bioaccumulation; zebra mussels to gobies to smallmouth bass)

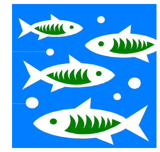
Photo credit: Sea Grant, David Jude

Photo credit: Sea Grant

  - Eurasian ruffe *Gymnocephalus cernuus* (ballast water introduction)
    - Has potential to occupy 6.6 million ha (16.3 million acres) of Great Lakes habitat suitable for use by native percid fishes for residence, feeding, etc.

Photo credit: Sea Grant

Photo credit: Sea Grant



▪ Sea lamprey *Petromyzon marinus* (gained entry through the Welland Canal which connected the Great Lakes and St. Lawrence Sea Way)

Photo credit: Sea Grant, GLFC

- Used native fish such as the lake trout as habitat
- Millions of dollars are spent annually on sea lamprey control
- Extermination of lake trout by sea lamprey allowed alewife to move quickly through the Great Lakes and experience almost unrestrained population growth

▪ Alewife *Alosa pseudoharengus* (gained entry through the Welland Canal)

Photo credit: Sea Grant, Shedd Aquarium

- Predation of alewife on fish larvae is believed to have impacted the quality of yellow perch spawning grounds
- Massive die-offs along lakeshores may contribute excess nutrient loads to aquatic and terrestrial habitat
- Competition for habitat and zooplankton with native prey fishes or juvenile sport fishes

▪ Chinook salmon *Oncorhynchus tshawytscha*, Coho salmon *Oncorhynchus kisutch*, rainbow trout *Oncorhyncus mykiss*, and brown trout *Salmo trutta* (intentional introductions)

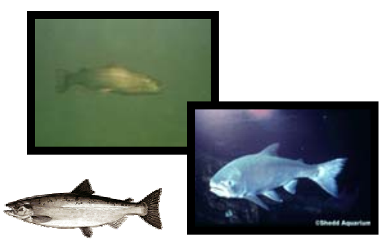
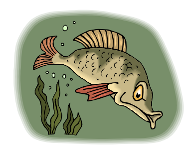


Photo credits: Sea Grant, Shedd Aquarium

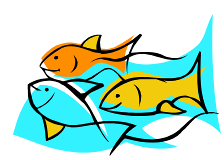


- Solution to treat symptoms of altered/degraded habitat (control alewife population)
- Compete for habitat and food with native salmonids and other fishes
- Now support major element of fishery valued at more than $6 billion dollars annually

▪ Three-spine stickleback *Gasterosteus aculeatus* (ballast water introduction or natural expansion through the Hudson Bay watershed)

Photo credit: FFWCC

- Impact feeding habitat of native fishes
- May compete with native sticklebacks for food
- May compete with juvenile sport fishes for zooplankton and insect larvae



▪ Rainbow smelt *Osmerus mordax* (intentional introduction to MI inland waters as forage for stocked salmonids, escapee to Great Lakes)

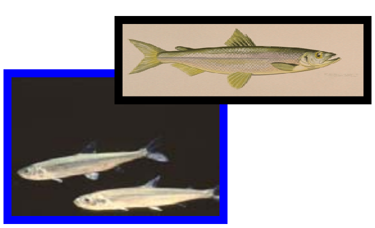


Photo credit: DFO, Sea Grant, Shedd Aquarium

- May impact spawning habitat of sportfish by feeding on larvae
- May impact feeding habitat by competing for zooplankton with young sportfish such as yellow perch

        - Resulted in reductions of lake herring and whitefish populations

- Common carp *Cyprinus carpio* (intentional introduction in the 19th Century by the U.S. Fish and Wildlife Commission as a food species)

Photo credit: Sea Grant, Shedd Aquarium

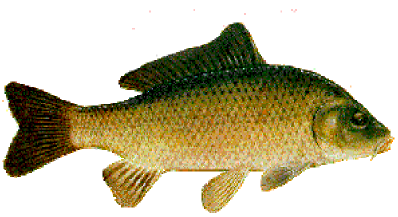


Photo credit: FFWCC

    - Disturb bottom habitat as they forage for food
    - Cause excess turbidity that can make habitat unsuitable for primary production by many native aquatic plants
    - Turbidity can impact feeding habitat of sight feeders (e.g., largemouth and smallmouth bass) by limiting their ability to capture prey
    - Can cause impacts to fish populations as a whole
    - Tolerates a wide range of environmental conditions (e.g., low dissolved oxygen, high temperature, high turbidity)
    - Can interfere with spawning habitat of fish by uprooting and consuming aquatic plants that species such as northern pike and yellow perch use for nesting and egg laying

- European rudd *Scardinius erythrophthalmus* (native to Eurasia; bait bucket introduction)


Photo credit: Sea Grant, D.K. Rowe

    - Compete with native bait fishes such as the golden shiner for food and habitat
    - Have been shown to hybridize with the golden shiner
    - Can cause damage to the native fishery

- White perch (native to Atlantic coastal regions, introduced through the Erie and Welland Canals)


Photo credit: Sea Grant

    - Prolific competitors with native fish species for food and habitat
    - Have the potential to cause declines of Great Lakes walleye and white bass populations
        - Have been found to eat eggs of walleye and white bass
        - Hybridized with native white bass in western Lake Erie

- Potential invaders: Asian carp (grass *C. idella*, silver *H. molitrix*, bighead *H. nobilis*, black *M. piceus*; escapees from aquaculture ponds; sightings in the Great Lakes)


Photo credit: Unknown

    - Electrical barrier constructed in the Chicago sanitary ship canal to prevent spread from Mississippi River system to Great Lakes

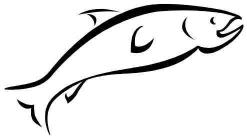


Photo credit: INHS

▫ Planktivorous silver and bighead carp may compete with juvenile fishes or native planktivores

▫ Black carp may disturb the habitat of native mussels as well as impact mussel populations

● Invertebrates

▪ Zebra mussels *Dreissena polymorpha* (ballast water introduction)

Photo credit: Sea Grant

- Can restructure zooplankton, and thus, phytoplankton communities
- Can invade native mussel habitat by fouling beds
- Competition for food with other mussels and fish
- Led to reductions in overall fish populations
- In some instances, are thought to increase habitat complexity for macroinvertebrates by increasing surface area/interstitial spaces for colonization
- Improve water clarity, but are a sink for contaminants (create the potential for bioaccumulation)
- Clear water does not necessarily mean good habitat
- Food for round gobies which may allow these fish to flourish
- Millions of dollars spent annually by municipalities and industries to control zebra mussels which foul intake pipes

▪ Spiny water flea *Bythotrephes cederstroemi* (ballast water introduction)

Photo credit: Sea Grant

- Occupying habitat of native zooplankton
- Competition for prey (phytoplankton)
- May lead to restructuring of zooplankton community
- Compete with larval fish for phytoplankton as they, themselves, lack natural predators which can easily consume them

▪ Purple loosestrife *Lythrum salicaria*

Photo credit: Unknown

- Replacing cattails in our wetlands
- Makes wetlands less suitable for wildlife populations
- Causes reduction in native flora and fauna

▪ Eurasian water milfoil *Myriophyllum spicatum*

Photo credit: Unknown

- Can make habitat less suitable for invertebrates and fish populations by changing light conditions
- Out competes native macrophytes for space (habitat)
- Reduces or changes native invertebrate and fish populations

Photo credit: Unknown

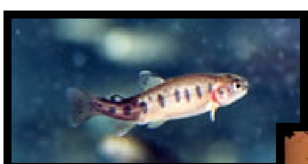
- Introduced species of algae
  - Have caused water quality problems (low dissolved oxygen levels)
  - Decomposition of decaying algae can lead to problems with low dissolved oxygen, which in turn, can impact fish populations
- Pathogens/Diseases/Parasites

Photo credits: Sea Grant, MDNR

  - *Renibacterium salmoninarum* (bacteria)
    - Lead to bacterial kidney disease (BKD)
    - Causes lesions in kidney, affects organs, body cavity fills with fluid
    - Severe cases are fatal
    - Attributed with massive mortalities of salmon in Lake Michigan in recent years

Photo credit: MDNR

  - *Aeromonas salmonicida* (bacteria)
    - Leads to furunculosis
    - Causes boils or furuncles on the skin of salmonids
    - Severe cases are fatal



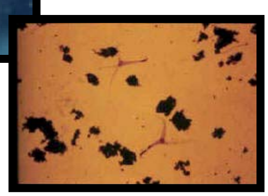


Photo credits: MDNR

  - *Myxosoma cerebralis* (bacteria)
    - Leads to salmon whirling disease
    - Attacks cartilage causing inflammation of damaged areas
    - Places pressure on nervous system causing fish to whirl when startled
    - Severely infected fish may be vulnerable to predation or may die because of inefficient feeding

  - *Glugea hertwigi* (protozoan)
    - Leads to microsporiasis
    - Causes cysts on internal organs
    - Severe cases are fatal
    - Caused massive die-offs of rainbow smelt in Lake Erie and Lake Ontario in the 1960s and 1970s

MANAGEMENT OF EXOTICS

- Chemical control

Photo credit: GLFC

- Lampricides
    - Target larval stage of sea lamprey
- Herbicides
    - Used to control/eliminate Eurasian water milfoil

Photo credit: GLFC

- Biological control
    - Introduction of a predator species
        - Pacific salmon stocked to control alewife
            - Pacific salmon are non-native species

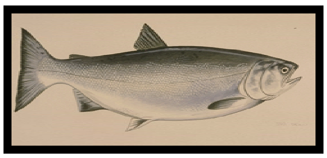


Photo credit: DFO

        - *Galerucella* beetles (*Galerucella pusilla*; *Galerucella calmariensis*), root weevils (*Hylobius* spp.), and flower feeding weevils (*Nanophyes* spp.)
            - Introduced to control purple loosestrife
                - Beetles and weevils are non-native species of European origin
                - Highly host specific

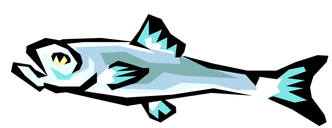
Photo credit: MSU

        - Native milfoil weevil *Euhrychiopsis lecontei* used to control Eurasian water milfoil
            - Prefers Eurasian over the native northern water milfoil

- Mechanical control
    - Electrical barrier
        - Installed in Chicago Sanitary Ship Canal
        - May slow spread of the round goby to the Mississippi River System
        - May keep Asian carp from entering the Great Lakes

Photo credit: INHS, Rip Sparks

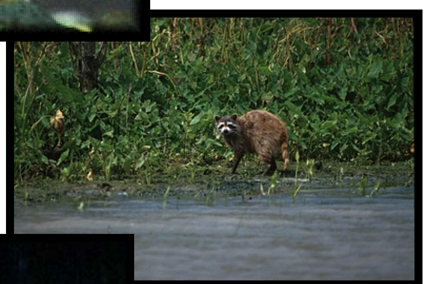
    - Cutters and harvesters
        - Used to control Eurasian water milfoil

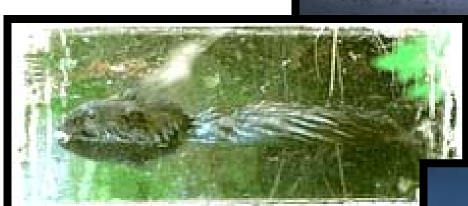


- Environmental law
    - Ships are required to exchange ballast water before entering the St. Lawrence Seaway
        - Coast Guard is strictly enforcing; however, very difficult
    - Regulations/restrictions (i.e., in Illinois as well as other Great Lakes states) governing what species aquaculture facilities may use; also, certain species are banned for use as bait and in trade (pet stores, nurseries)

Photo credit: NOAA

- Lacey Act prohibits the shipping or importation of mammals, birds, fish (including mollusks and crustacea), and amphibia that are deemed injurious to humans as well as native flora and fauna
- Environmental law prohibits the use or sale of water hyacinth via the horticulture industry





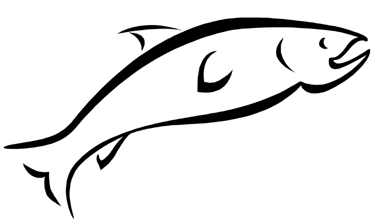


Photo credits: INHS, NOAA, USFWS , Sea Grant, PH.com, Unknown

SUMMARY

Impacts of Exotics on Great Lakes Habitat

Urbanization and agriculture are two examples of land-use changes that have resulted in the degradation of Great Lakes aquatic and terrestrial habitat. Often exotic species are more tolerant than native species to environmental stresses, and thus, are capable of surviving and reproducing in impacted environments. The opening of shipping canals, transport of organisms in ship ballast water, dumping of bait buckets into waterways, intentional introductions, and the nursery/water garden industry are all examples of vehicles for exotic species introductions. Fish such as the sea lamprey have caused major reductions in native lake trout populations. The alewife has restructured zooplankton communities; thus, limiting the recruitment of native prey and sport fishes. The spiny water flea competes with native zooplankton for prey (i.e., phytoplankton). Zebra mussels have caused changes in the community composition of zooplankton from large to small species; thus, leading to restructuring of phytoplankton communities. Purple loosestrife has replaced native plants in wetlands reducing the prevalence of many native flora as well as fauna. Exotic pathogens have led to disease in many native and non-native (e.g., salmonids) sport fishes. Control of exotics is achieved through the use of chemicals such as lampricides (to control sea lamprey) and herbicides (to control Hydrilla), use of biological agents such as *Galerucella* beetles (to control Eurasian water milfoil), and mechanical tools (electrical barrier to slow spread of the round goby to Mississippi River System and prevent Asian Carp from entering the Great Lakes). Environmental laws are geared towards preventing further introductions, and education of the public is critical to preventing introductions/range expansion of non-natives into/throughout native waters.

Impacts of Climate Change on Great Lakes habitat

Warmer Temps

Less Ice Cover

Increased Cloudiness

Photo credits: NOAA

Lower water levels

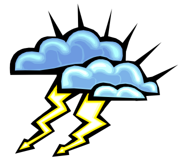
INTRODUCTION

Impacts of Climate Change on Great Lakes Habitat

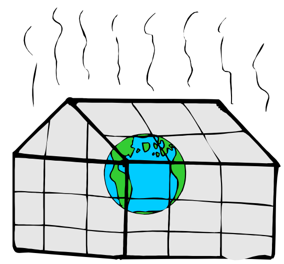
Changes in climate patterns can compound the negative effects of current environmental problems at the forefront in the Great Lakes basin. The Great Lakes ecosystem is particularly susceptible to the effects of global warming due to the heavy development of its shorelines. Warming seasons may be lengthened, water temperatures may increase, plankton populations may be lost, dissolved oxygen (D.O.) levels may decrease, and native fish populations may decline. Species (e.g., lake trout and whitefish) which have already been negatively effected may suffer even greater impacts or disappear entirely.

IMPACTS OF CLIMATE CHANGE on HABITAT

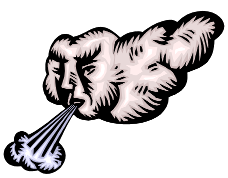
GLOBAL CLIMATE CHANGE



- General problems
  - Changes in climate patterns
  - Compounds the negative effects of current environmental problems
- Fragility of the Great Lakes region

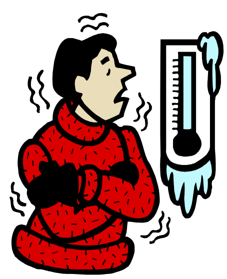


  - Particularly susceptible to the effects of rapid global warming
    - Due to heavy development on delicate shorelines
- Specific effects
  - Average temperatures may warm by 2 to 4º C



  - Precipitation could increase by 25% by the end of the 21st century
  - Despite increased precipitation, lake levels are expected to fall by 1.5 to 8 feet by 2100 because of higher temperatures
    - Serious implications for ecosystems
  - The recent series of warm years is to blame for a drop of 3.5 feet in water levels for Lake Huron, Michigan, and Erie since 1997

    - Not necessarily global warming, just unusually warm years
  - Fewer cold air outbreaks
  - Less lake-effect snow
  - Decreases in annual snowfall
  - Increased cloudiness
  - More summer precipitation
  - Will change wind patterns and intensity
  - Evaporation rates will change
  - Stream flows will be affected



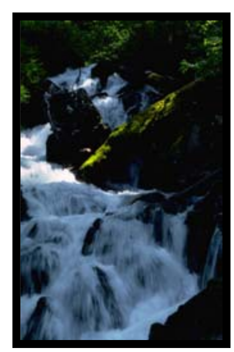


Photo credits: MPP

IMPACTS TO AQUATIC ECOSYSTEMS

- Lengthening warming seasons will reduce the seasonal mixing that replenishes critical oxygen to biologically productive lake zones
  - Lake biomass productivity may shrink by 20%

Photo credit: Unknown

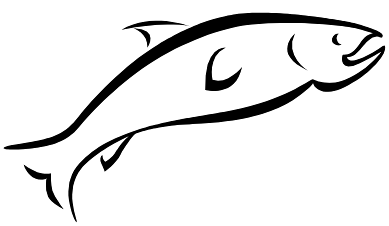
Photo credit: NOAA

- Populations of zooplankton and phytoplankton will be lost
  - These organisms form the base of aquatic food chains
  - Plankton are critical to the survival of many Great Lakes fishes
- Stream flow reduction coupled with warmer summer temperatures may account for the disappearance of various fish species which spawned in the tributaries of Lake Ontario
  - Atlantic salmon

Photo credit: NOAA

- Water in river and streams will warm
  - Warm water holds less dissolved oxygen (D.O.)
    - Fish species (e.g., trout) that are intolerant of decreased D.O. levels will move or die
      - Fish distribution and zonation will change
    - Seasonal cycles may be altered
      - Fish spawning may be affected

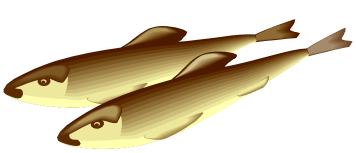
Photo credit: MPP



- Changing water levels may influence species that depend on an annual spring flood-pulse for access to spawning, nursery, and feeding grounds
  - Year-class strength and abundance may be impacted
  - Largemouth bass and white crappie require stable but high water levels in the Spring for spawning
- Wetlands used for spawning, nursery, and feeding may dry up
- The length of the growing season will expand
  - May alter mortality of young-of-the year fishes
  - Could cause changes to the fish community

Photo credit: MPP

- Fish may be less tolerant to the effects of predation, competition, disease, contaminants, eutrophication, and fishing at higher temperatures coupled with lower water levels
- Native fishes (e.g., lake trout, whitefish) are already on the edge of their temperature tolerances in the Great Lakes, and increases in water temp, ice cover, and system productivity will continue to impact these important species



SUMMARY

Impacts of Climate Change on Great Lakes Habitat

As a result of climate change, average air temperature throughout the Great Lakes basin may warm by 2 to 4 º C. Precipitation may increase by 25% by the end of the 21st century. Fewer cold air outbreaks may result in less lake-effect snow and decreases in annual snowfall. Skies may become increasingly cloudy, summer precipitation may increase, and wind patterns and intensity may change. Evaporation rates may be influenced, and stream flows may be altered. All of the aforementioned changes may have negative impacts on Great Lakes basin organisms. Disappearance or restructuring of plankton communities can negatively impact Great Lakes fishes as many depend on these organisms as a food source in early life stages. Changes in stream flow may already account for the disappearance of Atlantic salmon, which spawned in the tributaries of Lake Ontario. As water temperatures warm, the solubility of oxygen decreases, potentially rendering areas unsuitable for inhabitation by Great Lakes fishes. Wetlands used for spawning, nursery, and feeding may dry up causing reductions in fish populations. Terrestrial animals which depend upon aquatic animals as a food source may also suffer population declines. Understanding the effects of climate change on Great Lakes organisms is critical to their survival.

Impacts of water level fluctuations On Great Lakes habitat

Beach Erosion

Photo credits: NOAA

Exposed lake bottom

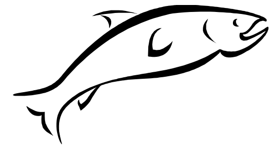
INTRODUCTION

Impacts of Water Level Fluctuations on Great Lakes Habitat

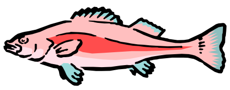
Fluctuations in Great Lakes water levels are a natural occurrence, but more recently have been greatly influenced by man-made factors. Extended periods of low water may negatively affect fish populations. Likewise, high water periods of long duration may cause severe erosion to Great Lakes shorelines. It is critical to seriously consider the negative impacts of altering habitat during periods of low water level. Wetlands should be not altered when dry, but rather preserved as they are critical habitat for many aquatic and terrestrial animals when water levels rise.

IMPACTS OF Water level fluctuations

WATER LEVEL



- Fluctuations are a normal occurrence
  - Have occurred in the Great Lakes since they were formed
  - Result of natural factors and human activities
  - Over 100 years of records indicate no predictable long term hydrologic cycle



- Contribute to natural erosion and deposition
  - Such a process maintains different shoreline types

Photo credit: Unknown

- Determinants of water level (natural and man-made)
  - Storage capacity
  - Outflow characteristics of the outlet channels
  - Operating procedures of regulatory structures
  - The amount of water supply received by each lake

Photo credit: NOAA

- Primary natural factors affecting lake levels
  - Precipitation on lakes
  - Run-off from drainage basin
  - Evaporation from the lake surface
  - Inflow from upstream lakes
  - Outflow from downstream lakes

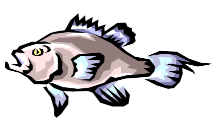
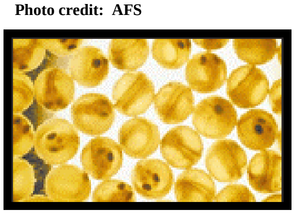


Photo credit: NOAA

- Primary man-made factors affecting lake levels
  - Diversions into or out of the basin
  - Consumption of the water
  - Dredging of outlet channels
  - The regulation of outflows
- Impacts to fish habitat
  - Low water

Photo credit: AFS



- Nearshore areas (littoral zone) may dry out
  - Fish cannot deposit eggs, feed, or seek protection from predators in these areas

Photo credit: NOAA

• Nearshore areas may retain too little water

- ▫ Fish may spawn unsucessfully
- ▫ Fish may seek out other areas to spawn
- ▫ May be less suitable for nursery and recruitment

▪ High water

Photo credit: NOAA

• During high water periods, nearshore areas are eroded through wind, wave, and ice energy

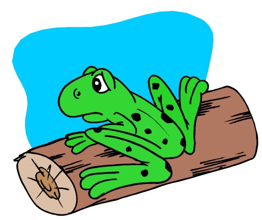
• Higher gradient areas such as rock and sand bluffs are eroded and provide sediment that will eventually settle into natural depositional areas such as beaches and wetlands

• Low gradient areas such as coastal wetlands, rock, or sand beaches are natural buffers of erosion, dissipating wind, wave, and ice energy

• Armoring shorelines prevents erosion and may starve depositional areas that require sediments to be maintained

PREVENTING HARMFUL IMPACTS TO FISH AND FISH HABITAT

● Get advice before altering habitat



- ▪ Seek advice from agencies regarding whether a nearshore area is considered fish habitat

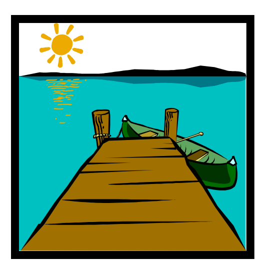
● Do your homework

- ▪ Be aware of long-term history of water levels

● Avoid dredging or blasting to gain boat access

- ▪ Will disturb fish habitat
- ▪ Often dredged areas will quickly fill with sediment through wind and wave energy when water levels rise

● Use alternatives to gain water access

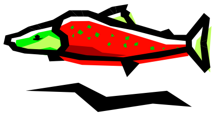


- ▪ Add temporary floating sections of dock when water levels are high
- ▪ Remove floating sections of dock when water levels are low

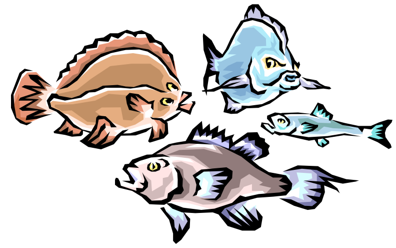
● Preserve wetlands

- ▪ Fish depend on coastal wetlands to complete their spawning, nursery, juvenile, or adult stages of their life cycles

    - During long-term periods of high water, wetlands are eroded or reduced in size, limiting habitat

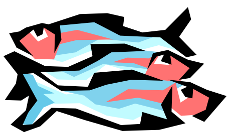


    - During long-term periods of low water, wetlands flourish and increase in size
    - Destroying wetlands at any time is detrimental to fish



    - Reduces the ability of fish to exist during high water periods

- Do not remove rocks or woody material
    - Rocks, stumps, logs, and other woody cover provide habitat and protect areas from erosion



    - Should not be removed from areas that are dry, but normally under water
    - Temporary removal of woody debris should be stockpiled and replaced in the area it came from or an adjacent area of equal or greater depth

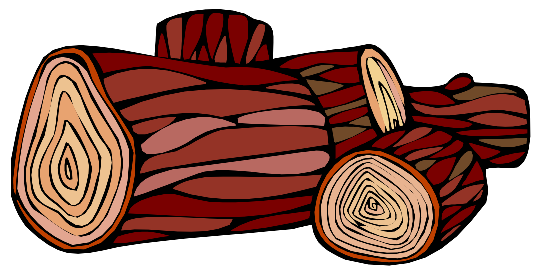
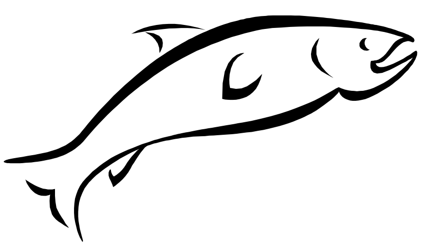


Photo credits: NOAA



SUMMARY

Impacts of Water Level Fluctuations on Great Lakes Habitat

Water level fluctuations have occurred in the Great Lakes since they were formed, and result from both natural and human activities. Water levels contribute to both natural erosion and deposition. Natural factors affecting water levels include precipitation, run-off from the drainage basin, evaporation from lakes surfaces, inflow from upstream lakes, and outflow flow from downstream lakes. Man-made factors affecting water levels include diversions into or out of the basin, human consumption of water, dredging of outlet channels, and the regulation of outflows. When nearshore habitats dry out, fish cannot deposit eggs or seek protection from predators in these areas. If water is retained, but in low volume, attempts at spawning may be unsuccessful or less suitable for nursery or recruitment. Humans have also removed natural buffers (e.g., coastal wetlands) of erosion, and armored shorelines, preventing natural erosion and starving depositional areas that require replenishment. Before altering habitat, consideration of whether a nearshore area is considered fish habitat is critical. One should be aware of the long-term history of water levels and avoid dredging to gain boat access, as these areas will quickly fill in with sediment when water levels rise. Fish depend on coastal wetlands to complete the spawning, nursery, juvenile, or adult stages of their life cycle; likewise, terrestrial organisms also depend on these areas for refuge, feeding, etc. Preservation of wetlands during periods of high, low, and normal water level is very important.

Impacts of stocking On Great Lakes Habitat

Competition

predation

Accidental Introductions

Stocking of non-natives

Treatment of Symptoms

Photo credits: IDNR, FFWCC, Sea Grant, Shedd Aquarium, DFO

INTRODUCTION

Impacts of Stocking on Great Lakes Habitat

Stocking is an important tool used in modern fisheries management, and is a very prevalent practice throughout the Great Lakes basin. Stocking efforts are undertaken for many different reasons such as to maintain a population until self perpetuation can be established or simply to support angling opportunities. Both native and non-native species have been stocked in the Great Lakes. Many stocked fishes compete with wild fishes for food and space as well as prey upon native prey fishes, invertebrates, or zooplankton. Interbreeding among stocked and wild fish may reduce genetic variation among natural fish populations, resulting in decreased resistance to pathogens or other stresses. Stocking alone may not reverse declining population trends of Great Lakes fish. Habitat restoration coupled with stocking programs may be more effective in preserving Great Lakes fisheries for some time to come.

IMPACTS OF Stocking on Habitat

MULTIPLE MODELS OF PROPOGATION AND STOCKING

Photo credit: DFO

- Conservation propagation and stocking
  - Goal is to maintain a fish population's natural gene bank until self perpetuation can be established

Photo credit: Sea Grant, Shedd Aquarium

    - Attempts to recover extirpated grayling, deepwater coregonids, or locally extirpated lake trout would typify conservation aquaculture and stocking
  - Attempted within a species native range while threats to viability and persistence of that species are addressed
    - Threats are addressed through rehabilitation of habitat of the native ecosystem

Photo credit: Sea Grant, Shedd Aquarium

  - Sometimes attempted in captivity or outside the population's range
    - Not effective
      - Fails to address problems with habitat or with the native ecosystem

Photo credit: Sea Grant, Shedd Aquarium

- Supplementation propagation and stocking
  - Is intended to augment harvestable populations that remain naturally despite harvest

Photo credit: GLSFC

    - Assumption is that the surplus supply of fish populations as harvestable commodities (fishery recruitment) can be expanded or enhanced sufficiently such that harvest pressures have an insignificant impact on the future stock-size recruitment relationship
      - Examples are the former commercial harvest of propagated lake trout and the present recreational exploitation of propagated walleye
- Mitigation propagation and stocking
  - Pursued as an approach to compensate for reduced or lost natural production associated with lost, modified, or degraded habitats or other functional elements of the ecosystem

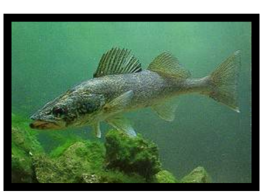


Photo credit: Unknown

    - Might be used in a situation where a resource is affected by a project

Photo credit: USACE

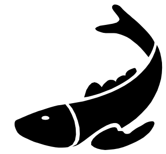
▫ Building of a dam on a river

▫ Fish are stocked to reconnect part of a species life history cycle

• Unfortunately, the term mitigation is often broadly or vaguely applied to various management actions when they compensate for lost or altered elements of the ecosystem by employing non-native or non-equivalent components of the original ecosystem

● Introduction propagation and stocking

Photo credit: Sea Grant, Shedd Aquarium



▪ Focuses on the intentional introduction of propagated non-native fish species or populations to a watershed

• Carp for food-fish production, mosquito fish for biological control, and rainbow trout for recreational interests

▪ Typically involve rearing individuals of exogenous origin that are often promoted for their beneficial outcomes from a local economic perspective

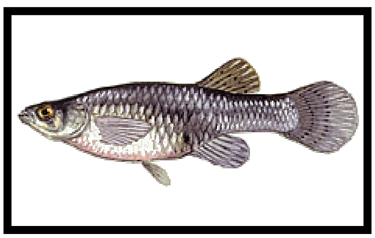
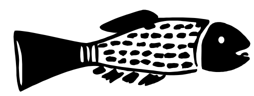


Photo credit: Sea Grant

• Particularly in reservoirs and other altered ecosystems where indigenous communities have been greatly modified or have become extinct or in man-made reservoir/quarries



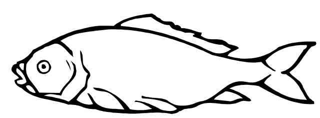
• The most notable examples of intentional introductions in the Great Lakes basin include Coho, Chinook, and Steelhead intended to create novel sport-fishing opportunities and control alewife

Photo credit: Sea Grant

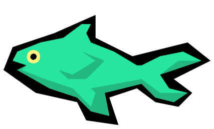
• Subtly defined introductions include the introduction of Atlantic salmon in the upper Great Lakes

▫ Once only native to Lake Ontario

● Put and take propagation and stocking



▪ Goal is short-term and total harvest of planted fish



▪ Plantings often consist of only catchable-sized fish

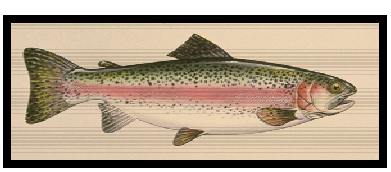
▪ The concept has extended to fish that grow in place to harvestable size (put-grow-take)

▪ Great Lakes put-and-take propagation and stocking focus on various trout species

• Both native and non-native

• States such as Michigan have abandoned the practice of stocking catchable-sized trout

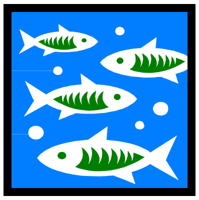
Photo credits: DFO



▫ Taking advantage of natural productivity by stocking fingerlings in more of a put-grow-take model

- Commodity aquaculture

Photo credit: Unknown



  - Closed-loop rearing systems in which all production is intended for complete capture followed by marketing or perpetuation of brood stocks
  - There is no stocking associated with propagation
  - Generally a private enterprise rather than a public action
  - In the Great Lakes, much of commodity aquaculture is confined to land-based trout production
    - There continues to be a growing interest in the private sector to develop an open-water-based netpen industry for economically important species

- Experimental and educational propagation and stocking

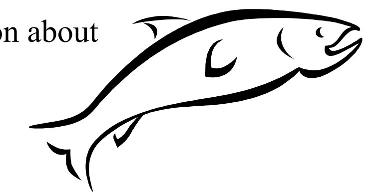


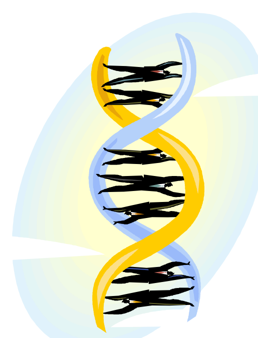
Photo credit: IDNR

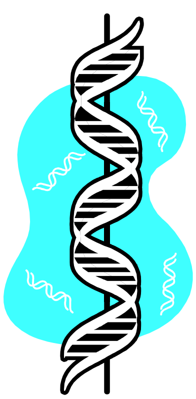
  - Focuses on the assembly and dissemination of information about fish biology and management
  - Production of fishes for release is a secondary outcome
  - Experimental stockings are undertaken for the purpose of uncovering basic information
    - Example is a study by Marsden et al. (1989) that examined the contribution of several lake trout strains to successful spawning on a reef in Lake Ontario

Photo credit: NCA

  - Propagation at public aquaria typify educational propagation
    - Displays of live propagated fish and information provide fundamental education to the public about fish biology and, in some cases, the need for conservation

- Risks and hazards of stocking





  - Concerns with conservation propagation and stocking
    - Inbreeding problems
    - Outbreeding depression
    - Genetic extinctions
  - Concerns with supplementation propagation and stocking
    - Degree of assimilation of propagated releases into the natural population
    - Genetic differences between the natural and supplementation populations
    - Degree of genetic substructure within the natural population

- Concerns with mitigation propagation and stocking
    - Same as those of supplementation propagation and stocking
- Concerns with introduction propagation and stocking
    - Temporary economic benefits have been followed by longer lasting and often unanticipated negative effects on native populations
    - Introduced populations that become established in some habitat either displace, diminish, or hybridize native populations
    - Often introduction of non-natives includes introductions of new pathogens
        - Native fish often lack resistance to exotic pathogens carried by introduced fish
            - Sometimes the consequences are disastrous (e.g., loss of a population)

Photo credit: TU

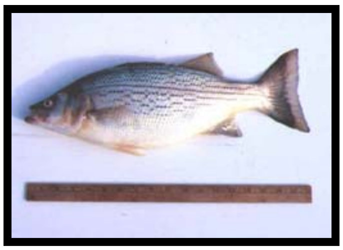


Photo credit: Unknown

- Concerns with put-and-take propagation
    - For native Great Lakes species such as brook trout
        - Outbreeding depression
    - For non-native species
        - Risks are the same as those for introduction and propagation stocking
        - Hybridization with native fish
            - Outbreeding depression

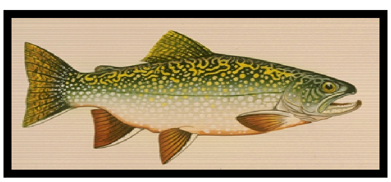


Photo credit: DFO

- Concerns with commodity aquaculture
    - Failures to contain propagated fish
        - Often result of storm and predator damage
        - Lead to inadvertent or accidental releases
            - Swamping, hybridization, competition, and displacement of indigenous populations may occur
            - Example is Florida which boasts a large culture industry associated with the sales of ornamental and tropical fishes

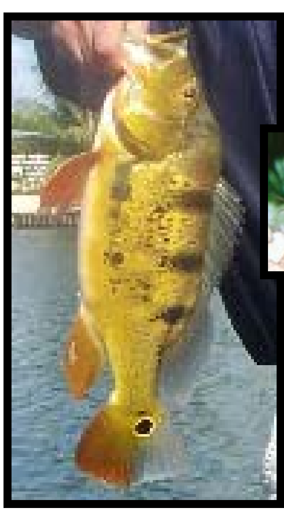


Photo credit: Unknown, FFWCC

Photo credit: FFWCC

- Many non-natives and transplanted fishes have become established in the state via escapement from the aquaria trade
    - Extent and exact risks are dependent upon whether production lines are native or non-native populations

- Concerns with experimental and educational propagation and stocking
    - Any of the risks outlined in the preceding stocking models

Photo credit: FFWCC

- Namely disease transfers, interbreeding with, or displacement of native fish
- In the case of private aquaria, rather than using euthanasia to eliminate unwanted or surplus production, fish are released into the wild, often with unintended or unmonitored consequences

HABITAT RESTORATION AS AN ALTERNATIVE OR SUPPLEMENT TO STOCKING

Photo credit: FFWCC

- Stocking may only treat symptoms of larger problems
    - Fix may be temporary and not long-term
    - Over-exploitation
        - May need to relieve fishing pressure
        - Stocking may provide fish, but the problem becomes circular because disturbed habitat is only capable of allowing a certain level of production
    - Alteration, degradation, destruction of habitat
        - May want to gear management towards restoration of habitat
        - Restoring habitat may help a species achieve higher levels of production and success naturally
        - If habitat cannot be restored, maybe stocking is a better alternative
    - Combination of over-harvest and degraded habitat
        - May need to both relieve the fishing pressure and restore habitat
        - A population may be more productive given restored habitat, and thus, may be able to withstand the current level of harvest

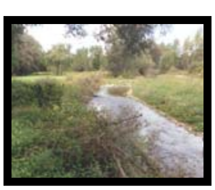
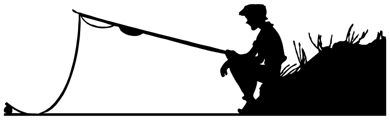


Photo credits: TU



- Fishing pressure may still be to high despite the increased production that results from restoration of habitat

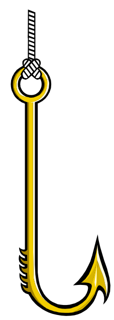
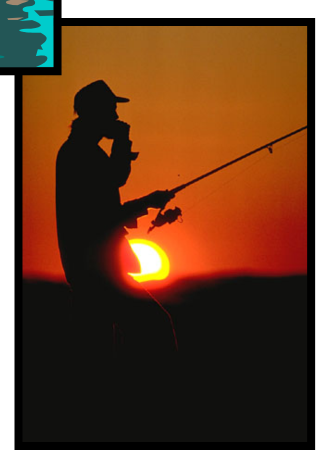


Photo credits: GLSFC, MPP



SUMMARY

Impacts of Stocking on Great Lakes Habitat

Stocking is a useful fisheries management tool, but this practice can both negatively and positively impact Great Lakes fish populations. Stocking can be used to support a natural population until sustainable through natural reproduction, to augment natural populations that exist naturally, to compensate for reduced or lost natural reproduction that results from degraded habitat, to introduce a species for food or biological control, to provide angling opportunities, to support the food-fish industry, and to support experiments and education. Risks of such measures include inbreeding, outbreeding, genetic extinctions, declines in native fish populations via competition and predation, introduction of exotic pathogens via non-native stocks, hybridization, and accidental releases that displace indigenous populations. In some cases, stocking may only treat symptoms of the problem. Aggressive efforts at restoring habitat may be needed to successfully sustain or improve natural populations. In addition, fishing pressure may need to be lessened or relieved to reverse declining trends. Stocking remains a useful tool, and in some instances, may be the best option to address select Great Lakes fisheries problems (e.g., controlling the overabundance of alewife throughout the Great Lakes via stocking of Pacific salmon).

Appendix A

A collection of websites and scientific literature to reference if interested in learning more about the Great Lakes, fisheries habitat types, uses of habitat, degradation of habitat, impacts of pollution, impacts of exotics, impacts of climate change, impacts of water level fluctuations, and impacts of stocking.

Websites

Great Lakes Habitat Types

1. Habitat and the Brook Trout
(http://sites.state.pa.us/PA_Exec/Fish_Boat/marap00/habtrout.htm)

2. Land by the Lakes: Nearshore Terrestrial Systems
(http://www.epa.gov/grtlakes/solec/96/landbylakes/communities.html)

3. Nearshore Water of the Great Lakes: A Fish and Wildlife Habitat
(www.epa.gov/grtlakes/solec/96/nearshore/fish_and_wildlife.html)

4. Coastal Wetlands of the Great Lakes
(www.epa.gov/grtlakes/solec/96/coastal/ecological.html)

5. Nearshore Water of the Great Lakes: Special Lakeshore Communities
(www.epa.gov/grtlakes/solec/96/landbylakes/communities.html)

6. Land by the Lakes: Nearshore Terrestrial Ecosystems
(www.epa.gov/grtlakes/solec/96/landbylakes/overview.html)

7. Optimum Conditions for Aquatic Species (i.e., Fish)
(www.rpi.edu/dept/chem-eng/Biotech-Environ/Environmental/THERMAL/bio.htm)

Great Lakes Habitat Uses

8. Availability of Lake Trout Reproductive Habitat in the Great Lakes
(www.glsc.usgs.gov/science/research/edreef.htm)

Degradation of Great Lakes Habitat

9. Current Lake Superior Environmental Issues
(www.glaquarium.org/learn/lakematters/ecology/environmental.html#Anghor)

10. Lake Trout in the Great Lakes
(http://biology.usgs.gov/s+t/noframe/m2130.htm)

11. Joint Strategic Plan for Management of Great Lakes Fisheries
(www.glfc.org/pubs/sglbod.htm)

12. A Joint Strategic Plan for Management of Great Lakes Fisheries, 1997 Revision
(www.glfc.org/fishmgmt/sglfmp97.htm)

13. State of the Lakes Ecosystem Conferences Page
(www.on.gc.ca/solec/intro.html)

Degradation of Great Lakes Habitat (cont.)

14. Biodiversity of Freshwater Mussels in the Lower Great Lakes Drainage Basin (www.eman-rese.ca/eman/reports/publications/nm97_mussels/intro.html)

15. Coastal Erosion of Southern Lake Michigan (http://marine.usgs.gov/fact-sheets/michigan/michigan.html)

16. Great Lakes of the U.S. and Canada (http://.people.clemson.edu/~jwfoltz/WFB418/subjects/grtlakes/grtlakes.htm)

17. State of the Great Lakes (1997) (www.epa.gov/grtlakes/solec/96/stofgl/stress_nearshore.html)

18. Biologists Breathing New Life Into Ancient Habitat of Sturgeon (www.greatlakesdirectory.org/zarticles/070202_sturgeon.htm)

19. State of the Lakes Ecosystem Conference 96': Nearshore Waters of the Great Lakes: Status and Trends (www.epa.gov/glnpo/solec/96/nearshore/status_and_trends.html)

20. Biology of the Lake Sturgeon (http://midwest.fws.gov/sturgeon/biology.htm)

Impacts of Pollution

21. Thermal Pollution (www.rpi.edu/dept/chem-eng/Biotech-Environ/Environmental/THERMAL/tte1.htm)

22. Great Lakes Aquatic Habitat News: Grassroots Group Fights Manure Pollution (www.glhabitat.org/news/glnews218.html)

23. NC Aquatic Dead Zone From Floods After Hurricane Floyd (www.mhhe.com/biosci/pae/es_map/articles/article_53.mhtml)

24. Great Lakes Success Stories: Don Williams, Scientist and Dedicated Environmentalist (www.on.ec.gc.ca/success-stories/gl/don-e.html)

25. Soils, Erosion, Siltation in Great Lakes Basin (www.city.bloomington.in.us/planning/env/ec/reports/2001beqi/soils.html)

26. Water Pollution in the Great Lakes (www.great-lakes.net/teach/pollution/water/water1.html)

27. Human Health: Infectious Organisms as Hazards (www.on.ec.gc.ca/solec/nearshore-water/paper/part8.html)

Impacts of Pollution (cont.)

28. Clean Water Act History
(www.epa.gov/region5/water/cwa.htm)

29. Contaminant Effects in the Great Lakes
(www.on.ec.gc.ca/wildlife/factsheets/fs_herring_gulls_table2_e.html)

30. Point versus Nonpoint Source Pollution
(http://creekconnections.allegheny.edu/NationalWaterMonitoringDay/PointvsNonpoint.html)

Impacts of Exotics

31. Aquatic and Invasive Species and the Great Lakes: GLERL's Program and Action Plan
(www.glerl.noaa.gov/pubs/brochures/invasive/invasive.html)

32. Cercopagis pengoi: Another ponto-caspian invader in the Great Lakes
(www.cs.uwindsor.ca/users/h/hughm/private/cercopagis.html).

33. Exotic Species and Their Effects on the Great Lakes
(www.great-lakes.org/exotics.html)

34. Index of Invasive Flora-Fauna
(www.great-lakes.net/envt/flora-fauna/invasive/invasive.html)

35. Exotics and Public Policy in the Great Lakes
(www.ijc.org/milwaukee/transcript/exotic)

36. Great Lakes Ballast Technology Demonstration Project: Reducing Aquatic Invasive Species Introductions
(www.nemw.org/GLBDTP.htm)

37. Sea Grant Nonindigenous Species Site
(www.sgnis.org)

38. Exotic Aquatics on the Move
(www.iisgcp.org/EXOTICSP)

39. Nonindigenous Species Links
(www.seagrant.wisc.edu/outreach/nis/nis_links.htm)

40. Nonindigenous Species Outreach
(www.seagrant.wisc.edu/outreach/nis/index.asp)

41. Biological Control of Asian Water Milfoil
(www.fw.umn.edu/research/milfoil/milfoilbc.html)

Impacts of Exotics (cont.)

42. Spread, Impact, and Control of Purple Loosestrife
(www.npwrc.usgs.gov/resource/1999/loosstrf/loosstrf.htm)

43. Galerucella Beetles to Control Purple Loosestrife
(www.ianr.unl.edu/pubs/weeds/g1436.htm)

Impacts of Climate Change

44. Impacts of Climate Change in the United States
(www.climatehotmap.org/impacts/greatlakes.html)

Impacts of Water Level Fluctuations

45. Great Lakes – St Lawrence Basin Level and Flow Stabilization
(http://home.thezone.net/~deltaprt/aquarius/greatlakes.htm)

Stocking and Habitat Restoration

46. Scientists Work to Restore Native Fish and Habitat to Great Lakes
(www.usgs.gov/public/press/public_affairs/press_releases/pr413m.html)

47. Conservation of Biological Diversity in the Great Lakes…
(www.epa.gov/glnpo/ecopage/glbd/issues/apnd4.html)

48. New Restoration Initiative Targets Lake St. Clair
(www.glc.org/announce/02/09stclair.html)

49. Habitat Project Summaries
(www.on.ec.gc.ca/water/greatlakes/data/fish-wildlife-habitat-rehab/summary.html)

50. Great Lakes Fish Stocking: A Tool for Sustainability?
(http://www.glu.org/publications/newsletters/Spring%202001/Contents.htm)

51. Loss of Genetic Diversity Among Managed Populations
(http://biology.usgs.gov/s+t/noframe/e221.htm)

General

52. Great Lakes Fishery Commission
(www.glfc.org)

53. Great Lakes Commission
(www.glc.org)

General (cont.)

54. Great Lakes United
(www.glu.org)

55. U.S. Committee of Advisors (By Lake)
(www.glfc.org/staff/advmem.htm)

56. Great Lakes Directory
(www.greatlakesdirectory.org)

57. Environment Canada's Great Lakes Home Page
(www.on.ec.gc.ca/water/greatlakes/intro-e.html)

58. Great Lakes Environmental Research Laboratory
(www.glerl.noaa.gov)

59. Illinois-Indiana Sea Grant
(www.iisgcp.org)

60. Illinois Natural History Survey
(www.inhs.uiuc.edu)

61. Illinois Department of Natural Resources
(www.dnr.state.il.us)

62. Indiana Department Natural Resources
(www.in.gov/dnr/)

63. National Oceanic and Atmospheric Administration
(www.noaa.gov)

64. United States Geological Survey
(www.usgs.gov)

65. United States Fish and Wildlife Service
(www.fws.gov)

66. Great Lakes Sea Grant Network
(www.greatlakesseagrant.org)

67. National Sea Grant College Program
(www.nsgo.seagrant.org)

68. United States Department of Commerce
(www.commerce.gov)

69. American Fisheries Society
(www.fisheries.org)

70. Lake Michigan Federation
(www.lakemichigan.org)

71. Great Lakes Sport Fishing Council
(www.great-lakes.org)

72. Michigan Sea Grant
(www.miseagrant.umich.edu)

Fact Sheets

73. GLERL Fact Sheets
(www.glerl.noaa.gov/pubs/brochures/)

74. USGS Fact Sheets
(www.glsc.usgs.gov/information/factsheets/factsheets.htm)

75. GLFC Fact Sheets
(www.glfc.org/pubs/FACT_1.pdf)

Scientific Literature

Allan, R.J. and M.A. Zarull. 1995. Impacts on biodiversity and species change in the lower Great Lakes. Lakes and Reservoirs: Research and Management 1(3):157-162.

Angel, J.R. 1995. Large-scale storm damage on the U.S. shores of the Great Lakes. Journal of Great Lakes Research 21(3):287-293.

Assel, R.A. Implications of CO2 global warming on Great Lakes ice cover. Climatic Change 18(4):377-395.

Biga, H., J. Janssen, and J.E. Marsden. 1998. Interactions between stone size, sculpin sie, and predation on salmonine eggs. Journal of Great Lakes Research 24:464-473.

Burns, R.F. 1995. Restoring the Great Lakes. Sea Technology 36(9):65-68.

Burton, T.M. and J.E. Hook. 1979. Non-point source pollution from abandoned agricultural land in the Great Lakes basin. Journal of Great Lakes Research 5(2):99-104.

Carpenter, S.R. 1995. Organochlorine contaminants in the Great Lakes. Ecological Applications 5(2):291-292.

Changnon, S.A. 1997. Climate change and the water levels of the Great Lakes. Shore and Beach 65(2):4-6.

Chapra, S.C. and A. Robertson. 1977. Great Lakes eutrophication: the effect of point source control of total phophorus. Science 196(4297):1448-1450.

Charlebois, P., J.E. Marsden, K. Wolfe, D. Jude, and S. Rudnicka. 1997. The round goby: a review of European and North American literature. Illinois Natural History Survey Special Publication 20. 76 pp.

Charlebois, P.M., L.D. Corkum, D.J. Jude, and C. Knight. 2001. The round goby (Neogobius melanostomus) invasion: current research and future needs. Journal of Great Lakes Research 27(3):263-266.

Chick, J.H. and M.A. Pegg. 2001. Invasive carp in the Mississippi River basin. Science 292(5525):2250-2251.

Chotkowski, M.A. and J. E. Marsden. 1999. Round goby and mottled sculpin predation on lake trout eggs and fry: field predictions from laboratory experiments. Journal of Great Lakes Research 25(1):26-35.

Clapp, D.F., P.J. Schneeberger, D.J. Jude, G. Madison, and C. Pistis. 2001. Monitoring round goby (*Neogobius melanostomus*) population expansion in eastern and northern Lake Michigan. 2001. Journal of Great Lakes Research 27(3):335-341.

Creque, S. and J.M. Dettmers. 2002. Growth and survival of nearshore fishes in Lake Michigan. Illinois Natural History Survey Technical Report F-138-R, 48 pp.

De rosa, C.T., Z.A. Rosemond, W. Zibulas, and A.P. Gilman. 1999. Research management in the Great Lakes and St. Lawerence River basins: challenges and opportunities. Environmental Research 80(3):274-279.

Djuricich, P. and J. Janssen. 2001. Impact of round goby predation on zebra mussel size distribution at Calumet Harbor, Lake Michigan. Journal of Great Lakes Research 27(3):312-318.

Dodge, D. and R. Kavetsky. 1995. Aquatic habitat and wetlands of the Great Lakes. SOLEC Working Paper presented at the State of the Great Lakes Ecosystem Conference. EPA 905-R-95-014. Chicago, IL: U.S. Environmental Protection Agency.

Edsall, T.A., T.P. Poe, R.T. Nester, and C.L. Brown. 1989. Side-scan sonar mapping of lake trout spawning habitat in northern Lake Michigan. North American Journal of Fisheries Management 9(3):269-279.

Evans, M.S. 1993. Toxic contaminants and Great Lakes ecosystem health: current understandings and strategies for improved assessments. Journal of Aquatic Ecosystem Health 2(2):87-93.

Ferber, D. 2001. Will black carp be the next zebra mussel? Science 292 (5515):203.
Gregg, K.L. 1995. Comparisons of three manufactured artificial reef units in Onslow Bay, North Carolina. North American Journal of Fisheries Management 15:316-324.

Hallac, D.E. and J.E. Marsden. 2000. Tolerance to and recovery from zebra mussel (Dreissna polymorpha) fouling in *Elliptio complanata* and *Lampsilis radiata*. Canadian Journal of Zoology 78:161-166.

Hickey, J.A. 1992. Great Lakes—clean waters, shifting sands. A new trend in water quality management. Water Environment and Technology 4(4):54-57.

Horns, W.H. Let's put someone in charge of this – a proposal to create a great lakes ballast water commission. Journal of Great Lakes Research 28(2):117-118.

Hudson, P.L., and C.A. Bowen. 2002. First record of a Neoergasilus japonicus (Poecilostomatoida: Ergasilidae), a parasitic copepod new to the Laurentian Great Lakes. Journal of Parasitology 88(4):657-663.

Jensen, A.L. 1999. Extinction in multiple species fisheries harvested with the same gear—the Great Lakes ciscoes. Journal of Great Lakes Research 25(4):892-896.

Keough, J.R. and T.A. Thompson. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. Wetlands 19(4):821-834.

Keppner, S.M., J. McClain, T.R. Busiahn, G. Johnson. 1997. Surveillance for ruffe in the Great Lakes-an overview. Great Lakes Research Review 3(1):17-26.

Kocik, J.F. and W.W. Taylor. 1996. Effect of juvenile brown trout habitat use in a low gradient Great Lakes tributary. Transactions of the American Fisheries 125:244-252.

Krantzberg, G. 1997. Research priorities for Great Lakes rehabilitation. Journal of Great Lakes Research 23(3):239-240.

Janssen, J. and D.J. Jude. 2001. Recruitment failure of mottled sculpin Cottus bairdi in Calumet Harbor, southern Lake Michigan, induced by the newly introduced round goby Neogobius melanostomus. Journal of Great Lakes Research 27(3):319-328.

Kashian, D.R. and T. M. Burton. 2000. A comparison of macroinvertebrates of two Great Lakes coastal wetlands: testing potential metrics for an index of ecological integrity. Journal of Great Lakes Research 26(4):460-481.

Kelso, J.R.M. 1976. Movement of yellow perch (Perca flavescens) and white sucker (Catostomus commersoni) in a nearshore Great Lakes habitat subject to a thermal discharge. Journal of the Fisheries Research Board of Canada 33(1):42-53.

Krueger, D.C., D.L. Perkins, E.L. Mills, and J.E. Marsden. 1995. Predation by alewives on lake trout fry in Lake Ontario: role of an exotic species in preventing restoration of a native species. Journal of Great Lakes Research 21(suppl. 1):458-469.

Langton, R.W., R.S. Steneck, V. Gotceitas, F. Juanes, P. Lawton. 1996. The interface between fisheries research and habitat management. North American Journal of Fisheries Research and Management 16:1-7.

Lipton, D.W. and I.E. Strand. 1997. Economic effects of pollution in fish habitats. Transactions of the American Fisheries Society 126:514-518.

Loughheed, V.L., B. Crosbie, and P. Chow-Fraser. 1998. Predictions on the effect of common carp (Cyprinus carpio) exclusion on water quality, zooplankton, and submergent macrophytes in a Great Lakes wetland. Canadian Journal of Fisheries and Aquatic Sciences 55(5):1189-1197.

Lynch, Jr., W.E., D.L. Johnson. 1989. Influences of interstice size, shade, and predators on the use of artificial structures by bluegills. North American Journal of Fisheries Management 9:219-225.

MacIsaac, H.J., T.C. Robbins, and M.A. Lewis. 2002. Modeling ships' ballast water as invasion threats to the Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59(7):1245-1256.

Magnuson, J.J., J.D. Meisner, and D.K. Hill. 1990. Potential changes in the thermal habitat of Great Lakes fish after global climate warming. Transactions of the American Fisheries Society 119:254-264.

Manny, B.A., D.J. Jude, R.L. Eshenroder. 1989. Field test of a bioassay procedure for assessing habitat quality on fish spawning grounds. Transactions of the American Fisheries Society 118:175-182.

Marsden, J.E. 1994. Spawning by stocked lake trout on shallow near-shore reefs in southwestern Lake Michigan. Journal of Great Lakes Research 20(2):377-384.

Marsden, J.E. and D.M. Lansky. 2000. Substrate preferences of zebra mussels, Dreissna polymorpha, relative to material, texture, and size. Canadian Journal of Zoology 78:787-793.

Marsden, J.E. and J. Janssen. 1997. Evidence of lake trout spawning on a deep reef in Lake Michigan using an ROV-based egg collector. Journal of Great Lakes Research 23:450-457.

Marsden, J.E., and M.A. Chotkowski. 2001. Lake trout spawning on artificial reefs and the effect of zebra mussels: fatal attraction? Journal of Great Lakes Research 27(1):33-43.

Marsden, J.E., D.L. Perkins, C.C. Krueger. 1995. Recognition of spawning areas by lake trout: deposition and survival of eggs on small, man-made rock piles. Journal of Great Lakes Research 21(sup1):330-336.

McCormick, M.J., G.L. Fahnensiel. 1999. Recent climatic trends in nearshore temperatures in the St. Lawrence Great Lakes. Limnology and Oceanography 44(3):530-540.

Mehan, G. T. Ecosystem management in the Great Lakes basin. Fisheries 21(4):12-13.

Meisner, J.D., J.L. Goodier, H.A. Regier, B.S. Shuter, and W. J. Christie. 1987. An assessment of the effects of climate warming on Great Lakes basin fishes. Journal of Great Lakes Research 13(3):340-352.

Miners, R.M.K. and F. Chiocchio. 2000. North American Great Lakes: Coastal-Zone Management. Sea Technology 41(10)34-40.

Minns, C.K., V.W. Cairns, R.G. Randall, and J.E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' areas of concern. Canadian Journal of Fisheries and Aquatic Sciences 51:1804-1822.

Morrison, H.A., C.K. Minns, and J.F. Koonce. 2001. A methodology for identifying and classifying aquatic biodiversity investment areas: application in the Great Lakes basin. Aquatic Ecosystem Health and Management 4(1):1-12.

Mortsch, L.D. 1998. Assessing the impact of climate change on the Great Lakes shoreline wetlands. Climatic Change 40(2):391-416.

Muzinic, C.J. First record of Daphnia lumholtzi sars in the Great Lakes. Journal of Great Lakes Research 26(3):352-354.

Naylor, R.L., S.L. Williams, and D.R. Strong. 2001. Aquaculture – a gateway for exotic species. Science 294 (5547):1655-1656.

Peck, J.W. 1986. Dynamics of reproduction by hatchery lake trout on a man-made spawning reef. Journal of Great Lakes Research 12(4):293-303.

Quinn, F.H. 2002. Secular changes in Great Lakes water level seasonal cycles. Journal of Great Lakes Research 28(3):451-465.

Randall, R.G. and C.K. Minns. 2002. Comparison of a habitat productivity index (HPI) and an index of biotic integrity (IBI) for measuring the productive capacity of fish habitat in nearshore areas of the Great Lakes. Journal of Great Lakes Research 28(2):24-255.

Ray, W.J. and L.D. Corkum. 2001. Habitat and site affinity of the round goby. Journal of Great Lakes Research 27(3):329-334.

Regier, H.A., T.H. Willhans, W.J. Christie, and S.A. Bocking. 1999. Over-fishing in the Great Lakes: the context and history of the controversy. 2(3):239-248.

Ricciardi, A. Facilitative interactions among aquatic invaders: is an "invasional meltdown" occurring in the Great Lakes? Canadian Journal of Fisheries and Aquatic Sciences 58:2513-2525.

Robillard, S.R., and J.E. Marsden. 2001. Spawning substrate preferences along a sand-cobble shoreline in southwestern Lake Michigan. North American Journal of Fisheries Management 21:208-215.

Roseman, E.F., W.W. Taylor, D.B. Hayes, R.L. Knight, R.C. Haas. 2001. Removal of walleye eggs from reefs in western Lake Erie by a catastrophic storm. Transactions of the American Fisheries Society.

Sproule-Jones, M. 1999. Restoring the Great Lakes: institutional analysis and design. Coastal Management 27(4):291-316.

Thompson, S., D. Mackay, and M. MacLeod. 1999. A modeling strategy for planning the virtual elimination of persistent toxic chemicals from the Great Lakes: an illustration of four contaminants in Lake Ontario. Journal of Great Lakes Research 25(4):814-827.

Tooney, M., D. McCabe, and J.E. Marsden. 2002. Factors affecting movement of adult zebra mussels (Dreissna polymorpha). Journal of the North American Benthological Society 21:468-475.

Trometer, E.S. and W.-D.N. Busch. 1999. Changes in age-0 growth and abundance following the introduction of zebra mussels Dreissna polymorpha in the western basin of Lake Erie. North American Journal of Fisheries Management 19:604-609.

Trout Unlimited. 1997. North America Salmonid Policy: science-based guidance for 21st century coldwater conservation. Trout Unlimited, Arlington, VA 22209 (USA). 46 pp.

Tucker, J.K., F.A. Cronin, R.A. Hrabik, M.D. Petersen, and D.P. Herzog. 1996. The bighead carp (Hypophthalmichthys nobilis) in the Mississippi River. Journal of Freshwater Ecology 11(2):241-243.

Vanderploeg, H.A., T.F. Nalepa, D.J. Jude, E.L. Mills, K.T. Holeck, J.R. Liebig, I.A. Grigovich, and H. Ojaveer. 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59:1209-1228.

Walters, D.A., W.E. Lynch, Jr., D.L. Johnson. 1991. How depth and interstice size of artificial structures influence fish attraction. North American Journal of Fisheries Management 11:319-329.

Wolfe, R.K. and J.E. Marsden. Tagging methods for the round goby (Neogobius melanostomus). Journal of Great Lakes Research 24(3):731-735.