Strategic Science Plan

Great Lakes Science Center

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VISION

To become one of the keystone biological research institutions in the Great Lakes by conducting relevant, cutting-edge, basin-wide ecosystem research and by developing and disseminating critical scientific information to our clients and partners that facilitates effective ecosystem management.

Mission

To advance scientific knowledge and provide 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 USGS serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life. The GLSC staff work directly with management agencies and key stakeholders to provide critical biological and ecological information needed to protect biological resources in the Great Lakes region. The GLSC responds to research and information needs of federal agencies of the United States, especially needs of the Department of Interior's U.S. Fish and Wildlife Service (USFWS) and National Park Service (NPS), and needs of Canadian federal agencies, eight states, the Province of Ontario, and Native American tribes found within the Great Lakes basin. GLSC research spans a range of topics including: fish populations and communities; aquatic habitats; nearshore, coastal, terrestrial, and wetland communities; and the biological processes that occur in the complex Great Lakes ecosystem. Long-term data sets gathered by Center researchers are powerful tools for studying Great Lakes processes on broad spatial and temporal scales. The Center's science plan focuses on developing forward-looking approaches to the development of effective research and monitoring programs and indicators of ecosystem change in offshore, coastal, and terrestrial ecosystems. The science plan also addresses 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. The U.S. Bureau of Fisheries and the U.S. Fish and Wildlife Service (USFWS), the two agencies in which the Great Lakes program has resided the longest, evolved from these early investigations. The basis of much of the science program currently carried out by GLSC originated in 1927 with the establishment of the Great Lakes Biological Laboratory, with John Van Oosten as its Director, to address the collapse of the lake herring (cisco) fishery in Lake Erie in 1925. However, prior to the establishment of this large-scale research effort, the Bureau of Fisheries had continuously employed John Van Oosten (starting in 1921) and his predecessor, Walter Koelz (employed 1917-1925) to compile statistics on the Great Lakes commercial fishery and to conduct limited scientific fishery studies. The

Great Lakes Science Center has resided in the Department of Interior since 1939. A major change occurred as a result of Presidential Executive Order 11564 in 1970 when the commercial fishery aspects of the program were transferred to the newly-created National Oceanographic and Atmospheric Administration (NOAA) with the caveat that NOAA was specifically excluded from those functions remaining with the USFWS in Great Lakes fisheries and activities related to the Great Lakes Fishery Commission. In 1993, the Department of Interior consolidated all departmental biological research positions into the newly-created National Biological Survey (NBS, soon renamed the National Biological Service). All positions, functions, and authorities in the NBS were transferred to the U.S. Geological Survey (USGS) in 1996. Although the Center name has changed, the mission has remained similar in that the Center has always been at the forefront of providing information that supports scientific management of aquatic resources in the Great Lakes region and has maintained a tradition of working with management agencies.

Headquarters of the GLSC are located on the North Campus of the University of Michigan in Ann Arbor, Michigan. The GLSC has about 43 permanent researchers, 21 permanent technical staff, 24 non-permanent research and technical staff, and 27 permanent non-scientific support staff. About half of the Center's staff is located in Ann Arbor and the others are located at the Center's field stations and satellite laboratories. The Center has eight field extensions including four field stations, one vessel base, and three field station/vessel base combinations dispersed across the large geographic area of the Great Lakes. Strategic placement of the Center's field operations facilitates research conducted throughout the Great Lakes basin and enables more of the most important Great Lakes issues to be addressed. Logistical and administrative support for the ongoing research is provided through the headquarters location.

Unique among USGS centers is the fleet of large vessels that the GLSC owns and operates. These vessels, which range in length from 45 to 107 feet, are well-equipped for community assessment and limnological and ecological studies within the Great Lakes. Equipment on these vessels include 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. Side-scan sonar and remotely-operated vehicles may also be deployed from these vessels.

The Center has always featured a varied research program in addition to those carried out by scientists using its unique fleet of large research vessels. A long history of ecological work dates from the program’s founding in 1927 and includes work on water quality as well as benthic and planktonic invertebrates. Some of this work is conducted from the large vessels, but most is accomplished by use of the Center’s smaller vessels and laboratory facilities. The Center’s decades-long program in contaminant chemistry is evolving into research that supports important emerging issues such as thiaminase and trophic transfer in the food chain. Cutting-edge studies on bioenergetics modeling, physiology, behavior, genetics, and invasive species are carried out at the Ann Arbor facility and several of the field stations. Ann Arbor, Hammond Bay (Michigan), and Tunison (New York), in particular, have facilities for fish holding and rearing giving them the capability of conducting live-animal research. Terrestrial and wetlands research are also carried out at Ann Arbor and several of the field stations, but work at Ann Arbor, Porter (Indiana), and Munising (Michigan) is perhaps where this emphasis is strongest.

Major strengths of the GLSC include the long-term databases of forage fish, benthic invertebrate, and zooplankton populations and associated information in each of the Great Lakes that have been maintained by Center researchers over more than fifty 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. Other significant databases, such as the commercial catch in U.S. waters of the Great Lakes (maintained by the Center since 1920), are also housed at the GLSC (see Appendix). These databases have grown in content, quality, utility, and accessibility to provide managers in the region with reliable and unbiased information necessary for making management decisions. Many Center research studies build on these databases, adding community and ecosystem context to the picture of population trends documented by fish assessments. Predictive models are constructed by Center scientists, anticipating needs of Great Lakes managers. GLSC researchers are increasingly undertaking cross-lake collaborations with other GLSC researchers and collaborative efforts with researchers and resource managers outside of the USGS to produce the syntheses necessary to understand ecological trends and predict how humans might influence future ecological states.

CORE CAPABILITIES: FACILITIES AND SCIENCE SUPPORT

Strategic placement of the Science Center's field operations facilitates research conducted over the large geographic area of the Great Lakes Basin. Biological stations and component laboratories 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 *Sturgeon* 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 R/V *Kiyi* (built in 1999; 107 ft.) 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 *Sturgeon* (1975; 101 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.) 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; 65 ft.) is the primary research vessel on Lake Ontario and 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*. The vessels 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 with deepwater capability 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.

Nearshore Sampling Capabilities

The Center operates a fleet of 12 small (18-25 feet) research vessels outfitted with advanced navigation systems and specialized equipment required for fishery and limnological research in inland, nearshore, and connecting waters of the Great Lakes. Small vessels have been modified to serve as electrofishing boats, shallow-water fish trawlers, gill-netters, trap-netters, substrate samplers, plankton and water samplers, and macrophyte samplers. These small vessels, along with john boats and canoes, facilitate a variety of aquatic sampling methods including: sampling of fish for wetland, nearshore, and predator-prey contaminant studies; capturing of specimens for laboratory studies; sampling of bottom substrates; sampling of wetland and nearshore aquatic vegetation; 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, which are easily moved from lake to lake as well as from project to project, are used for field collections 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 large or small vessels including: a Global Positioning Systems (GPS) community base station; GPS 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, and gather high resolution data about the physical structure of the lakes.

Fish Holding and Rearing Facilities

The headquarters facility 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 and physiological studies. This wet laboratory facility can provide flow-through (100 gallons/minute well water), recirculating, and static systems. The Hammond Bay Biological Station (HBBS) and the Tunison Laboratory of Aquatic Science (TLAS) also have extensive fish rearing and holding facilities. The HBBS facility is supplied by a deep-water intake from Lake Huron and includes tanks and flow-through "living streams" primarily used for research on the effects of sea lamprey on Great Lakes fishes. These facilities are heavily used by university as well as USGS researchers. The HBBS also has a specialized facility for sterilizing male sea lamprey for a biological control program. At TLAS, outdoor fish rearing facilities consist of 24 concrete raceways, and indoor facilities include 600-gallon fiberglass tanks, four raceways and egg incubators. TLAS also has fish isolation facilities equipped with living stream recirculating tanks and photoperiod and temperature control capability.

Other Laboratories

Analytical laboratories central to the Center's research mission are maintained in the GLSC facility in Ann Arbor. Chemistry laboratories have primarily conducted contaminant residue analyses. Instrumentation includes a mass spectrophotometer, gas chromatographs, and mercury analyzer. Fume hoods, organic chemical storage, and bench space exist in potential support of several research projects. Reverse osmosis water is plumbed and available throughout the laboratories. The Ann Arbor laboratory is equipped to perform genetic analysis of aquatic invertebrates, vertebrates, plants and microbes using most analytical tools available today. The Ann Arbor lab has standard electrophoretic capabilities, thermal cyclers to perform PCR and an automated DNA sequencer. These tools allow genetic analysis of both mitochondrial and nuclear DNA and the protein products of gene coding loci. The Lake Michigan Ecological Research Station also maintains PCR equipment for identifying different strains of microbial populations that may cause public health problems on Great Lakes beaches.

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 otolith and coded-wire tag removal, diet analyses, and tissue preparation for genetic and chemical analyses.

Laboratories are dedicated to analyses of benthic and planktonic invertebrates 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. Field stations also have general laboratory space for processing and analyzing samples (including identifying, measuring, and ageing fish and invertebrates). Laboratory space at the Munising Biological Stations is primarily used for studies of coastal dune succession and other ecological studies that relate primarily to the National Lakeshores in the Great Lakes.

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 analysis 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 (1927-1949), contains one of the largest printed collections of aquatic sciences literature in the region to support the research activities of the GLSC. The John Van Oosten Library contains a specialized collection of books, journals, serials, reprints, and several CD-ROM databases. Many of the printed materials are of historical importance and exist nowhere else. 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. Genetics and archival scale databases are being developed as well. 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

The Great Lakes Science Center's Science Plan is consistent with the strategic goals of the USGS' Strategic Plan for 1999-2009 (Appendix). The major strategic goals of this plan are outlined below.

The Vision and Mission statements of the Great Lakes Science Center are stepped down from the larger vision and mission of USGS. Similarly, the Center will step down the larger focus of USGS' strategic goals to goals that are specific and appropriate for the Center's partners, programs, people, and operations in the Great Lakes basin.

Relationship to the Eastern Region Science Plan

The science program at the Great Lakes Science Center must simultaneously relate to several distinct priorities and partners. As a part of the Eastern Region of the USGS, the Center's science is necessarily in harmony with Regional priorities while remaining relevant to the needs and priorities of the Center's many partners in the Great Lakes basin. The Eastern Region has organized its priority societal and integrated science issues into four major categories: Urban Dynamics, Ecosystem and Natural Resources, Human Health and Safety, and Natural Hazards. The Center's science program is relevant to most of the Regional priority categories, but not to all. The following table summarizes these relationships.

ER Science Plan Priority Issues	GLSC Projects

	Deepwater Science	Restoration Ecology and Aquatic Ecosystem Health	Wetlands and Coastal Ecosystems	Invasive Species
I. Urban Dynamics				
Water Quality & Availability		**X**	**X**	
Habitat Fragmentation		**X**	**X**	**X**
River & Coastal Processes		**X**	**X**	**X**
Urban Expansion & Land Use Change		**X**	**X**	
II. Ecosystem & Natural Resources				
Climate Change	**X**	**X**	**X**	**X**
Fish & Wildlife Health	**X**	**X**	**X**	**X**
Eutrophication & Hypoxia	**X**	**X**	**X**	
Biodiversity, Habitat Integrity & Restoration	**X**	**X**	**X**	**X**
Invasive & Nuisance Species	**X**	**X**	**X**	**X**
Energy & Mineral Resource Extraction				
III. Human Health & Safety				
Contaminants	**X**	**X**	**X**	**X**
Pathogens & Disease		**X**	**X**	**X**
Air Quality				
IV. Natural Hazards				
Flooding, Storms and Drought		**X**	**X**	
Earthquakes				
Slope Failure & Subsidence				

PROJECTS AT THE GREAT LAKES SCIENCE CENTER

Research studies at the GLSC are organized into four major Projects related to conceptual and interrelated focus areas. These Projects are: (1) Great Lakes Deepwater Science, (2) Great Lakes Restoration Ecology and Aquatic Ecosystem Health, (3) Great Lakes Coastal and Wetlands Ecology, and (4) Great Lakes Invasive Species. Projects are broken into Tasks – these are the studies of Primary Investigators at GLSC. Although many researchers will focus on Tasks associated with one Project, some researchers may be working on several Tasks that are each assigned to different Projects. The GLSC encourages collaboration throughout the Center to provide the variety of expertise required to tackle the priority research needs. Funding for these projects include the internal USGS Programs, DOI cyclical funding (USGS, USFWS, and NPS), and reimbursable funding (from outside DOI). See the Appendix for more information on how the USGS Programs relate to GLSC Projects.

GREAT LAKES DEEPWATER SCIENCE

Background

The Center's fish population research has focused mainly on long-term dynamics of native and non-native aquatic species and the sustainability of Great Lakes fisheries. Data sets describing the abundance of both predator and prey fish species in each lake span several decades, and thus are among the most highly-valued data sources in the Great Lakes Basin for: (1) understanding the long-term dynamics of the fish community in relation to biotic and abiotic influences; and (2) modeling ecosystem dynamics in the Great Lakes. Fish community structure has changed substantially in the Great Lakes since the Center was established in 1927. Species extinctions and establishment of invasive species have occurred in each lake. Consequently, Center scientists have studied the sustainability of angling and commercial fisheries for top predators that rely on non-native prey fish communities (alewife and rainbow smelt). Understanding how food webs supported by non-native species compare to historic fisheries supported by native prey species (such as deepwater ciscoes) remains a necessary area of research. The Center is recognized for its work on issues affecting the entire aquatic ecosystem in the Great Lakes basin. For example, annual fish stock assessments provide timely information directly to state, provincial, and tribal partners responsible for managing the fisheries. In addition, the unique communities and local disturbances (i.e., habitat alterations) associated with each lake have provided opportunities to study ecological processes in a comparative manner. The progressive spread of invasive species in the Great Lakes basin provides additional opportunities for comparative analyses from areas that are uncolonized by the invasive to those with varying degrees of colonization.

Most funding for the Deepwater Science Project has come from the Status and Trends of Biological Resources Program of USGS, but substantial funding also comes from the Fisheries: Aquatic and Endangered Resources Program (USGS), cyclical funding (USGS and DOI partners), and reimbursables.

Future Direction

The Great Lakes Deepwater Science Project is responsive to the goals of the DOI, USGS, and the needs of management agencies such as the Council of Lake Committees, Great Lakes Fishery Commission. Strong partnerships with the states, tribes, provinces, other federal agencies, and universities will continue. As opportunities arise, new Tasks will be initiated to meet the

increasingly complex needs of the scientific community, fishery and resource managers, policy makers, and the public. The complexity of resource issues also requires an integrated approach across traditional "research boundaries" of the various Projects within the GLSC as well as cross-basin studies. Thus, one challenge is to identify important links between habitat boundaries (e.g., offshore and coastal), and develop collaborative and integrative research studies to take advantage of the diverse scientific expertise within the GLSC. Specific goals and objectives that could foster this collaborative research across Projects within GLSC are identified in the Five-Year Goals and Objectives section.

Future research efforts in the Deepwater Science Project will be directed at evaluating existing survey designs to modify and improve surveys where necessary. This effort will include integrating long-term bottom trawl surveys with other sampling technologies (e.g., acoustics and midwater trawls) to provide more comprehensive assessments of fish communities and account for varying life histories (e.g., pelagic versus demersal species and/or life stages). To address managers' key information needs, future research will increasingly attempt to understand how gradients of habitat structure and density of invasives influence recruitment of key species, and how this recruitment affects community change and succession. Traditional and newer sampling technologies, sampling of lower trophic levels and abiotic factors, as well as development of conceptual frameworks to identify knowledge gaps, will play an important role in meeting this objective. Communication and collaboration with management agencies will be critical for anticipating and developing novel or overlooked research approaches of practical importance that includes both native and important non-native species. For example, modeling and field research to identify the relative importance of mortality between lake herring life stages in Lake Superior will not only guide Lake Superior management decisions, but could provide scientifically- and economically-sound information to guide possible restoration efforts for lake herring in the lower Great Lakes. Evaluation of sampling designs in each of the Great Lakes can help guide potential standardization of sampling designs to facilitate cross-lake comparisons that may highlight important basin-wide responses to environmental factors such as global climate change.

GLSC will develop and apply new technology for real-time, on-line interaction with population databases. GLSC will ensure that the technology infrastructure is sufficient to provide state-of-the-art database management, storage, and retrieval to meet the increasing information demands from management and scientific communities.

GREAT LAKES RESTORATION ECOLOGY AND AQUATIC ECOSYSTEM HEALTH

Background

Restoration and rehabilitation of native aquatic species and habitats is an integral component of the research program at the GLSC. Studies focus on restoration of native fish species such as lake trout, lake sturgeon, Atlantic salmon, American eel and others, as well as restoration of the habitats essential for sustaining their populations. Fish population assessment, analyses of fish community structure, and studies to assess habitat availability, quality, and connectivity help scientists identify research priorities and strategies. The GLSC also works closely with partners to evaluate and address research needs using a multi-disciplinary ecosystem approach and following the Strategic Vision of the Great Lakes Fishery Commission (2001).

Trophic level investigations by GLSC scientists examine organisms from invertebrates to fish and birds. Research to determine the ecological role of native species within and between trophic levels in the Great Lakes helps determine the vulnerability of species to replacement or depletion. Researchers evaluate natural and human-induced environmental stressors including climate, land-use patterns, management practices, habitat, contaminants, and invasive species that can cause changes in the populations and communities of Great Lakes organisms. Some studies aim to restore ecological resilience to communities of native species by identifying and working to restore depleted and extirpated species. In conjunction with these studies, measures of biodiversity applicable to Great Lakes species assemblages are being developed to identify specific locations and species that are most at risk from environmental changes. Biodiversity studies also contribute to development of rehabilitation strategies for species and their habitats.

The structure and dynamics of species assemblages can be used to infer the status of aquatic ecosystem health, as well as some functions of natural communities. Several useful measures of ecosystem health based on structure (e.g., richness, diversity, and non-native species) and productivity have been identified. Measures of community stability need to be identified to assist in understanding persistence of aquatic assemblages. Some management actions affect the diversity and sustainability of aquatic species; models relying on predator-prey dynamics or species-habitat relationships can be used to demonstrate these effects and can be used to evaluate alternative management strategies in the Great Lakes basin.

Fish community dynamics investigations are aided by the ability to analyze genetic variation both above and below the species level. Data on protein and nuclear and mitochondrial DNA variation, collected by Center scientists, are used to investigate genetic relationships within and among fish populations and to determine the species, stock, or hatchery origin of fish. Center scientists are currently focusing on combining genetic data with GIS and traditional fisheries data to monitor trends in stock structure and abundance.

Laboratory and field research studies are also undertaken to identify factors impeding restoration of native species, including studies on fish behavior, habitat, recruitment, survival, and population genetics. Special effort has been made to understand factors affecting restoration and management of lake trout. In addition, the Center has long and distinguished history of conducting behavioral, physiological, toxicological, and analytical chemistry studies to determine the effects of stressors on aquatic biota. It is currently recognized that exotic species, physical habitat changes, environmental contaminants, and other biogeochemical factors influence the health of aquatic biota in the Great Lakes. Bacterial contamination plagues beaches throughout the region and throughout the country resulting in frequent beach closures that may or may not be warranted. Invasive species may be suppressing lake trout populations by changing thiamine availability to young trout. Application of risk assessment to evaluate progress toward setting and meeting target conditions of contaminant reduction 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.

Funding for this Project comes from the Fisheries: Aquatic and Endangered Resources Program (USGS), the Contaminants Program (USGS), cyclical funding (USGS and DOI partners), and reimbursables.

Future Direction
Future research efforts at the GLSC will aim to restore ecological resilience to the Great Lakes Basin. Research in this Project will continue to emphasize restoration ecology, effects of habitat loss and alteration, invasive species, climate change, contaminant movement through food webs, trophic relationships, effects of decreased lake productivity, changes in water clarity, genetics, physiological and behavioral ecology, and the effects of environmental change on native aquatic and terrestrial species. New experimental approaches and survey techniques, development of new technologies, and expanded predictive modeling will be integral to this Project.

Due to the complexity and scale of the Great Lakes landscape, the GLSC will strive to integrate scientific expertise among the Center's science staff 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. Their interactions will help GLSC scientists identify and prioritize the future research direction of the Center in the Project. The GLSC will encourage the use and development of new and innovative approaches and technologies in the research carried out by Center scientists.

GREAT LAKES WETLANDS AND COASTAL ECOSYSTEMS

Background
Embayments, wetlands, river mouths, beaches, moraines, and coastal dunes are found along 7,500 km of shoreline of the Great Lakes and in inland aquatic habitats managed by the U.S. Fish and Wildlife Service and National Park Service. There are 1,150 km of connecting channels between the Great Lakes including the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence rivers, and over 1,300 distinct coastal wetlands, with a total area of 1,200 km^2, along the shores of the Great Lakes and its connecting channels in the United States. Because of the desirability of coastal habitats for residential, industrial, and recreational uses, these areas are highly susceptible to habitat modification, contamination, and water-level regulation. Research is being conducted to: (1) understand the relationships between lake-level fluctuations, lake-level regulation, and wetland and terrestrial habitats; (2) understand the effects of climate change on wetlands and terrestrial habitats and species; (3) assess alternative techniques for restoration of diked and ditched wetland habitats; (4) examine environmental factors, including contaminants and changes in fire regimes, that affect survival of aquatic or terrestrial species; and (5) develop means of assessing distribution and enhancing and protecting habitats for rare species, such as Karner blue butterfly and native clams. Center researchers work to understand how perturbations, such as shoreline development, vessel traffic, changes in rates of sand deposition, or invasive species affect nearshore aquatic and terrestrial habitats, with a goal of developing restoration techniques to remediate these impairments. Center scientists also work to document linkages, such as nutrient exchange, between nearshore habitats and lakes, as well as the role of the nearshore zone in the recruitment of larval fishes into offshore, deepwater fisheries.

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: (1) examining how fire frequency and timing affect animal and plant populations; (2) studying how the heterogeneous light environments of savannas influence abundance of plants and animals; and (3) developing

landscape composition models that evaluate the relationships between landscape vegetation composition and animal presence on the landscape to assist managers in setting restoration goals.

Funding for this Project comes from the Terrestrial, Freshwater, and Marine Ecosystem Program (USGS), the Fisheries: Aquatic and Endangered Resources Program (USGS**),** cyclical funding (DOI agencies), and reimbursables.

Future Directions

The consolidation of biological research positions from the management agencies within the Department of Interior (first, the National Biological Survey, and now USGS), has given USGS, and the Great Lakes Science Center by association, a major responsibility to provide science for these DOI agencies in the Great Lakes basin. The GLSC will engage in interdisciplinary research to address high priority management issues in coastal ecosystems of the Great Lakes, with continued emphasis on DOI 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 natural functions in coastal ecosystems is necessary to make knowledgeable management decisions. An understanding of the landscape settings and developmental processes that dictate the manner in which these ecosystems operate today is required to determine the differences between historical and contemporary coastal ecosystem functioning. Despite its importance, information of this type is currently limited. Filling that gap in knowledge is the foundation of future research by the GLSC 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 component mixed with natural areas in the landscape matrix. Efforts will be made to improve the usefulness of research results through communications with 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.

GREAT LAKES INVASIVE SPECIES

Background

The GLSC and its predecessors have a long history of conducting research on non-Great Lakes species beginning with investigations of the population biology of the rainbow smelt in the 1930s. Perhaps the best known example of the Center's work on exotic species has been its long-term study of the sea lamprey that was initiated in 1950. 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. Other studies are funded through the Invasive Species Program (USGS) and the Fisheries: Aquatic and Endangered Resources Program (USGS).

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 invasive and exotic species has had substantial effects in open lakes (e.g., alewife and rainbow smelt), wetlands (e.g., common reed, 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). Today, zebra and quagga mussels are colonizing deeper water habitats as well. Research to identify effects of invasive species in the Great Lakes basin provides opportunities to study the links between species diversity and ecosystem stability. The introduction and colonization of invasive species may affect genetic diversity through genetic bottlenecks in affected native biota or hybridization between native and non-native species, which in turn may play a role in maintaining or undermining 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 of these species. Combinations of field, laboratory, and modeling studies are conducted to provide information pertinent to prevention, containment, and control of exotic species. This research is dedicated to determining the ecology, distribution, life history, and reproductive behavior of exotic species.

Future Directions

We must improve our ability to forecast invasions of exotic species to prevent them from becoming established and to assess the effect of specific invasions on native species. 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 our ability to predict which species are most likely to be the next successful invader and their likely routes of invasion; our ability to predict ecological and economic impact before widespread colonization of an invasive species occurs; our ability to develop new tools for control or elimination of exotic species; and improving collaboration among stakeholders to increase available expertise while moving toward a broader strategy for prevention of introduction and control of problem species. In the event that an invasion does occur, we need to document this as soon as possible to initiate the appropriate response. Strengthening the ecological resilience of native species is a potential strategy that may slow or even stop colonizing by invasive species.

GOALS AND 5-YEAR OBJECTIVES

The following **Goals** are taken from the Strategic Plans of five Program Elements of USGS; (1) Status and Trends of Biological Resources; (2) Fisheries: Aquatic and Endangered Resources; (3) Terrestrial, Freshwater, and Marine Ecosystems; (4) Invasive Species; and (5) Contaminants. These Programs provide the Congressionally-appropriated science funds with which GLSC conducts many of its research studies. Providing this direct link between USGS Program Elements and GLSC Goals illustrates how GLSC research activities help meet the research objectives of the USGS. The Goals are hence labeled as "USGS Goals". The **Objectives** are specific to the science conducted at GLSC, and the numbered sub-objectives detail more specific studies that will be conducted in the next five-year period. The Objectives are labeled as "GLSC Objectives". The research science program at GLSC is not easily partitioned into specific USGS Programs, GLSC Projects, nor specific supervisory groups (e.g. Branches or Sections), but exists in a more collaborative cross-disciplinary environment. For example, research in the area of deepwater science occurs primarily in the Great Lakes Deepwater Science Project and the Great Lakes Restoration Ecology and Aquatic Ecosystem Health Project, but is not necessarily restricted to these Center Projects. Ultimately, the particular focus of a research study will determine the Project to which it is assigned—not the supervisory alignment of the research personnel nor the funding source. The GLSC Project(s) to which the various USGS Goals and GLSC Objectives potentially apply are indicated parenthetically (and highlighted in capital letters).

USGS Goal 1. To assess, project, and report the status and trends of the Great Lake's deepwater biota to facilitate research, improve resource management and stewardship, and to promote public understanding and appreciation of the living resources within the Great Lakes basin. (DEEPWATER, RESTORATION)

GLSC Objective 1.1: 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.

1.1.1. Conduct annual surveys to assess the status and trends of fishes in the deepwater areas of the Great Lakes. (DEEPWATER)

1.1.2. Link GLSC scientific expertise with scientific and management expertise of resource managers and collaborators to carry out scientifically sound and meaningful research in the basin. (DEEPWATER, RESTORATION)

1.1.3. 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. (DEEPWATER, RESTORATION)

1.1.4. Provide study findings and cruise updates at winter and summer lake technical meetings and at annual spring Lake Committee Meetings. (DEEPWATER)

GLSC Objective 1.2: Develop and evaluate inventory and monitoring methods, protocols, experimental designs, analytic tools, models, and technologies to measure biological status and trends.

1.2.1. Explore developing technologies for their ability to improve the processing and management of population databases. (DEEPWATER)
1.2.2. Merge directly measured and remotely-sensed environmental data with ongoing population assessments to evaluate how environmental factors might produce population change. (DEEPWATER)
1.2.3. Develop sampling designs using hydroacoustic technology to determine biomass and abundance of pelagic fish and invertebrates across habitat, depth, light incidence, and photoperiod gradients. (DEEPWATER)
1.2.4. Evaluate sampling design of bottom trawl surveys to improve biomass and abundance estimates of benthic fish and invertebrates. (DEEPWATER)

USGS Goal 2: Provide scientific research that coordinates with priorities of the Department of the Interior, other Federal agencies, the States, Tribes, and the Nation's natural resource managers on the biota of deepwater and coastal habitats in the Great Lakes basin. (DEEPWATER, RESTORATION, COASTAL, INVASIVES)

GLSC Objective 2.1: Coordinate with natural resource managers to develop research and technology tools to evaluate the scientific effectiveness of adaptive management strategies for restoration efforts to sustain declining species and habitats in the Great Lakes basin.

2.1.1. Evaluate adaptive management techniques for restoring lake trout in the Great Lakes. (DEEPWATER, RESTORATION)
2.1.2. Develop and evaluate adaptive management techniques for restoring coregonines in the Great Lakes (DEEPWATER, RESTORATION)
2.1.3. Determine spawning habitat use, success, and movement of lake sturgeon in the Detroit, Niagara, and Genesee rivers (RESTORATION)
2.1.4. Develop initiatives to characterize, identify, and assist in restoring suitable habitat for native species such as lake sturgeon in the Lake Huron-Lake Erie corridor. (RESTORATION)
2.1.5. Develop thiamine initiative to explore techniques to restore Great Lakes lake trout and Atlantic salmon populations. (DEEPWATER, RESTORATION)
2.1.6. Develop initiatives to restore native clams (Unionidae) populations to the nearshore waters and wetlands of the lower Great Lakes and interconnecting channels. (COASTAL)
2.1.7. Provide research and technical support critical to recovery planning for the endangered Karner blue butterfly, including insight into relationships between landscape structure and species distribution. (COASTAL)
2.1.8. Develop improved methods for assessing aquatic ecosystem health for deepwater, coastal, nearshore, tributary, and wetland communities in the Great Lakes basin. (DEEPWATER, RESTORATION, COASTAL, INVASIVES)

GLSC Objective 2.2: Quantify and describe functional relationships among species and habitats to provide information to conserve or restore community function in the Great Lakes basin.

2.2.1. Determine biodiversity and interactions of native and invasive aquatic invertebrate species in benthic and pelagic deepwater communities in the Great Lakes. (DEEPWATER, RESTORATION)
2.2.2. Determine the genetic diversity of salmonids (such as brook trout in the Lake Superior basin and Atlantic salmon in Lake Ontario) for potential use in restoration efforts. (RESTORATION)
2.2.3. Determine the diversity of plants, fish, and invertebrates in coastal and nearshore areas of the Great Lakes. (COASTAL)
2.2.4. Determine bathythermal habitat selection by commercial, sport, and priority native species in the Treaty-ceded water of the upper Great Lakes. (DEEPWATER, RESTORATION)
2.2.5. Determine the effects of global climate change on Great Lakes wetlands and recruitment of Great Lakes fishes. (COASTAL, DEEPWATER)
2.2.6. Develop models to predict how habitat quality, habitat spatial arrangement, and habitat variability in time, affect endangered and threatened species in nearshore terrestrial environments. (RESTORATION, COASTAL, INVASIVES)

USGS Goal 3: Investigate factors that significantly influence ecosystem structure, function, and condition in the Great Lakes Basin. (DEEPWATER, RESTORATION, COASTAL)

GLSC Objective 3.1: Develop indices of Great Lakes ecosystem sensitivity to change and vulnerability to potential stressors, and tools to predict ecosystem responses to environmental change.

3.1.1. Develop models to predict effects of savanna and grassland restoration on native animal and plant populations. (RESTORATION, COASTAL)
3.1.2. Develop biomass size spectra models as ecosystem indicators for offshore and nearshore aquatic community structure and function, and predict impacts of management decisions, environmental change, and unanticipated perturbations on these indicators. (DEEPWATER, RESTORATION)
3.1.3. Develop an improved understanding of interactions among landscape setting, underlying geology, resultant hydrology, biological development, chemical and physical properties, and time scale of change in Great Lakes coastal ecosystems in site-specific studies of embayments and dunes. (COASTAL)
3.1.4. Identify and quantify the effects of disturbance regimes from anthropogenic and natural stressors, such as climate change, upland-to-aquatic material and energy movement, shoreline modification, sediment transport, land-use change, microbial deposition, non-native species invasions, and fire on habitats in the coastal zone. (COASTAL)
3.1.5. Characterize the chemical and physical properties of coastal ecosystems across the continuum from upland to aquatic environments in hydrologic studies of beach ridge systems in coastal embayments. (COASTAL)
3.1.6. Develop models that evaluate the probable long-term evolution of the shoreline, coastal processes, and coastal ecosystems to determine how the current ecosystem

deviates from historic functioning and how the extent of this deviation might change in the future. (COASTAL)

3.1.7. Develop reference sites and long-term datasets that can be used to document the structure, dynamics, and natural functions of different coastal habitats across spatial and temporal scales. (COASTAL)

GLSC Objective 3.2: Devise a restoration and adaptive management framework for impaired Great Lakes nearshore aquatic, wetland, and terrestrial ecosystems.

3.2.1. Develop models to predict effects of alternative terrestrial landscape compositions on conservation value of nearshore ecosystems. (RESTORATION, COASTAL)

3.2.2. Devise new techniques, or extend existing techniques, for restoration of damaged and altered nearshore terrestrial ecosystems and provide methods for evaluating the efficacy of these techniques. (RESTORATION, COASTAL)

3.2.3. Assist managers to evaluate the feasibility of reversing physical and biological changes or restoring degraded sites, thus allowing sound goals for restoration to be set. (COASTAL)

3.2.4. Develop improved methods for rehabilitating, managing, and creating coastal ecosystems and their component flora and fauna that incorporate an ecosystem approach and establish or retain connectivity across the landscape. (COASTAL)

3.2.5. Work in partnership with managers to evaluate the success of on-land applications of management practices, including development of monitoring programs tailored to increase success of adaptive management programs (COASTAL)

3.2.6. Identify effects of lake-level regulation on wetlands of Lake Ontario and the St. Lawrence River, develop models to predict effects of new regulation plans, and assist in developing an environment-friendly regulation plan. (COASTAL)

GLSC Objective 3.3: Model factors controlling Great Lakes nearshore aquatic and terrestrial ecosystem patterns at various scales and develop decision support systems that integrate this information with management options.

3.3.1. Develop models that describe effects of scales of landscape fragmentation, heterogeneity, and connectivity, and human development on nearshore, basin watershed, and terrestrial ecosystem function and living resource status, including barriers to biological movement within and among habitat components. (RESTORATION, COASTAL)

3.3.2. Develop models of historic coastal ecosystem processes and biota to provide managers with baseline knowledge of the resources they manage and an improved understanding of how current ecosystems deviate from historic functioning and how the extent of this deviation might change in the future. (COASTAL)

USGS Goal 4: Combat invasive species in the Great Lakes basin through early detection and assessment of newly established invaders; monitoring of invading populations; improving understanding of the ecology of invaders and factors affecting the resistance of habitats to

invasion; and development and testing of prevention, management, and control methods. (DEEPWATER, RESTORATION, INVASIVES, COASTAL)

GLSC Objective 4.1: Improve early detection and rapid response to invasions by identifying and reporting new invasions and proactively assessing risk of invasions in terrestrial and aquatic habitats.

4.1.1. Integrate invasive research and monitoring by Center biologists with other federal and state research and monitoring activities to provide necessary information in an accurate and timely manner on the movement of invasive species into and across the Great Lakes and its impact on native biota. (DEEPWATER, INVASIVES, RESTORATION, COASTAL)

GLSC Objective 4.2: Conduct research and develop methods and technologies to control established populations of sea lamprey.

4.2.1. Develop alternatives to chemical lampricide treatments as control techniques for sea lamprey, such as pheromone attractants to disrupt sea lamprey reproduction. (INVASIVES)

4.3.2. Investigate potential control methods for invasives species such as round goby, ruffe, and Asian carp. (RESTORATION, INVASIVES)

GLSC Objective 4.3: Determine effects of invasive species and susceptibility of habitats to invasions through a variety of models, analytical techniques, and focused studies that include trophic linkages.

4.3.1. Determine direct and indirect effects of invasive species such as zebra mussel and round goby on nearshore and deepwater communities in the Great Lakes. (DEEPWATER, RESTORATION, INVASIVES)

USGS Goal 5: Investigate the effects and exposure of environmental contaminants to the Nation's living resources, particularly those under the stewardship of the Department of the Interior. (DEEPWATER, RESTORATION, COASTAL)

GLSC Objective 5.1: Determine the sources and fates of environmental contaminants in the Great Lakes basin and the lethal and sub-lethal effects of exposure to these contaminants.

5.1.1. Improve the scientific basis for assessment, restoration and monitoring of Great Lakes beach habitats by determining sources of bacterial contamination of beaches and developing methods for predicting conditions that foster unhealthy bacterial loads. (RESTORATION, COASTAL)

5.1.2. Develop predictive models for evaluating the effect of multiple stressors, multiple levels of biological organization and multiple temporal and spatial scales on bacterial contaminants of public beaches in the Great Lakes. (COASTAL)

5.1.3. Work with State, Federal, and Tribal partner agencies to foster a venue to facilitate information exchange specifically about early detection and monitoring efforts. (COASTAL)

GLSC Objective 5.2: Improve the scientific basis for evaluating the effect of multiple stressors, multiple levels of biological organization, and multiple temporal and spatial scales in the Great Lakes basin.

5.2.1. Develop proficiency in both theory and application of appropriate tissue analyses to address ecological problems such as disruption of trophic transfer pathways and stressor interference. (DEEPWATER, RESTORATION)

5.2.2. Develop collaborations to improve investigations of trophic transfer interferences from chemical stressors occurring in the Great Lakes, including pharmaceuticals, personal care products, endocrine disruptors, and nutrients. (DEEPWATER, RESTORATION)

5.2.3. Evaluate Great Lakes basin Lake Management Plans and Remedial Action Plans with the aim of fine-tuning research goals to meet the needs of the basin resource management community. Develop collaborations with appropriate committees to relay needed data as developed. (DEEPWATER, RESTORATION)

IMPLEMENTATION

Research Development

Development of specific research Tasks or studies is usually a bottom-up procedure. The Primary Investigator (PI) is expected to integrate the needs of clients and provide research studies to address these concerns. To begin the process, the PI develops a study concept proposal that justifies the research need and outlines the scientific approach. Supervisors and Branch Chiefs provide guidance regarding priority of the research for partners and GLSC and approve the time and resource commitments represented by the proposal. The PI then develops study plans that are peer-reviewed and approved by supervisors and Branch Chiefs. The Center Director, upon advice of the Policy Management Council, may provide base funding for well-justified, priority studies. Study plans for outside funding must also be peer-reviewed (either by GLSC or funding agency) and approved by GLSC management as relevant and high priority studies.

The development of research studies for the GLSC will be focused on three major drivers: (1) management needs; (2) emerging issues; and (3) large-scale initiatives. Management needs define much of the work conducted at the GLSC. Recognition of management needs involves direct and long-term interactions with management agencies to determine the highest priority research required by managers. Emerging issues are based on immediate needs of USGS, managers, and sometimes members of Congress in addressing recently defined research issues that significantly affect the Great Lakes basin. They may temporarily divert researchers' time from ongoing studies to quickly address topics that require immediate attention, such as invasive species, new species at risk, or environmental crises. Initiatives are a proactive way to secure funding to carry out large-scale interdisciplinary research that addresses future management needs through a more in-depth understanding of the structure and function of specific components of the Great Lakes ecosystem.

The Great Lakes Deepwater Science Project works closely with fishery managers to determine the highest priority research needs on each of the Great Lakes. The PIs who conduct research as part of the Project are either voting members or resource members on at least one of the Lake Technical Committees that are organized through the Great Lakes Fishery Commission. These committees are comprised of fishery biologists from each state, province, tribal entity, USFWS Fisheries Resource Office, and USGS/GSLC. They meet once or twice a year and provide information on the status of fish populations, management alternatives, and guidelines for making and evaluating fisheries management decisions to the lake committee. The Lake Committee is comprised of one senior staff member from each management agency (state, province, or tribal entity) on the lake. Researchers provide presentations and reports at the spring meeting of the Lake Committees. The Lake Committee decides on the overall fisheries management of each lake based on input from the Lake Technical Committee. Most of the funding for this project is through USGS base funding, although there are opportunities to secure reimbursable funding for new and innovative studies. The GLSC will continue to have an annual meeting that brings most of the Center scientists working on deepwater science from across the Great Lakes to discuss research findings, operational issues, and future research directions for at least the 5-year time frame of the Strategic Plan.

USFWS and NPS also work closely with GLSC researchers to address management concerns. Both agencies have avenues to provide funding for research studies. These studies often emphasize restoration ecology. Resource managers of the NPS, for example, are frequently interested in obtaining research information relevant to restoring habitat for species at risk. Managers of the USFWS are also often interested in restoring species at risk and request help in evaluating adaptive management strategies. These studies are usually associated with our Great Lakes Wetlands and Coastal Ecosystems Project and Great Lakes Restoration Ecology and Aquatic Ecosystem Health Project.

The Great Lakes Invasive Species Project is largely supported by the Great Lakes Fishery Commission (GLFC). They provide almost total funding (less some administrative, facilities, and cost-share expenses) to run the Hammond Bay Biological Station and fund the staff and research on sea lamprey control. The researchers submit proposals that go through a review process by the GLFC and address their highest research priority needs. In addition to the lamprey-directed research at Hammond Bay, other staff members of the Center can be funded for research projects on other invasive species either through the Center's internal budgeting decisions, competition for funding within DOI, or reimbursable agreements with various partners.

Emerging issues may address national or regional concerns. Requests from management agencies, USGS, or even Congress for research to help understand or control an emerging problem come to GLSC management or to individual researchers. In the past, emerging issues have often included questions about new invasive species – their effect on the aquatic community and possible methods to limit their spread. If deemed to be of sufficient priority and relevant to the mission by GLSC management, researchers explore possibilities with partner agencies also involved in the emerging issue. USFWS is concerned with invasive species issues and has requested help on research studies to understand the impact of new invasive species on the community and to help control or limit the spread of invasive species. Usually a collaborative strategy is developed for emerging issues and funding is garnered to support the research. These can also be cost-share studies in which staff time and available resources are provided by the Center and funding is sought to cover science operation costs. If emerging issues persist in time as a relevant research issue then they may become a long-term management need or develop into a large scale initiative that better addresses the issue.

Initiatives are large scale studies with a multi-disciplinary approach to provide information of great societal value. An issue of high importance is determined by managers and researchers. Then a consensus-building approach is used with a team of managers and researchers from natural resource agencies, universities, and other organizations involved or interested in resolving the issue. The team develops research questions, determines research priorities, and formulates a coordinated plan of approach to obtain the scientific information required for effective management of the issue. To move forward on an Initiative, the research themes are discussed with our partners to determine research priorities within these themes and to begin strategic planning on a high profile study. Funding for these large initiatives are sought outside GLSC, although initial or pilot studies may be accomplished with internal funding. Initiatives

are expected to add to the Great Lakes Restoration Ecology and Aquatic Ecosystem Health Project and to the Great Lakes Coastal and Wetlands Project.

Priority of research studies at GLSC is determined in several ways. We have four research focus Projects that address a variety of partner and management needs. Partners and managers provide input directly to key GLSC staff who work collaboratively with them on various committees and projects in the Great Lakes (such as the Lake Committees organized through the Great Lakes Fishery Commission), through recommendations derived from specific workshops and conferences, and through periodic reviews of the Centers programs and Science Plan. On a somewhat more elevated level, the annual assessment of the GLSC program by the CLC is a way for fishery managers in the Great Lakes to publicize their priorities for USGS and GLSC and evaluate responses to these priorities. Traditionally, the GLSC has been partnered with, and responsive to, the needs and priorities of agencies managing deepwater fish communities of the Great Lakes. However, the GLSC has substantial expertise and involvement in research on nearshore and wetland communities that will increasingly allow GLSC scientists to aid agencies involved in management of these communities as well. We expect to see much greater involvement of GLSC staff in these evolving priorities. As stated earlier, the GLSC Research Program Strategic Goal is to 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. This goal is achieved through a mix of science activities that balance long-term data collection and monitoring, research and development, and assessments and applications to be responsive and flexible. Researchers are central to the development of relevant and high quality scientific studies through interactions with managers and colleagues. GLSC managers provide guidance on research topics, authorization of research studies, and internal funding to carry out the research mission. Together they decide the scientific studies (Tasks) that address immediate (emerging issues), ongoing (management needs), and future (initiatives) research needs of the Great Lakes Basin ecosystem.

Measures of Research Accomplishment

The goals and objectives that will guide the science program of the Great Lakes Science Center will have little meaning if a measure of accomplishment is not quantified. Congress and the Executive Branch both recognize this implicitly and require annual, in the case of Congress (Government Performance and Results Act, GPRA), or periodic, in the case of the Office of Management and Budget (Program Assessment Rating Tool, PART), reports and reviews of the research programs of the Department of the Interior and the U.S. Geological Survey. Common to both Congressional and Presidential assessments of research performance are the concepts of outputs and outcomes. Outputs can be equated to products, and outcomes can be equated to results or significant effects on problems. Outputs can generally be quantified either directly or with simple metrics, and performance goals can then be determined based on suitable baseline data. Outcomes, on the other hand, are more nebulous than outputs, and, in many cases, are actually more important for the science program than some outputs. Outcomes should relate directly to the Center's Mission and Vision statements, and successful outcomes are often based on the quality, relevance, and usefulness of the science. Perceptions by partners and customers are extremely important for achieving successful outcomes, and the ultimate satisfaction of

partners and customers is based on many factors including quality, relevance, and timeliness of output delivery. In addition, aspects of interpersonal interactions between various individuals involved in the planning, conduct, management, and application of research results (competency, respect, and credibility, for example) figure prominently in achieving successful outcomes.

The Great Lakes Science Center will compile an annual assessment of progress and achievement of goals or objectives for outputs and outcomes. The overriding context for these assessments can be found in the Department of Interior's Strategic Plan FY 2003-2008. Additionally, USGS's Strategic Goals for Environment and Natural Resources Programs, Customers, Operations, and People, as detailed in its Strategic Plan for 1999-2009 provide guidance on priorities in the agency (Appendix). These goals, objectives, strategies, outcomes, and measures are stepped down in the strategic plans for each program in the Biological Resources Discipline. The Center's annual assessment will be made available to the staff, agency, and interested partners, and will be posted on its website. This annual retrospective evaluation is expected to improve both the conduct and management of science in the Center.

Outputs

Outputs will be tracked and quantified. These will be linked with the goals and objectives from the Center's four projects that are detailed in this Strategic Science Plan.

Manuscripts and reports are two of the most important outputs from the Center. Peer-reviewed journal submissions and publications are the most telling example of research productivity. The Center has most recently had a standard of one peer-reviewed manuscript submission (to a journal) for each researcher each year. The Center is increasing the expected output for GS-12 to GS-15 research scientists, and plans to phase in an averaged publication expectation that will increase the Center's productivity to a value of two submitted manuscripts per year. Timeliness of report submission will be tracked and quantified because this is an important measure of responsiveness to partner needs. Because the timeliness of a report's delivery is as important as the actual report, a metric that reflects this needs to be developed and will be implemented by 2007.

Presentations at professional society meetings, lectures, seminars, workshops, committee service, and technical meetings are an important outlet for the research and expertise of the Center. Involvement in this type of output needs to be quantified, but neither adequate baseline data nor a suitable metric has been identified to address this. The Center proposes to report the number of such events in which staff are involved and, over the next two years (goal 2007), establish a metric to measure progress and set appropriate performance goals.

Generalized Center accomplishments consist of outreach activities and various requests for information from the public and press. These are currently quantified from our Highlights for GPRA, and will also be summarized in the Center's planned annual research assessment. As part of this process, appropriate fact sheets on research items of interest will be developed and made available. Adequate baseline data can be determined from previous activity, but, because much of this activity is in response to requests, setting specific output goals may not be meaningful. The Center proposes to report the number of such events in which staff are involved

and, over the next two years (goal 2007), establish a metric to measure progress and set appropriate performance goals.

Professional maturity in the research staff is often reflected in membership and involvement in professional societies. For example, many staff members serve on important committees or occupy leadership positions with diverse professional organizations. Such involvements not only help the professional development of the individual scientist, but reflect on the quality of the Center's research environment. The Center has supported professional activities but has not previously monitored or assessed such activities. Neither adequate baseline data nor a suitable metric has been identified to address this. The Center proposes to report the number of such activities in which staff are involved and, over the next two years (goal 2007), establish a metric to measure progress and set appropriate performance goals.

The Research Grade Evaluation (RGE) process is used by USGS to evaluate the performance of individual research scientists every four years. Individual scientists can be promoted, retained in grade, or assigned to a lower grade based on the conclusions of these national panels. A measure of the success of the Center's research program is reflected in the results of these research performance evaluations and is currently quantified for regional reporting purposes. The Center plans to add the results of the RGE process to the annual assessment of its research program and to develop appropriate goals by 2006 based on past performance in the RGE process.

Outcomes

Outcomes are perhaps the most important of the Center's performance measures, but are difficult to quantify. The outcome goals will relate to the Center's Mission Statement: "To advance scientific knowledge and provide scientific information for restoring, enhancing, managing, and protecting the living resources and their habitats in the Great Lakes basin ecosystem." And, the outcome goals will relate to the Center's Vision Statement: "To become one of the keystone biological research institutions in the Great Lakes by conducting relevant, cutting-edge, basin-wide ecosystem research and disseminating critical scientific information that facilitates ecosystem management through interactions with our clients and partners."

Maintaining good relationships with partners and customers is the most important of the Center's outcomes. The Center and the Council of Lake Committees (CLC) have signed a Memorandum of Understanding between the CLC and USGS that mandates the development of an annual Memorandum of Agreement (MOA) between the CLC and the GLSC. The MOA defines several actions and outcomes performed annually by the Center's Deepwater Science program. Fulfilling the terms of this MOA and working with the Center's CLC partners to develop a new MOA each year provides an excellent vehicle for mutual exchange on expected outputs and outcomes. Some partner interactions are documented in the Center's Highlights, and are ultimately reported for GPRA purposes. However, the Center intends to document these interactions more fully to assist in determining a baseline from which annual and long-term goals can be developed. The Center plans to have the data in place by 2007 to allow development of these goal measures.

Implementation of the recommendations of the 2004 Strategic Science Review of the Center is a major priority. These recommendations include emphasis on the following key natural resource issues: deepwater stock assessment and monitoring; ecology of nearshore and coastal habitats and their linkage to deepwater biota; invasive species; biological informatics; and restoration of populations and systems. Several specific recommendations were made by the review panel and include: complete the GLSC Strategic Plan; maintain and expand partnerships and collaborative relations, and manage them strategically; review and update peer-review and approval policies and science management files; instigate and follow a comprehensive communications strategy; hire an administrative officer; develop a workforce and staffing plan that aligns with the Strategic Science Plan; adopt an organizational structure that is consistent with the Strategic Science Plan and effectively accommodates the geographic distribution of Center resources; improve internal communications through more frequent contacts and through development of a web-based intranet; ensure that effective Information Technology support is provided for all employees and make certain that wide-area connectivity is properly secure; build a comprehensive vessel management plan that is consistent with the Center Strategic Science Plan; and compile formal business cases for all proposed major facilities projects while pursuing, as top priority, a new Ann Arbor combined Federal facility. The details and timelines for satisfying these recommendations will be completed in 2005.

A substantial portion of the Center's budget is derived from competitive grants and contracts. The number and amount of such awards reflect positively on both the expertise and reputation of the Center's scientists and also on the perception that the Center can accomplish the research or product for which the award was granted. The Center has previously tabulated such awards for annual regional reporting, and proposes to report the extent of such activities over the next two years (goal 2007) to establish a metric that will measure progress and allow the Center to set appropriate performance goals.

Management of the Center's research program requires that a number of procedures be followed. These procedures are all documented and maintained by the Center, and a measure of the research success of the Center is reflected in the condition and availability of these documents. The documents vary from research protocols and administrative procedures, which are codified in specific Standard Operating Procedures (SOPs), to the Study Plans of the actual research projects. The SOPs are maintained on the Center's internal electronic bulletin board, while the Study Plans are filed in the Ann Arbor facility of the Center. Keeping both SOPs and Study Plans current and available is a priority and a goal of the Center. Similarly, USGS uses BASIS+ software for funds and research management to promote common business practices throughout the agency. Keeping the entries in BASIS+ up-to-date is vital for the Center because USGS Program managers use the system to retrieve data for key decisions in budgeting and program direction. The Center will keep the BASIS+ entries up-to-date. To maintain the high reputation that USGS science enjoys requires rigorous adherence to the agency's peer and policy review procedures and maintenance of necessary documentation. The Center is dedicated to producing the highest quality, peer-reviewed science that meets the highest expectations. The Center has not previously monitored or assessed such activities except on an occasional basis, and neither adequate baseline data nor a suitable metric has been identified to address this. The Center proposes to report the status of such activities in its assessments over the next two years (goal

2007) to establish a baseline from which to measure progress and set appropriate performance goals.

The following table provides a visualization of the various outputs and outcomes that the Center will assess annually. For many, the Center does not currently have sufficient information to set annual performance goals, but will strive to do so by 2007. Progress in achieving the goals will be reported annually.

Annual Goals

Outputs	**2005**	**2006**	**2007**	**2008**	**2009**
Manuscripts	1/researcher	1.25/researcher	1.5/researcher	1.75/researcher	2/researcher
Reports	Develop metric	Develop metric	Set goals based on metric	Meet goals	Meet goals
Presentations etc.	Develop metric	Develop metric	Set goals based on metric	Meet goals	Meet goals
Accomplishments	Develop metric	Develop metric	Set goals based on metric	Meet goals	Meet goals
Professional Involvement	Develop metric	Develop metric	Set goals based on metric	Meet goals	Meet goals
Outcomes					
Strategic Science Review Recommendations	Implementation Plan	Set goals	Meet goals	Meet goals	Meet goals
Consultations	Develop metric	Develop metric	Set goals based on metric	Meet goals	Meet goals
RGE	Develop metric	Set goals based on metric	Meet goals	Meet goals	Meet goals
Grants	Develop metric	Develop metric	Set goals based on metric	Meet goals	Meet goals
Documentation	Develop metric	Develop metric	Set goals based on metric	Meet goals	Meet goals

Appendix

The U.S. Geological Survey Strategic Plan – 1999 to 2009

Vision

USGS is a world leader in the natural sciences through our scientific excellence and responsiveness to society's needs.

Mission

The USGS serves the Nation by providing reliable scientific information to:

- describe and understand the Earth;
- minimize loss of life and property from natural disasters;
- manage water, biological, energy, and mineral resources; and
- enhance and protect our quality of life.

Strategic Direction

Combine and enhance USGS' diverse programs, capabilities, and talents and increase customer involvement to strengthen our scientific leadership and contribution to the resolution of complex issues.

Customer

Customer Strategic Goal

Optimize service to our customers (users of our information) and broaden customer base with timely, innovative products and effective interactions as outlined in our mission.

Thrusts:

- *Increase integrated assessments*
- *Create robust decision support systems*
- *Increase customized products/services*
- *Expand data integration and develop predictive models*
- *Enhance the mutually beneficial relationship between USGS and our customers/partners*
- *Increase the continuity and reliability of long-term national data sets.*

Customer Long-Term Goals

- Measurement Framework
  Understand the USGS customer base, their needs, and their interactions with our programs.

- Products and Services
  Develop new products and services that are responsive to and reflect internal and external customer needs.

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

- Internal Communications
  Clearly communicate to targeted audiences consistent messages about our programs, capabilities, and relevance to society's needs.

Program

Program Strategic Goal

Provide science for a changing world in response to present and anticipated needs.

Thrusts:

- *Focus efforts to predict and monitor hazardous events in near-time and real-time and to conduct risk assessments to mitigate losses*
- *Strategically position the USGS as the provider of choice for assessments of real and anticipated changes in the environment and resources*
- *Expand our understanding of environmental and natural resource issues through integrated science on regional, national, and global scales*
- *Optimize the mix among the science activities (long-term data collection and monitoring, research and development, assessments, and applications) to target increases in the customer base*
- *Enhance predictive/forecast modeling capabilities.*

Program Long-Term Goals

- Hazards
  Ensure the continued transfer of data, risk assessments, and disaster scenarios needed by our customers before, during, and after natural disasters, and increase the delivery of real-time hazard information to minimize loss of life and property.

- Environment and Natural Resources
  Maintain, provide and improve long-term environmental and natural resources information, systematic analyses and investigations, and predictive tools for scenario building and decision making about natural systems.

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

People

People Strategic Goal

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

Thrusts:

- *Align reward system with Vision, Mission, and Strategic Direction*
- *Generate and sustain the value of leadership and teamwork at all levels in the USGS*
- *Increase flexibility to get work done by using all options other than permanent staff*
- *Continue to attract and maintain highly innovative, diverse, and skilled workforce.*

People Long-Term Goals

- Skills
  Enhance science and technical skills of the USGS workforce.

- Reward System
  Reinforce strategic direction through reward system.

- Flexibility
  Achieve human resources flexibility to meet changing needs.

- Leadership
  Foster visionary leadership and management professionalism.

Operations

Operations Strategic Goal

Continuously improve our infrastructure and operational process and practices to efficiently and effectively support our people, programs, and customers.

Thrusts:

- *Save resources through efficiency of processes and practices throughout the bureau*
- *Ensure effective distribution of employees and facilities*
- *Define important technological problems/issues and application opportunities in conjunction with others*
- *Increase opportunities to work with partners*
- *Build a Bureau-wide information infrastructure*
- *Establish a Bureau-wide communication strategy*
- *Achieve measurable improvements in quality.*

Operations Long-Term Goals

- Information Infrastructure
  Ensure efficient data integration and access to satisfy both internal and external customers.

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

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

- Communication
  Use new technologies and practices to effectively communicate information about bureau science and operational activities, policies, and expectations to all USGS employees.

USGS RESEARCH PROGRAMS FUNDING GLSC

USGS provides internal funding for science operations through its Programs. The Programs allow USGS to organize the funding and research results on a nationwide basis. USGS Program Coordinators consolidate budget needs and products for the USGS Associate Director for Biology to respond to queries from Congress and the Office of Management and Budget, among others. The various Programs are not directly related to any other structure in USGS or in the Center. The GLSC receives funding from six of the USGS Programs: Status and Trends of Biological Resources; Fisheries: Aquatic and Endangered Resources; Terrestrial, Freshwater, and Marine Ecosystems; Invasive Species; Contaminants; and Biological Informatics. The text that is quoted in the following sections about each Program is taken from the USGS/BRD website http://biology.usgs.gov/pub_aff/usgsbio.html that describes each Program.

STATUS AND TRENDS OF BIOLOGICAL RESOURCES PROGRAM

The goals of the Status and Trends of Biological Resources Program are: "(1) 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 the Nations plants, animals, and ecosystems; (2) develop and evaluate inventory and monitoring methods, protocols, experimental designs, analytic tools, models, and technologies to measure biological status and trends; (3) 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; and (4) produce and provide analyses and reports that synthesize information on the status and trends of our Nations flora, fauna, and ecosystems and are responsive to the needs of the scientific community, land and resource managers, policy makers, and the public." The GLSC maintains continuous, long-term surveys of the fish communities in each of the Great Lakes. Fish community structure has changed substantially in the Great Lakes since the Center was established. During the late 1960's and 1970's, piscivores, including top predators such as the lake trout, were nearly extirpated by sea lamprey predation. The fish community was dominated by two non-Great Lakes invaders (alewife and rainbow smelt) that had reached nuisance levels of abundance. Fishery managers alleviated these conditions by controlling sea lampreys and stocking both Pacific salmonids and native predators such as lake trout and walleye. This rehabilitated the Great Lakes ecosystem but created a novel fish community in which stocked predators preyed on non-native forage fishes. By the 1980s, predator rehabilitation was so successful that prey shortages occurred. The situation was complicated by increases in predator recruitment that further exacerbated prey shortages, by changes in prey fish dynamics and system-wide changes in food webs that resulted from new invasives such as zebra mussels. Many of these changes were documented through GLSC annual bottom trawl surveys in all five Great Lakes.

Today, the Program works closely with the resource management community to provide scientifically sound approaches to measuring, assessing, and reporting the status and trends of the Great Lakes fishery. Each Great Lake has a unique fish community and the GLSC surveys many fish populations in each lake. Trawl surveys assess health of both predator and prey species, although much of the Center's work is focused on prey fish 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 is only determined through long-term surveillance. We provide critical information and methods to support fisheries management agencies and their stakeholders. Within the USGS, the GLSC is the lead Center 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 and the factors affecting changes in communities and populations. This work leads to development of methods to assess status and trends for the full range of Great Lakes region taxa of interest to DOI and its clients.

FISHERIES: AQUATIC AND ENDANGERED RESOURCES PROGRAM

This Program has six goals to: "(1) provide scientific information about the diversity, life history and species interactions that affect the condition and dynamics of aquatic communities; (2) provide scientific information about factors and processes that affect aquatic organism health in support of survival, protection, conservation and recovery; (3) quantify and describe functional relationships among aquatic species and habitats to provide information to conserve or restore aquatic community structure and function; (4) provide science support for natural resource managers by investigating the factors that contribute to the conservation and recovery of aquatic species at risk; (5) develop research and technology tools to provide the scientific basis for developing adaptive management strategies and evaluating their effectiveness for restoration efforts to sustain aquatic resources; (6) and provide research support and technical assistance to DOI bureaus, other Federal and State government agencies, Tribes, and non-governmental groups to support natural resource management problem solving and decision making."

The research funded by this Program at the GLSC is focused on the study of fishes, fisheries, aquatic invertebrates, and their aquatic or water-dependent habitats. The Center's historic databases include long-term data on a variety of species and habitats in addition to its continuous series on the offshore forage fish species. Species in decline or threatened by extinction, are of special research interest, as is study of factors affecting population growth and recruitment to key aquatic habitats. Investigations determine the physiological, behavioral, and genetic responses of aquatic biota 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. Predictive models of population and community interactions help forecast species abundance and elucidate predator-prey and habitat relationships. The objectives of the research at the Program level are: (1) to conduct field and laboratory investigations on the biology of fish and invertebrates in the Great Lakes watershed to delineate environmental tolerances of these taxa; (2) to conduct field and laboratory investigations on the ecology of fish and invertebrates in the Great Lakes watershed to understand better niche requirements and interactions with other species in their biotic communities; and (3) 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.

TERRESTRIAL, FRESHWATER, AND MARINE ECOSYSTEMS PROGRAM

"Studies conducted by the USGS Terrestrial, Freshwater, and Marine Ecosystems Program focus on understanding the factors which control ecosystem structure, function, and condition. Investigations evaluate the consequences of short and long-term environmental changes, including how human activities modify ecosystems, and predict how modified ecosystems can be restored and managed. Information from Ecosystem research guides the design and evaluation of scientifically based strategies to manage and restore ecosystems and landscapes." The Program's goals are: "(1) quantify and understand factors influencing patterns of temporal and spatial variability in key ecosystem components; (2) model factors controlling ecosystem patterns at various scales and develop decision support systems which integrate this information with management options; (3) develop indexes of ecosystem sensitivity to change and vulnerability to potential stressors, and tools to predict ecosystem responses to environmental change; (4) devise a restoration and adaptive management framework for impaired ecosystems; and (5) identify research areas representative of U.S. ecosystems and initiate a research reference site network."

Interdisciplinary research on coastal ecosystems of the Great Lakes brings together investigations of geology, hydrology, and biology. One integrative study examines the role of ground-water input or withdrawal on nearshore invertebrate and fish communities. Other investigations quantify the relationships between Great Lakes water levels and wetland structure and function, as well as the role of ground water in wetland response to climate change. Chronosequences of beach ridge sites have been established by Center scientists that serve as model systems for evaluating potential effects of climate change in the Great Lakes basin. Insights from these studies are applied to developing and evaluating restoration and management strategies for USFWS refuge wetlands and developing new water-level regulation plans for Lake Ontario. Water availability for domestic, industrial, and agricultural uses is an issue increasingly considered and addressed by state and national legislatures in the region. These legislatures are now requesting information on the effects of water withdrawals on terrestrial biota. GLSC scientists are generating such information.

Public lands and aquatic ecology researchers emphasize priority topics in support of National Park and National Wildlife Refuge management in the Great Lakes coastal zone. Studies of the developmental history of coastal dune ecosystems are central to conservation and restoration of an ecosystem that is highly susceptible to degradation associated with increasing human use. Savannas were historically a dominant terrestrial ecosystem with the coastal zone but are today rare. Investigations of the relationships among fire regimes, woody vegetation structure, and the

plant and animal communities found in restored and degraded savannas aid land managers in determining the feasibility of savanna restoration and in setting long-term landscape restoration goals. Evaluation, by GLSC researchers, of the scope of non-native plant invasions in Great Lakes National Parks is the first step in control of a large and increasing source of habitat degradation.

Several studies focused on watersheds, tributaries, and nearshore areas of the Great Lakes are improving our understanding of the relationships between environmental conditions and both fish communities and populations. Results include predictive models that will provide managers with valuable tools to plan the most effective use of their resources to achieve their goals. 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 restoration of burrowing mayfly populations in the corridor.

INVASIVE SPECIES PROGRAM

"USGS plays an important role in Federal efforts to combat invasive species in natural and semi-natural areas through (1) Early detection and assessment of newly established invaders. (2) Monitoring of invading populations. (3) Improving understanding of the ecology of invaders and factors in the resistance of habitats to invasion. (4) Development and testing of prevention, management and control methods." The Program's goals are: "(1) provide and coordinate the collection, synthesis, and accessibility of invasive species information (Information Management Goal); (2) identify and report new invasions and assess risks to natural areas and waters (Early Detection & Rapid Assessment Goal); (3) assess changes in populations and distributions of established invaders (Monitoring and Forecasting Goal); (4) provide approaches to contain, reduce, and eliminate populations of invasive species and restore habitats and native species (Control and Management Goal); (5) conduct research and develop methods and technologies to prevent the introduction of invasive species (Prevention Goal); and (6) determine effects of invasive species and susceptibility of habitats to invasions (Effects Goal)."

The GLSC 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, hundreds of exotic algae, fish, invertebrates, and various plant invaders have become established in the Great Lakes basin. 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 Great Lakes waterways 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 water intake and treatment facilities.

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. Zebra mussels, for example, were first introduced into the Great Lakes around 1986. In fewer than ten years, zebra mussels, and the related quagga mussel, spread throughout the Great Lakes and into many small inland lakes and rivers in most of the states bordering the Great Lakes. They have since moved into the Mississippi River, down to New Orleans. A second exotic species, the round goby, is poised to repeat this invasion pattern, and others, the black, silver, and bighead carp, are poised to move from the Mississippi River and its tributaries into the Great Lakes.

The Center's current invasive species research varies by species and distributional pattern of the invasion. Much of this research focuses 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. Distribution and density of specific invasives are tracked in certain areas, including studies on ruffe population dynamics in Lake Superior, round goby in northern Lake Michigan, and zebra mussels in northern Lake Huron, as well as non-native plants in National Lakeshores in the western Great Lakes. Other studies focus on ecosystem impact, for example in Lake Ontario, where zebra and quagga mussels have altered ecosystem function to such an extent that key native species, such as *Mysis* shrimp and the amphipod *Diporeia,* are in decline.

CONTAMINANT BIOLOGY PROGRAM

"The USGS Contaminant Biology Program investigates the effects and exposure of environmental contaminants to the Nation's living resources, particularly those under the stewardship of the Department of the Interior." The Program's goals are: "(1) Toxicology and Chemistry - develop methods and generate information to determine sources, fate, exposure and effects of environmental contaminants. Develop and standardize biomarkers, molecular biology methods and other analytical and toxicological assays; (2) Contaminated Habitats - develop the scientific basis for assessment, restoration and monitoring of habitats that are contaminated by mining, agriculture, urban wastewater, industry, and chemical control agents. Develop toxicological criteria to remediate or prevent contaminant effects; and (3) Integration of Ecological Stressors - improve the scientific basis for evaluating the effects of multiple stressors at all levels of biological organization and at multiple temporal or spatial scales."

Chemical stressors affect fish and other biota in the Great Lakes on many levels. Monitoring chemical stressor levels and assessing the effects of these chemicals on fisheries is a priority research need of the U. S. Fish and Wildlife Service, the U. S. Environmental Protection Agency, Great Lakes basin states, the province of Ontario, and numerous 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 this ecosystem particularly susceptible to chemical stressors. The Great Lakes Contaminant Monitoring Program, dating from the 1960s, has long provided good science and needed information to the Great Lakes basin community by monitoring chemical residues, estimating chemical properties, and developing software that predicts contaminant behavior, fate, transport, and hazard. Emphasis within the USGS Contaminant Biology Program at the GLSC has shifted recently from monitoring chemical residues within individual trophic levels to understanding the ramifications of contaminants within food webs, specifically understanding patterns of how chemical stressors are transferred among trophic levels. These stressors include traditional contaminants, emerging issue contaminants, and dietary components, such as thiaminase (that may lead to Early Mortality Syndrome in salmonids). Because food webs change along with population dynamics, dietary components that were once normal and unremarkable within a food web may become a stressor as food sources change. The long-term goal of our work in support of the Contaminant Biology Program is to provide the capability for hazard and impact assessment of thousands of observed and potential chemical stressors found in biota, sediment, and water on trophic transfer processes of the Great Lakes food webs.

Center scientists are leaders in understanding the sources of bacterial contamination of recreational waters in the Great Lakes basin and in developing and evaluating new monitoring technologies and sampling procedures for bacterial contamination. All swimming beaches on the Great Lakes are encouraged to monitor *E. coli*, according to the BEACH Act of 2000. Recently, GLSC researchers have shown that *E. coli* may be more widespread than previously suspected and may occur naturally in some environments. To improve public advisories, GLSC investigators are developing models that use water and air conditions to predict, at regional and local scales in the Great Lakes, when beaches are most likely to be safe for swimming.

BIOLOGICAL INFORMATICS PROGRAM

“Decisions concerning the stewardship of the Nation's natural resources require reliable, relevant, and timely information.” The Program’s goals are: “(1) identify and prioritize the content required to inform the interests of our customers and provide access to the high priority content; (2) develop, integrate, and apply tools that maximize the efficiency and effectiveness of user interactions with biological data and information; (3) develop and implement the infrastructure to support biological data content availability and use; (4) advance a biodiversity and ecosystem informatics research agenda to support the discovery and application of biological data and information; (5) develop and implement a multi-level user care program that will expand the customer base and anticipate and satisfy user needs; and (6) improve Program management by better coordinating the efforts of Program components and increasing communication among existing and potential participants and partners.”

GLSC staff applies innovative technologies and practices to the management of biological data, information, and knowledge, thereby increasing its value to the internal and external customers of the GLSC. The DOI standard for databases is Oracle and GLSC has a long-term goal to convert all current databases to properly documented databases to the DOI standard platform.

Several large Oracle databases are currently maintained at GLSC including substantial data that were collected by partner agencies:

The Research Vessel Catch System (RVCAT): contains fish sampling data from 1954 - present. This database holds all biological data collected on the large vessels operating in the five Great Lakes and is the central data resource of the Deepwater Science Project.

Great Lakes Aquatic GAP: The GLSC is constructing and housing the central database of this project. This is a five-year interagency project and is part of the National Biological Information Infrastructure (NBII).

Genetics: The GLSC Laboratory of Molecular Ecology generates data on the genetics of Great Lakes fish stocks and is in the process of implementing an Oracle database to contain biological and genetic data.

Commercial Catch (COMCAT): Daily fishing records of U.S. waters of the Great Lakes. Data from 1971 to present are served on the GLSC and NMFS web sites.

Coded Wire Tag: Database housed in Ann Arbor contains the history of captured Coded Wire Tag lake trout from Lake Huron. Contributors include the Ontario Ministry of Natural Resources, GLSC, Michigan Department of Environmental Quality, U.S. Fish and Wildlife Service, and the Chippewa-Ottawa Resource Authority (CORA).

Lake Erie Environmental Investigations: Contains data from a study of Lake Erie tributaries from the 1980s and 90s that demonstrate linkage between sediment contaminants and fish health, fish communities, and invertebrate communities.

Lake Erie Nearshore: Contains general ecological data from 2000-2002. Includes larval and juvenile fish, benthic invertebrates, zooplankton, and limnological parameters using three different sampling designs.

Contaminant Chemistry: Contains fish tissue archive and organic pesticide and PCB results since the early 70s. Also contains contaminant sediment data.

Interagency Cisco Database: Small mesh gillnet captures of cisco (chubs) from Lake Superior, contributed by the Minnesota Department of Natural Resources, Wisconsin Department of Natural Resources, Michigan Department of Natural Resources, Keweenaw Bay & Redcliff tribes, CORA, USGS.

Interagency Predator Prey Database: Lake Superior returns of several predator species contributed by all agencies in Cisco database plus OMNR.

Card Image Data: Various collections of benthic invertebrates, *Hexagenia*, macrophytes from the 1960s - 1980s.

GIS: Site specific data sets including Metzger Marsh, Lake Erie; maps of spawning habitats in the Great Lakes. GIS maps of terrestrial wetlands and aquatic habitats at Indiana Dunes National Lakeshore.

The National Biological Information Infrastructure (NBII) is a portal into the nation's biological information. The GLSC participates directly and indirectly in the NBII. Direct involvement includes participation in the Great Lakes Aquatic GAP regional project. Indirect involvement includes most of the science conducted at the Center. During the next five years, the GLSC will be exploring ways to become more directly involved in the NBII. Specifically, the Center will improve its participation in the production and posting of metadata. The Center will improve the timeliness of distribution of GLSC research findings on invasive species through methods such

as the development of topic-targeted web pages. The Center will also be the host of the NBII Great Lakes node.

INTEGRATION OF GLSC SCIENCE ACROSS USGS PROGRAMS

While particular studies are classified under a single Program, their objectives and the utility of their findings often contribute to information needed to achieve the goals of other programs. GLSC's research investigations are designed to enhance this integration, while addressing the most important needs of our customers.