Draft Strategic Science Plan
Great Lakes Science Center

Mission

Advancing scientific knowledge and providing scientific information for restoring, enhancing, managing, and protecting the living resources and their habitats in the Great Lakes basin ecosystem.

Background

The Great Lakes Science Center (GLSC) is a biological research center of the U.S. Geological Survey (USGS). The GLSC works directly with management agencies and key stakeholders to provide the critical biological and ecological information needed to protect biological resources in the Great Lakes region. The GLSC responds to research and information needs of the two sovereign nations, eight states, the Province of Ontario, and Native American tribes that are found within the Great Lakes basin. The Center's research spans a range of topics including fish populations and communities, aquatic habitats, nearshore and coastal communities, terrestrial ecology and the biological processes that occur in the complex Great Lakes ecosystem. The GLSC's long-term data sets are a powerful tool for studying Great Lakes processes on broad spatial and temporal scales. The Center's science plan focuses on developing a forward-looking approach in main themes such as: the development of effective monitoring programs and indicators of ecosystem change in both offshore and coastal ecosystems; theme areas of critical need such as the role of thiamine deficiency in aquatic ecosystems; initiatives to improve biological resources within the Huron-Erie Corridor; and emerging issues such as aquatic and terrestrial invasive species.

The GLSC traces its origins to 1871 when Congress, by joint resolution, established the United States Fish Commission and charged it with responsibility for investigations and inquiries concerning the supply of food fishes of the coasts and lakes of the United States and the determination of protective, prohibitory, or precautionary measures to be adopted. Initial investigations began in 1871 in Lake Michigan, and the U.S. Fish and Wildlife Service and its two Bureaus, the Bureau of Commercial Fisheries and the Bureau of Sport Fisheries and Wildlife evolved from these early investigations. The current GLSC was established in 1927 as the Great Lakes Biological Laboratory, with John Van Oosten as its Director. This program was started as a consequence of the furor generated by the collapse of the cisco fishery in Lake Erie in 1925. The Great Lakes Science Center has resided in the Department of Interior since 1939, but has changed bureaus and undergone several name changes over the last half century.

The headquarters of the GLSC is located on the North Campus of the University of Michigan in Ann Arbor. The GLSC has about 40 researchers and 60 support staff. About half of the Center's staff are located in Ann Arbor and half are located at the Center's field stations. Strategic placement of the Center's field operations facilitates research conducted over this large geographic area. The Center has four field stations, one vessel base, and three field station/vessel base combinations dispersed throughout the Great Lakes Basin. Research support for ongoing projects is provided through the headquarters location.

Unique among USGS centers is the fleet of large vessels that the GLSC maintains and employs. These vessels, which range in length from 45 to 107 feet, are well-equipped for population assessment and limnological studies in the Great Lakes. Equipment on these vessels includes wet laboratories, trawls, gillnets, larval fish tow nets, equipment for limnological and contaminant sampling, hydroacoustical fish-detection systems, and Loran C/GPS navigation computer systems for the precise location of sampling stations. The Center has side-scan sonar and a remotely operated vehicle.

A major strength of the GLSC are the long-term databases, especially of forage fish in each of the Great Lakes, accumulated by Center researchers during 50 years of surveys. These continue to be an important source of information on the dramatic changes that have occurred and continue to occur in the Great Lakes ecosystem. Database management is also growing in content, capability, and accessibility

to provide managers with reliable and unbiased information necessary for making management decisions in the region. Many of our research studies build on these databases, complementing assessments of the resource in a community and ecosystem context. Synthesis activities using interdisciplinary approaches or creating predictive models are now essential for moving the field forward and anticipating needs of Great Lakes managers. GLSC researchers are continually increasing collaborative efforts with university and agency personnel to achieve these syntheses.

Core Capabilities

Science

Fish Population Research

The GLSC has a long history of significant contributions to the understanding of aquatic resources in the Great Lakes, through partnerships and interactions with state, tribal, and U.S. and Canadian federal agencies. The main focus of the Center's fish population research is on the long-term dynamics of native and non-native aquatic species and the sustainability of Great Lakes fisheries. Fish community structure has changed substantially in the Great Lakes since the Center was established. Species extinctions and establishment of invasive and non-native species including sea lamprey, alewife, rainbow smelt, ruffe, gobies have occurred in each lake. Because of changes in fish community structure over the last few decades, Center scientists study whether fish communities based on non-native species (such as alewife and rainbow smelt) are capable of sustaining both angling and commercial fisheries for top predators in all five Great Lakes. Even if these fisheries are sustainable, it is necessary to understand how food chains supported by non-native species compare to that of fisheries that are supported by native prey species such as the several species of deepwater ciscoes that once existed in most of the Great Lakes. Research is also undertaken to identify the factors impeding progress towards restoration of native species, including studies on fish behavior, habitat, recruitment, survival, and population genetics. The Center is recognized for its work on issues affecting the entire aquatic ecosystem in the Great Lakes basin including lake trout restoration, sea lamprey control, and annual fish stock assessments that provide timely information directly to our state and tribal partners who are responsible for managing the fisheries. In addition, the unique communities and local disturbances (i.e., habitat alterations) associated with each lake provide opportunities to study ecological processes in a comparative manner. Data sets describing the abundance of both predator and prey fish species in each lake encompass several decades and are among the most highly valued data sources in the Basin for understanding the long-term dynamics of the fish community in relation to biotic and abiotic influences, and for modeling Great Lakes ecosystem dynamics.

Fish community dynamics investigations are aided by the ability to perform genetic analyses to identify population substructure and patterns of gene flow. Both protein electrophoretic and DNA recombinant technology are used at the Center to investigate spatial and temporal genetic relationships within and among Great Lakes fish populations. Center scientists are also using genetics to survey endangered fish species and to provide historical population genetic information about extinct fish populations and species. Center scientists are currently focusing on the use of non-lethal tissue extraction techniques for these analyses.

Health of Aquatic Biota

The Center has had a long and distinguished history of conducting physiological, toxicological, and analytical chemistry studies to determine the effects of environmental contaminants on aquatic biota. In addition to contaminants, it is currently recognized that exotic species, physical habitat changes, and other biogeochemical factors influence the health of aquatic biota in the Great Lakes. Scientists have also been conducting biological monitoring of lake trout egg hatchability for several years by collecting wild eggs and monitoring their health as they develop and hatch. Center researchers are concurrently exploring and refining likely methodologies for quick and accurate estimation of chemical environmental behavior, hazard, and fate based on the chemical's structure. An evolving database of compounds, their measured properties, and theoretical parameters is the basis for predictive software. Application of risk

assessment to evaluate progress toward setting and meeting target conditions of contaminant decline and improvement in species diversity, habitat, and food provides managers with a scientific basis for making decisions concerning the health and sustainability of fish populations.

Trophic Interactions

Trophic level studies in the Great Lakes encompass a wide variety of organisms from invertebrates to fish and birds. Field studies of Great Lakes organisms often lead to laboratory studies designed to provide information under controlled conditions. For example, feeding preferences of predators and competition within a trophic level can be determined by combinations of field and laboratory studies. Specialized tanks and video monitoring equipment are used to examine competitive interactions of native and exotic fish species. Center scientists are experienced in rearing, holding, and experimenting with coldwater exotic and native species. The Center maintains facilities to quarantine exotic species such as the Eurasian ruffe, which can then be used to study competition with desirable endemic species such as yellow perch.

The Center maintains equipment for collecting and identifying most of the invertebrates and fish found in the Great Lakes. Diet studies conducted at the GLSC aid in determining preferences of predators and competition within a trophic level for different assemblages of fish. A variety of technical capabilities including GIS, acoustics, and side-scan sonar allow researchers to study the interplay of fish diet and habitat and provide a link between fish population dynamics and trophic studies.

Research to determine the ecological role of native species within and between different trophic levels in the Great Lakes help determine which species are vulnerable to replacement or depletion. Researchers evaluate natural and human-induced factors including climate, land-use patterns, management practices, habitat, contaminants, and invasive species that can cause changes in the abundance of Great Lakes species. In conjunction with these studies, measures of biodiversity applicable to Great Lakes assemblages are being developed to identify specific locations and species that should be prioritized for protection. Biodiversity studies also contribute to development of rehabilitation strategies for species and their habitats. The structure and dynamics of fish assemblages can be used to infer the status of aquatic ecosystem health. Several useful measures of ecosystem health based on structure (richness, diversity, non-native species) and productivity have been identified. Measures of community stability need to be identified to further assist in understanding persistence of aquatic assemblages. Some management actions affect the diversity and sustainability of aquatic species; models relying on predator-prey dynamics to demonstrate these effects can be used to evaluate alternative management strategies in the Great Lakes basin.

Exotic and Invasive Species

To date, over 140 exotic aquatic species have been documented in the Great Lakes. In addition, Center scientists working at Indiana Dunes National Lakeshore have identified over 325 non-native species in a flora of 1460 species. Establishment of exotic species has had substantial effects in open lakes (e.g., alewife and rainbow smelt), wetlands, (e.g., reed canary grass and purple loosestrife), terrestrial systems (e.g., garlic mustard and Asiatic bush honeysuckle), and nearshore waters (e.g., zebra mussels and ruffe). Research to identify impacts of invasive species in systems of the Great Lakes basin provides opportunities to study the links between species diversity and aquatic ecosystem stability. The introduction and colonization of invasive species may affect genetic diversity (through genetic bottlenecks or hybridization) of native species, which in turn may play a role in maintaining the overall health and persistence of native populations. Understanding habitat requirements and adaptive ecology of invaders may also shed light on the types of organisms most likely to invade and colonize particular systems. Knowledge about potential invasive species may help in the control and prevention of these species and increase our management capability of habitats. A combination of field, laboratory and modeling studies are conducted to provide information pertinent to prevention, containment, and control of exotic species. Some research efforts have been dedicated to determining the ecology, distribution, life history, and reproductive behavior of exotic species.

Perhaps the best known example of the Center's work on exotic species has been its longterm work on the sea lamprey. Research at the Hammond Bay Biological Station focuses on the effects of sea lampreys on Great Lakes fishes. Specific areas of research include alternate control techniques, application of lampricides, life history studies, population assessment, and interactions between fish and sea lampreys. Research activities on sea lamprey biology and impacts are supported through the Great Lakes Fishery Commission.

Terrestrial Ecology

The Indiana Dunes, where Henry Cowles of the University of Chicago formulated his theory of ecological succession in the 1890's, is often recognized as the birthplace of the modern science of ecology. Today Center scientists, some working at the very site of Cowles pioneering investigations, continue along his line of inquiry with examinations of how anthropogenic and non-anthropogenic disturbances affect native terrestrial ecosystems. Investigations by Center staff are informed by the great changes in the context of native ecosystems that have occurred since Cowles' time. Linkages among changing lake levels, climate, and terrestrial vegetation communities are investigated. Patterns of exotic plant invasion into the Great Lake's national parks, and how these invasions displace native communities, are documented. The effects of loss of historic disturbance patterns, such as changes in fire regimes, are examined.

The species-rich savanna and prairie habitats that once dominated the western reaches of the Great Lakes region have faired especially poorly over the past 150 years. Restoration of even remnant areas is important if this native habitat is to remain on the landscape. Center scientists are actively involved in studies to improve the restoration toolkit by examining how fire frequency and timing affect animal and plant populations, by studying how the heterogeneous light environments of savannas influence abundance of plants and animals, and by development of models to assist managers in setting restoration goals.

Coastal Ecosystem Studies

Embayments, wetlands, river mouths, beaches, moraines, and coastal dunes are found along 7,500 km of shoreline of the Great Lakes and inland aquatic habitats managed by the U.S. Fish and Wildlife Service and National Park Service. There are 1,150 km of connecting channels in the lakes proper (the St. Marys, St. Clair, Detroit, Niagara and St. Lawrence rivers), and over 1,300 distinct coastal wetlands (total area of 1,200 km^2) along the shores of the Great Lakes and connecting channels in the United States. Because of the desirability of coastal habitats for residential, industrial, and recreational uses, these areas have been highly susceptible to human-induced perturbations, such as habitat modification, contamination, and water-level regulation. Field and laboratory research is conducted to determine the effectiveness of restoration programs in altered habitats (e.g., diked and dredged), identify rare species (e.g., ciscoes and native clams), investigate the causes of frequent beach closures due to bacterial contamination that plague beaches throughout the region (and, indeed, throughout the country), determine environmental factors that correlate with survival of species (e.g., contaminants and climate change) and develop means of enhancing and protectiing habitats for rare species (e.g., Karner blue butterfly). One goal is to understand how perturbations, such as shoreline development, vessel traffic, or changes in rates of sand deposition, affect nearshore habitats with a goal of developing restoration techniques to remediate these impairments. Center scientists also work to better document linkages, such as nutrient exchange, between nearshore habitats and lakes.

Facilities and Science Support

The Great Lakes Science Center headquarters is located on the North Campus of the University of Michigan in Ann Arbor where one half of its 100 staff members are located. In addition, the Center has four biological stations, one vessel base, and three vessel base-biological station combinations dispersed throughout the Great Lakes basin. Strategic placement of the Science Center's field operations facilitates research conducted over this large geographic area. Biological stations are located at: Munising, Michigan (Munising Biological Station); Millersburg, Michigan (Hammond Bay Biological Station); Porter, Indiana (Lake Michigan Ecological Research Station); and Cortland, New York (Tunison Laboratory of

Aquatic Science). A mid-basin vessel base is located at Cheboygan, Michigan. Combined biological stations and vessel bases are located at: Ashland, Wisconsin (Lake Superior Biological Station); Sandusky, Ohio (Lake Erie Biological Station); and Oswego, New York (Lake Ontario Biological Station).

Large Lake Sampling Capabilities

The Center operates five large research vessels in the Great Lakes: the R/V *Kiyi* (stationed at the Lake Superior Biological Station), the R/Vs *Siscowet*, *Sturgeon* (expected in operation in 2004 to replace the *Siscowet*), and *Grayling* (stationed at the Cheboygan Vessel Base), the R/V *Musky* II (stationed at the Lake Erie Biological Station), and the R/V *Kaho* (stationed at the Lake Ontario Biological Station). The vessels, which range in length from 45 to 107 feet, are equipped with wet laboratories, trawls, gillnets, larval fish tow nets, equipment for limnological and contaminant sampling, acoustic fish-detection systems, and computers. All vessels also have state-of-the-art navigation systems for the precise location of sampling stations. The Center is the only organization in the United States and Canada that has a research vessel on each of the Great Lakes. This makes the Center unique in its ability to conduct comparative offshore field studies on fish population dynamics and related limnological and habitat research topics.

The R/V *Kiyi* (built in 1999; 107 ft. long) is dedicated primarily to research on Lake Superior. The R/V *Grayling* (1977; 75 ft.) is dedicated to research on lakes Huron, Michigan, and Superior as is the R/V *Siscowet* (1946; 57 ft.) and the R/V *Sturgeon* (1975; 107 ft.). As the Center's largest vessels, the R/Vs *Grayling*, *Sturgeon*, and *Kiyi* are the most versatile and are equipped to conduct a wide range of limnological, habitat, and fisheries studies including specialized equipment for conducting acoustic fish sampling. The R/V *Musky* II (1960; 45 ft. long) is the smallest vessel in the Great Lakes fleet and conducts research on Lake Erie. It is used for fisheries, limnological, and habitat research studies. The R/V Kaho (1961: 65ft.) is the primary research vessel on Lake Ontario that conducts fish, limnological, and habitat studies. The recent addition of the R/V *Stickleback* (2002; 40 ft.) to the fleet at Ashland, Wisconsin allows for more nearshore work on Lake Superior than does the larger, deeper-draft R/V *Kiyi*.

Nearshore Sampling Capabilities

The Center operates a fleet of twelve small (18-25 feet) research vessels outfitted with various types of gear such as advanced navigation systems and specialized equipment required for fishery and limnological research in inland, nearshore, and connecting waters of the Great Lakes. These small vessels facilitate a variety of aquatic sampling methods including sampling of fish for predator-prey contaminant studies, capturing of specimens for laboratory studies, sampling of bottom substrate, sampling of plankton, sampling of water quality, ground truthing aerial photographs, telemetry, and diving with SCUBA to support various research activities.

Small vessels are effective because of their size and relatively low operating costs. Small vessels have been modified to serve as electrofishing boats, shallow-water fish trawlers, gill-netters and trap-netters, substrate samplers, plankton and water samplers, and macrophyte samplers. Small vessels may be easily moved from lake to lake as well as from project to project to conduct research of short duration.

The ability to examine the ecological, physical, and spatial characteristics of plant and wildlife habitat (e.g., coastal wetlands, reefs, shoals) is enhanced by technologies that can be used on small vessels including: a Global Positioning Systems (GPS) community base station; GPS receivers; PLGR+96 receivers; and a Geographic Information System (GIS) to locate, manage data, facilitate data analyses, and increase research precision. Scientists also use side-scan sonar and a remotely operated vehicle (ROV) with video to document difficult to observe events, such as trout spawning behavior.

Fish Holding and Rearing Facilities

The Center in Ann Arbor has extensive fish rearing and holding facilities, including 200- and 600-gallon fiberglass tanks, egg incubators, and other tanks for holding fish and conducting behavioral, physiological, and toxicological studies. The facilities are supplied by two 100-gallon-per-minute wells

with associated equipment that includes iron filters, deionizers, settling tanks, permanent and portable chillers, and pumps and reservoirs for conditioning water. Fish rearing and holding facilities supplied by a deep water intake from Lake Huron are also available at the Hammond Bay Biological Station (HBBS). The HBBS includes tanks and flow-through "living streams" primarily used for research on the effects of sea lamprey on Great Lakes fishes. The HBBS also has a specialized facility for sterilizing male sea lamprey for a biological control program.

Chemistry and Other Laboratories

The Center in Ann Arbor has several dedicated chemistry laboratories that have primarily conducted contaminant residue analyses. The main instrumentation consists of a mass spectrophotometer and gas chromatographs. Fume hoods, organic chemical storage, and bench space exists in potential support of several research projects.

Other laboratory space in Ann Arbor is dedicated to preparation and identification of samples collected in the field. Separate areas are dedicated to preparation of larger fishes for a variety of studies including such activities as otolith and coded-wire tag removal and tissue preparation for chemical analyses. Some of the laboratories are dedicated to analyses of benthic and planktonic invertebates as well as larval fish and contain a variety of specialized microscopes. An attached greenhouse in Ann Arbor is used to conduct controlled experiments on wetland processes.

Statistical Support Services

Statistical support is an essential feature of the research cycle during study design, data management, and analyses. During the study planning phase, statistical support assists with experimental design, survey sample design, and choice of statistical methods. During the conduct of studies, statistical support assists with data management and analytical questions and with interpretation and presentation of results as necessary. The Center employs a staff statistician to provide support throughout the research cycle.

Library and Information Services

The library, named in honor of Dr. John Van Oosten, the Center's first director, contains technical materials supporting the research activities of the Center. A specialized collection of books, journals, serials, reprints, and several CD-ROM databases are available in the library. In addition, the library subscribes to various on-line services for computerized literature searches and participates in a shared cataloging and interlibrary loan system. The library's Internet home page (**http://www.glsc.usgs.gov/library**) provides further information about the library's activities and services.

Database and Information Management

The GLSC uses current technology for database and information management. The Center employs local area networks (LAN) to connect computers within the Center and within field stations. Databases served from computers at the GLSC headquarters are accessible by researchers at field stations. LAN technology allows access to relational databases on fish population dynamics in the Great Lakes, commercial catch statistics, contaminant analyses for Great Lakes fishes, and the administrative information system. Data entry capabilities on the Center's large vessels and in the laboratories are provided using Oracle technology. Internet connectivity permits Center scientists to browse the World Wide Web and allows our partners and the public to view our home page (**http://www.glsc.usgs.gov**).

GUIDING PRINCIPLES

Strategic Direction

Enhance the Great Lakes Science Center's diverse science programs, capabilities, and talents to strengthen our scientific contribution to the resolution of complex Great Lakes ecosystem issues.

Customer Strategic Goal

Improve service to users of our information, our customers, and broaden our customer base with timely and pertinent scientific information and effective interaction that increases our understanding of customer needs.

Customer Long-term Goals

- **Measurement Framework**
  Understand and anticipate the needs of the Great Lakes Science Center's customer base and periodically evaluate how our science programs relate to these needs.

- **Products and Services**
  Develop new products and services that are responsive to and reflect the needs of both DOI and external customers.

- **Customer Engagement**
  Increase involvement of multiple partners, cooperators, and coalitions in contributing to mutually beneficial science program outcomes and impacts.

Program Strategic Goal

Provide significant scientific insight into the structure, function, and status of the dynamic and changing ecosystems of the Great Lakes region, in response to present and anticipated threats to the integrity of these ecosystems, through focus on management-driven, critical need, and emergent issues.

Program Long-term Goals

- **Great Lakes Environment and Natural Resources**
  Increase usefulness of long-term deep-water monitoring data and aquatic resource information to clients, expand systematic investigations, provide managers with better understanding of trends in habitat degradation and with better tools to mitigate damage and to restore degraded habitats, increase quality and quantity of predictive tools for scenario building and decision-making in Great Lakes natural systems.

- **Mix of Science Activities**
  Balance the mix of long term data collection and monitoring, research and development, and assessments and applications to be responsive and flexible.

People Strategic Goal

Attract and maintain a diversified, quality workforce with the skills that enhance our science programs and serve our customers.

People Long-term Goals

- **Skills**
  Enhance science and technical skills of the Great Lakes Science Center's workforce.

- **Reward Program**
  Reinforce strategic direction through a Center reward system.

- **Flexibility**
  Achieve human resources flexibility to meet changing needs.

- **Leadership**
  Foster visionary leadership and management professionalism.

Operations Strategic Goal

Maintain a level of infrastructure and operational processes and practices to efficiently and effectively support the Center's workforce, science programs, and customers.

Operations Long-term Goals

- **Information Infrastructure**
  Ensure efficient data integration and access to satisfy both the Center's internal and external customers.

- **Operational Process and Practices**
  Improve the efficiency of the Center's administrative and science support and science program activities through streamlining, quality improvements, and cost reductions.

- **Facilities Infrastructure**
  Optimize facilities location, distribution, and use to reduce costs while ensuring science program effectiveness and quality of work environment.

- **Communication**
  Clearly communicate to all audiences consistent message about our strategic direction and science programs.

VISION

To become the keystone biological research institution in the Great Lakes through conducting relevant cutting-edge basin-wide ecosystem research and disseminating critical scientific information that facilitates ecosystem management through interactions with our clients and partners.

PROGRAM GOALS

STATUS AND TRENDS

Current Program

Fish community structure has changed substantially in the Great Lakes since the Center was established. During the late 1960's and 1970's, piscivores were rare due to sea lamprey predation, and the fish community was dominated by two invaders: alewife, and rainbow smelt that had reached nuisance levels of abundance. Fisheries managers alleviated these conditions by controlling sea lampreys, and stocking both Pacific salmonids and native predators such as lake trout and walleyes. This rehabilitated the Great

Lakes ecosystem, but created a novel fish community in which stocked predators preyed on non-native prey. By the 1980's predator rehabilitation was so successful that prey shortages occurred. The situation was complicated by recent increase in predator recruitment that exacerbated prey shortages, changes in prey fish dynamics, and system-wide changes in food webs that resulted from new invasives such as zebra mussels that were introduced via ship ballast water. Many of these changes were documented through GLSC annual bottom trawl surveys that occur in all five Great Lakes.

Currently, the program works closely with the resource management community to provide scientifically sound approaches to measuring, assessing, and reporting the status and trends of biological resources. GLSC maintains surveys in each lake because each Great Lake has a unique fish community. Trawl surveys assess health of both predator and prey species, although much of our work is focused on preyfish communities. The GLSC has also conducted long-term gillnet assessment of native lake trout in Lake Superior and of hatchery-reared lake trout in all of the Great Lakes to evaluate the status of lake trout rehabilitation. Because lake trout are a long-lived fish, effectiveness of management efforts are only determined through a long-term surveillance. We provide critical information and methods to support fisheries management agencies and their stakeholders. GLSC has the USGS lead for a long-term program of research for assessing status and trends of Great Lakes fish populations and management of associated databases. GLSC biologists conduct original research on systematics and biodiversity of vertebrates. GLSC also develops methods to assess the status and trends for other taxa of interest to DOI.

Future Direction

The Center's Status and Trends Program is responsive to the goals of the DOI and USGS. Strong partnerships with the states, provinces, federal, and universities will be maintained. As opportunities permit, new tasks will be initiated to meet the increasingly complex needs of both the biological and governmental arms of the aquatic conservation community.

Our annual bottom trawl estimates are an important long-term data set that have documented wide fluctuation in the Great Lakes prey fish communities and can be used for a variety of long term ecological studies. Future research efforts will be directed at understanding the mechanisms underlying these changes to better address the managers' information needs. Immediate priorities will be to maintain existing expertise in open water fish community assessment, including marrying historical trawling techniques with new ones, as well as improving gill net and acoustic surveys. New technology for real-time, on-line interaction with population databases will be developed and adapted for use by USGS partners. To better understand the factors influencing the prey fish community, we will incorporate value-added sampling of lower trophic levels to the overall survey design. Center researchers are still investigating the important factors affecting the status of lake trout, a keystone species, in the Great Lakes. Surveys of lake trout will continue to aid in development of management plans and will evaluate the effects and consequences of new management strategies.

The goals of future collaborations will be to explore ways of (1) identifying and minimizing biases that may exist in survey design, (2)) modifying survey techniques to allow the estimation of detection probability with the subsequent integration of detection probability into population estimates, and (3) improving the value of monitoring programs through collection of ancillary data on potentially significant environmental attributes. Finally, GLSC will assure that the technology infrastructure is sufficient to provide state-of-the-art database management, storage, and retrieval to meet the increasing demands for information by the conservation and scientific communities.

Goals and 5-Year Objectives

Goal 1. To assess, project, and report the status and trends of the Great Lake's biological resources to facilitate research, enable resource management and stewardship, and promote public understanding and appreciation of our living resources.

Objective 1: Develop and evaluate inventory and monitoring methods, protocols, experimental designs, analytic tools, models, and technologies to measure biological status and trends.
Objective 2: Provide a framework that facilitates the integration of information from a variety of sources at multiple spatial and temporal scales to describe and track the abundance, distribution, productivity, and health of Great Lakes plants, animals, and ecosystems.
Objective 3: Collaborate with partners to identify opportunities for tailoring long-term status and trends assessment programs to meet specific management and conservation needs as they arise, without compromising the ability to draw basin wide inferences.
Objective 4: Explore developing technologies for their ability to improve the processing and management of population databases.
Objective 5: Incorporate directly measured and remotely-sensed data on potential environmental correlates of population change into status and trends surveys.
Objective 6: Collect, archive, and share selected, critical, high-quality monitoring data in cooperation with our partners to enable a determination of the status and trends of biological resources.
Objective 7: Produce and provide analyses and reports that synthesize information on the status and trends of Great Lakes' ecosystems and are responsive to the needs of the scientific community, fish and resource managers, policy makers, and the public.

FISHERIES: AQUATIC AND ENDANGERED RESOURCES (FAER)

Current Program
Research is focused on the study of fishes, fisheries, aquatic invertebrates, and their aquatic or water-dependent habitats. Species in decline and those that are threatened by extinction are of special research interest as is study of factors that affect population growth and recruitment to key aquatic habitats. Investigations determine the physiological, behavioral, and genetic responses of fish populations to environmental change. Novel methods for restoration and management involving culture techniques, artificial propagation, habitat enhancement, and the diagnosis and control of disease are developed and tested. Systematic research evaluates species relationships using classical morphological and modern molecular genetic techniques. Microbiological studies of fish pathogens lead to important advances in disease control. Predictive models of population and community interactions help forecast species abundance and elucidate predator-prey and habitat relationships. The objectives of the program are to conduct field and laboratory investigations on the biology of fish and invertebrates in the Great Lakes watershed to better delineate environmental tolerances and constraints of these taxa; to conduct field and laboratory investigations on the ecology of fish and invertebrates in the Great Lakes watershed to better understand niche requirements and interactions with other species in their biotic communities; and to provide information on the biology and ecology of fish and invertebrates to assist resource managers with decisions to restore, enhance, maintain, and protect the freshwater biological resources and their supporting ecosystems in the Great Lakes watershed.

The GLSC, in dialogue with DOI and other resource managers, determines those species and habitats of highest priority for investigation. GLSC researchers, in collaboration with agency and academic partners, focus their efforts on species and habitats of greatest concern for protection and restoration. Investigations in the laboratory emphasize taxonomy, physiology, and behavior while field investigations focus on biodiversity and life histories, seasonal and spatial distribution patterns, ecological interrelationships and habitat requirements.

Future Program
Research carried out under the FAER program in the GLSC will continue to emphasize restoration ecology, effects of habitat loss and alteration, trophic relationships, genetics, physiological and behavioral ecology, and the effects of environmental change on native aquatic species. Anthropogenic impacts including invasive species, habitat loss and alteration and global climate change, decreased lake productivity, and increased water clarity greatly affect native biota in the basin and demand increased scientific attention by GLSC scientists within the FAER program. Because of these ecosystem-level

changes, new approaches, development of new technologies and increased predictive capability will be integral to the GLSC's FAER program.

Due to the complexity and scale of the Great Lakes landscape the GLSC will strive to integrate the scientific expertise and expand upon existing linkages and networks with resource managers and collaborators that will be required to carry out scientifically sound and meaningful research in the basin. There interactions will help GLSC scientists identify and prioritize the future research direction of the Center under the FAER program. The GLSC will encourage the use and development of new and innovative approaches and technologies in the research carried out by Center scientists.

Goals and Five-Year Objectives

Goal 1: To understand functional relationships among aquatic species and their habitats.
- Objective 1: Study factors that affect population fitness and recruitment to key aquatic habitats.
- Objective 2: Provide integration of scientific investigations across disciplines and emphasize landscape scale studies.
- Objective 3: Provide better predictive capability.
- Objective 4: Develop and explore new technologies, perspectives, approaches, and partnerships.
- Objective 5: Share data, information, and knowledge with managers.

Goal 2: Provide scientific leadership in understanding factors affecting the health of aquatic organisms in support of their conservation and recovery.
- Objective 1: Determine the physiological, behavioral, and genetic responses of fishery populations to environmental change.
- Objective 2: Develop and explore new technologies, perspectives, approaches, and partnerships.
- Objective 3: Share data, information, and knowledge with managers.

Goal 3: Improve understanding and provide information on the dynamics of life history and species interactions that affect aquatic communities.
- Objective 1: Evaluate species relationships using classical morphological and modern molecular genetic techniques.
- Objective 2: Develop new or alternative approaches for fisheries management.
- Objective 3: Develop population viability analyses, limiting factor determination, and modeling for population and community resilience and recovery.
- Objective 4: Evaluate food webs in aquatic systems.
- Objective 5: Evaluate effects of life history variation on aquatic communities

INVASIVE SPECIES

Current Program

The Great Lakes Science Center (GSLC) conducts a combination of field, laboratory, and modeling studies to provide information pertinent to impact, prevention, containment, and control of invasive species. The Great Lakes ecosystem has been threatened by the continuing invasion of exotic species for over 100 years. Since the 1800's, over 136 exotic algae, fish, invertebrates, and various plants have become established in the Great Lakes. Surveys by GLSC scientists have documented more than 300 non-native plant species at a single terrestrial study site and found that, even in protected areas, non-native species often comprise more than 20% of total plant richness. Particularly with the opening of the St. Lawrence Seaway, the rate of successful introduction of exotic species into the Great Lakes has surged. More than one-third of these invasive organisms were introduced since the 1960s and many now dominate the aquatic community in both numbers and biomass. The most problematic aquatic invasive species include the common carp, Eurasian ruffe, Eurasian water milfoil, purple loosestrife, quagga mussel, round goby, rusty crayfish, sea lamprey, spiny waterflea, and the zebra mussel. These ten invasive species alone have contributed to massive extinctions of native fauna, severe alterations in local

food webs supporting the entire Great Lakes ecosystem, and, in cases such as the zebra mussel, have resulted in millions of dollars of damage to local water users such as power plants.

Exotic species in the Great Lakes rarely remain a regional issue due to the interconnectivity of watersheds through canals, commercial and private boat traffic, and recreational practices. A prime case of rapid expansion from a regional to a national issue can be seen with the invasion of the zebra mussel. Zebra mussels were first introduced into the Great Lakes around 1986. In less than ten years, these mussels spread throughout the Great Lakes, into many small inland lakes and river in most of the states bordering the Great Lakes, and moved down into the Mississippi River, where they now occur all the way down to New Orleans. A second exotic species, the round goby, is poised to repeat this invasion pattern and a third, the silver carp, is poised to move from the river up into the Great Lakes.

Our current program focuses on many aspects of the invasive species issue that vary by species and distributional pattern. Distribution and density of specific invasives are tracked in certain areas, including studies on ruffe population dynamics in Lake Superior, round goby in upper Lake Michigan, and zebra mussels in upper Lake Huron. Other studies focus on ecosystem impact, such as in Lake Ontario, where zebra and quagga mussels have altered ecosystem function to such an extent that key native species, such as *Mysis* shrimp, are in decline. Other studies focus on control issues, such as reducing lamprey populations through the use of pheromones, or preventing the spread of round gobies into the Mississippi River by using electric barriers.

Future Directions

We must improve our ability to forecast invasions of exotic species and to prevent exotic species from becoming established in the Great Lakes watershed. Management efforts to limit the expansion of exotic species once they become established are generally costly and rarely successful. Our ability to prevent future successful invasions will depend on improvement in key areas, specifically: in our ability to predict which species are most likely to be the next successful invader; on our ability to predict ecological and economic impact before widespread colonization of an invasive species occurs; on our ability to develop new tools for control or elimination of exotic species; and, on improving collaboration between the Great Lakes community and other watersheds to increase available expertise while moving toward a broader strategy on prevention and control of shared species.

Goals and 5-Year Objectives

Goal 1. Tracking the changing population structure of biota in the Great Lakes basin.
- Objective 1. Monitor the population dynamics of exotic species.
- Objective 2. Determine the impact each exotic species has on native fauna.
- Objective 3. Determine the role of each exotic species on ecosystem energy, nutrient, and contaminant pathways.

Goal 2. Development of predictive models to provide an early warning on new invaders and on potential ecosystem impact.
- Objective 1. Which is the next most likely invader; what are the pathways for likely invasion, and how can invasion be stopped?
- Objective 2. What impact will the new invader have on ecosystem function, native biota, and surrounding communities?

Goal 3. Development of tools to prevent, minimize impact, and eradicate invasive species.
- Objective 1. Develop alternatives to chemical treatments such as pheromone attractants to disrupt exotic species reproduction.
- Objective 2. Improve efficacy of physical barrier technology to prevent physical movement of the exotic species into and across the region.

Goal 4. Collaborate with Center biologists and outside state, federal, agencies to provide necessary information in an accurate and timely manner on the movement of the exotic species across the region and its impact on native biota.

Objective 1. Enhance existing early warning systems so that relevant individuals and organizations in the region are quickly notified when a new invasive is identified or poised to enter the Great Lakes.

Objective 2. Improve the timeliness of distribution of GLSC research findings through development of topic-targeted web pages.

CONTAMINANTS

Current Program

Chemical stressors of many classes impact on fisheries in the Great Lakes to different degrees and on many levels, and are a priority with the U. S. Fish and Wildlife Service, the U. S. Environmental Protection Agency, and Great Lakes basin states, Canadian provinces, and their municipalities. The combination of the large surface area and volume; heavy concentration of agriculture, industry and municipal development; and the long hydraulic retention time of the Great Lakes make fisheries particularly susceptible to these stressors. This program, dating from the 1960s and 1970s, has had a long history of providing good science and needed information to the Great Lakes basin community by way of residue monitoring, property estimation, and software development for contaminant behavior, fate, and transport studies, as well as hazard assessment.

Future Directions

A major emphasis of this program has shifted very recently from residue monitoring to food and energy web considerations, specifically the elucidation of chemical stressor trophic transfer patterns, bioaccumulation, and like problems important to the Center mission. These stressors include both traditional and emerging issue contaminants as well as dietary components. There is need to elucidate the identity and trophic transfer pathways of many of these chemical stressors. Once identified, the hazard these stressors present to Great Lakes biota are assessed and communicated.

The long-term goal of our program is to provide the capability for hazard and impact assessment of thousands of observed and potential chemical stressors found in fish, sediment, and water on trophic transfer processes of the Great Lakes food and energy webs.

To meet this goal, we utilize the ecosystem approach to stressors that involves a) identifying natural processes and functions for ecosystems and b) subsequent study of the nature and effects of perturbations to allow us to predict consequences. Within this context, in order to achieve the long-term goal, we 1) make analytical measurements of chemical stressors for identification and quantitation (where necessary), and elucidate stressor impacts on trophic transfer through food and energy webs, 2) either use existing or develop new (where needed) mathematical models and chemical property databases to help compile necessary physicochemiical information to describe chemical stressor environmental behavior including toxicity, persistence and bioaccumulation potential, 3) develop a hazard ranking using additional literature data on toxicities, bioaccumulation, biodegradation, and sources, 4) assess risk of site-specific contamination to biota, and when possible 5) suggest remediation strategies.

Goals and 5-Year Objectives

Goal 1. Elucidate trophic transfer interferences and pathways of chemical stressors such as traditional and emerging contaminants, pharmaceuticals and personal care products (PPCPs), endocrine disruptors, and dietary components, in Great Lakes food webs.

Objective 1. Develop laboratory assay capability for use in early mortality syndrome investigations in Great Lakes basin. Collaborate research efforts with known Centers and researchers, and create viable database for all data.

Objective 2. Develop proficiency in both theory and application of stable isotope analysis to ecological problems such as trophic transfer pathway elucidation and stressor interference.

Develop in-house capability, if possible, for stable isotope work or else establish collaborations allowing for stable isotope measurements.

Objective 3. Develop collaborations with both Center PI biologists and outside research groups for the investigation of trophic transfer interferences from identified chemical stressors such as traditional and emerging contaminants including pharmaceuticals, personal care products , endocrine disruptors, and nutrients in Great Lakes biota.

Goal 2. Develop property-predictive QSARs where necessary for general field use with observed chemical stressors from Goal 1, Objective 3 to fill in critical data gaps, especially for inorganic and heavy metal species. .

Objective 1. Assimilation of existing QSAR methodology and databases for use as a generic "toolbox" to assist ecosystem health investigations including environmental fate and risk and hazard assessment.

Objective 2. Continue development, refinement, and distribution of QSAR-based risk and hazard assessment tools, including metal property-prediction parameters such as databases and software for field use. Create CDs and complete the CRADA process for external application of finished product(s).

Goal 3. Determine likely sources, exposure routes, speciation, bioavailability, and ultimate environmental fate(s) for critical chemical compounds identified in Goal 1, Objective 3.

Objective 1. Understand derivation of and improve existing quality criteria by incorporating chemical stressor speciation and bioavailability factors for more accurate risk and hazard assessment.

Objective 2. Develop subsequent quality criteria database(s) reflecting these modifications.

Goal 4. Apply data, data estimation methods, and tools derived from the relevant Objectives in Goals 1 - 3 to current and future risk and hazard assessment issues for more accurate and useable assessments.

Objective 1. Compile "toolbox" of software and databases to facilitate risk and hazard assessments at affected sites and/or with national databases.

Objective 2. Work with BEST and NAWQA as part of their National Synthesis Teams, assisting with the analyses of their numerous databases. Work with other research consortia such as LEEI to lend a more accurate risk and hazard assessment.

Goal 5. Apply crucial assessments in Goal 4, Objective 1, to development of restoration and adaptive management frameworks for impaired ecosystems. These assessments will improve the scientific basis for rehabilitation and restoration of ecosystems such as wetlands, fish spawning grounds, etc. They will also assist in the development of strategies to designate and characterize Index Sites representative of the nation's ecosystems.

Objective 1. Compile and understand needs of Great Lakes basin LaMPs and RAPs with the aim of fine-tuning research goals to answering the needs of the basin community.

Objective 2. Develop collaborations with appropriate committees and such to relay needed data as developed.

TERRESTRIAL, FRESHWATER, AND MARINE ECOSYSTEMS: PUBLIC LANDS AND AQUATIC ECOLOGY PROGRAMS

Current Program

Within the Great Lakes Science Center, interdisciplinary research on coastal ecosystems of the Great Lakes is carried out by the Coastal and Wetland Ecology Branch. Current wetland research efforts focus on quantifying the relations between Great Lakes water levels and wetlands directed toward developing and testing environmentally sensitive regulation plans for Lake Ontario, determining the role of ground water in wetland response to climate change and refining proxies for climate change over the past 4700 years in chronosequences of beach ridges and intervening swales, and developing and evaluating restoration and alternative management strategies for wetlands on USFWS refuge lands. Public lands and aquatic ecology programs currently emphasize research on priority topics in support of public lands management, especially management of Great Lakes' national parks and wildlife refuges in the coastal

zone. Studies areas include determining the developmental history of dune ecosystems to further conservation and restoration efforts, investigating the relations between fire regimes and maintenance of savanna habitats and the plant and animal communities they support, evaluating potential methods for controlling invasive plant species and assessing the importance of factors that might increase susceptibility to invasion, and developing and evaluating new monitoring technologies and sampling procedures for bacterial contamination in support of management of swimming beaches. Studies within the corridor extending from southern Lake Huron through the St. Clair River, Lake St. Clair, the Detroit River, and into western Lake Erie currently focus on assessing fish and wildlife resources and their habitats. Initiatives include creation and evaluation of spawning habitat for lake sturgeon in the Detroit River and use of aquatic remote sensing technologies to evaluate the extent and quality of essential habitats within the corridor, as well as evaluating the natural restoration of burrowing mayfly populations in the corridor.

Future Directions

The Great Lakes Science Center will engage in interdisciplinary research to address high priority management issues in coastal ecosystems of the Great Lakes, with continued emphasis on Department of the Interior and other public lands. Coastal ecosystems function at multiple spatial and temporal scales and cannot be divorced from their surrounding watersheds, landscapes, and developmental histories. Understanding of natural functions in coastal ecosystems is necessary to provide support for knowledgeable management decisions; an understanding of the landscape settings and developmental processes that dictate the manner in which those ecosystems operate today is required. Despite its importance, limited information of this type is currently available. Filling that gap in knowledge is the foundation of GLSC future research on coastal ecosystems. Upon that foundation, the interactions between physical and biological processes will be assessed and the effects of natural stressors of coastal ecosystems will be studied. With appropriate background information, the role of human stressors and disturbances can then be evaluated and quantified, including the influence of the increasingly urban matrix in which natural areas are embedded. Efforts will be made to improve the usefulness of research results through communications with natural resource managers, who may then make informed decisions on actions to halt unnatural disturbances and to initiate mitigation or restoration programs. The GLSC will provide scientific guidance to support those management actions, including evaluation of the potential for success, development of methods that are compatible with the natural functions and processes of the ecosystems, evaluation of success in on-land applications, and follow-up studies to support adaptive management such that successful results can be retained. Looking further into the future, the GLSC will evaluate probable long-term evolution of the Great Lakes shoreline, coastal processes, and coastal ecosystems to develop trajectories and models for predicting how the altered coastal zone will behave in the future.

Goals and Five-Year Objectives

Goal 1. Increase scientific understanding of the development, structure, dynamics, and functions of Great Lakes coastal ecosystems (e.g., wetlands, shallow waters, beaches, dunes, oak savannas) in relation to surrounding landscapes.

- Objective 1. Develop an understanding of landscape setting, underlying geology, resultant hydrology, ensuing biological development, time scale of development, and interactions in Great Lakes coastal ecosystems.
- Objective 2. Apply knowledge of development of coastal ecosystems to understanding of naturally sustainable functions.
- Objective 3. Develop reference sites and long-term datasets that can be used to document the structure, dynamics, and natural functions of coastal ecosystems across spatial and temporal scales.
- Objective 4. Develop models of coastal ecosystems that demonstrate natural processes and functions and provide managers with knowledge of the resources they manage.

Goal 2. Increase scientific understanding of how interactions between physical and biological processes affect coastal ecosystems.

Objective 1. Improve characterization of the chemical and physical properties of coastal ecosystems across the continuum from upland to aquatic environments.
Objective 2. Improve understanding of how landscape setting, geology, and hydrology affect distribution of biological components of Great Lakes coastal ecosystems.
Objective 3. Identify natural stressors to coastal ecosystems, including stressor feedbacks among biological, chemical, and physical properties.
Objective 4. Develop spatial models of coastal ecosystems that incorporate landscape heterogeneity, fragmentation, connectivity, and barriers to biological movement between, within, and among components.

Goal 3. Increase scientific understanding of effects of anthropogenic disturbance on coastal ecosystems.
Objective 1. Develop an understanding of the effects of human stressors, such as climate change, disruption of upland-to-aquatic linkages, shoreline modification, altered sediment supply and transport, altered hydrology, land-use change, development on uplands, chemical and microbiological alterations, invasive species and introduction of non-native organisms, and disruption of fire regime on habitats in the coastal zone.
Objective 2. Evaluate the temporal implications of disturbance regimes, including length of disturbance events, frequency of recurrence, severity, and long-term effects.
Objective 3. Develop methods to quantify the effects of disturbance, including interaction of multiple threats, and develop predictive tools and indicators for evaluating disturbance effects.
Objective 4. Develop mechanistic models for coastal processes and disturbance effects that enable managers to understand the implications of disturbance regimes to habitats, biota, public health, and critical processes that extend beyond the coastal zone.

Goal 4. Increase scientific understanding of restoration, mitigation, and management methodologies for conservation of coastal ecosystems.
Objective 1. Determine the realistic possibilities for reversing physical and biological changes or restoring degraded ecosystems, thus allowing sound goals for restoration to be set.
Objective 2. Develop new and improved methods for restoring, rehabilitating, managing, protecting, and creating coastal ecosystems and their component flora and fauna that incorporate an ecosystem approach and establish or retain connectivity across the landscape.
Objective 3. Develop models for predicting success of projects, including indicators and performance criteria that quantify ecological responses and risk-assessment models, especially in the field of public health.
Objective 4. Work in partnership with managers to evaluate the success of on-land applications of management practices, including development of monitoring programs tailored to allow adaptive management that retains successes achieved.

Goal 5. Increase scientific understanding of the potential future of coastal ecosystems.
Objective 1. Evaluate the probable long-term evolution of the shoreline, coastal processes, and coastal ecosystems in the absence of human disturbance to understand how the natural system might have behaved if not disturbed.
Objective 2. Develop landscape and successional trajectories and models that predict and project how the altered coastal zone will behave in the future.