GIS APPLICATION FOR FISHERIES AND COASTAL RESOURCES MANAGEMENT

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PREFACE

The Gulf States Marine Fisheries Commission (GSMFC) is a compact of the five states bordering the Gulf of Mexico, including Texas, Louisiana, Mississippi, Alabama, and Florida (west coast only). The GSMFC was authorized in 1949 through individual state enabling legislation and through passage of Public Law 81-66 of the U.S. Congress. In that legislation, the stated purpose of the GSMFC is "to promote better utilization of the fisheries, marine, shell, and anadromous, of the seaboard of the Gulf of Mexico, by the development of a joint program for the promotion and protection of such fisheries and the prevention of the physical waste of the fisheries from any cause."[1]

The GSMFC is composed of three members from each of the five Gulf States. One is the head of the fishery resource agency of the state, who serves concurrently with his/her term in office. The second is a member of each state legislature. The third is a citizen of each state, appointed by their respective governor, who has a knowledge of and interest in marine fisheries. Under this fifteen member board of commissioners, there are a variety of standing committees and technical subcommittees, generally comprised of state and federal agency scientists, policy makers, and administrators. Fishery management programs for research, data, policy and administrative issues are addressed by the appropriate committees or subcommittees, who provide the commissioners with recommendations for action.

Through participation in the GSMFC, member states relinquish none of their rights or responsibilities to regulate their own fisheries. The GSMFC is given power to recommend actions to the governors and legislatures of the states on programs helpful to the management of interjurisdictional fisheries. The basis for such recommendations comes from studies made by experts employed by the states and by the United States agency with marine fisheries responsibility, which is the National Marine Fisheries Service. The GSMFC is also authorized to consult with and advise the proper administrative agencies of the member states regarding fishery conservation problems. In addition, the GSMFC advises and testifies before the U.S. Congress on legislation and marine policies that affect the Gulf States. One of the most important functions of the GSMFC is to serve as a forum for the discussion of various problems and programs of marine fisheries management, recreational and commercial industry activities, research etc., and to develop a coordinated Gulf policy to address those issues for the betterment of the resource and all who are concerned.

The collection, management, and use of fisheries data is one of the most significant areas of interest to all state and federal fisheries management agencies. As such, data issues are of vital interest to the GSMFC. In 1981, the GSMFC began coordination of the Southeast Area Monitoring and Assessment Program (SEAMAP). SEAMAP is a state-federal-university program for the collection, management, and dissemination of fishery independent data. In 1988, the GSMFC began an initiative to establish a coordinated data program for recreational fisheries. By 1993, a Southeast Regional program was initiated known as the Recreational Fisheries Information Network

1. Quoted from legislation.

[RedFIN(SE)], which involves twelve state and federal fishery management agencies. It is expected that the Commercial Fisheries Information Network (ComFIN) will be implemented in 1995, rounding out GSMFC regional coordination of fisheries data programs. As evidenced by this document, developments in Geographic Information Systems (GIS) technology can and should be applied to meeting practical fisheries management challenges now and into the future. The GSMFC is proud to have sponsored the GIS Symposium, and extends much gratitude for the participation of the various presentors, who gave their time and talents to make it a success. Please use and enjoy this mental journey into the world of GIS.

SUMMARY

Geographic Information Systems (GIS) technology is revolutionizing geographic analysis and has applications in many scientific fields. GIS is shown to be primarily comprised of a data base management system and spatial analytical software. The ability to integrate information is the main strength of GIS. The present symposium covers GIS applications for fisheries using both high-end workstations and low-end microcomputer-based systems. Several GIS-related systems are described from the full function GIS used in mapping and data base management to more function-specific desktop spatial data analysis systems (SDAS), and program-oriented spatial decision support systems (SDSS). With distributed computing, the data base may reside over a series of servers within an organization or between agencies. The work-flow within an agency can benefit by sharing spatial information over networks.

GIS analyses can be used to optimize sampling, explain the spatial distributions of marine fisheries species and/or communities, and to assist with decision-making. Models tied to GIS data bases can be used for ecological impact assessment pertaining to the effects of fishing, point and non-point source pollution, oil spills, other perturbations, and natural catastrophies on fisheries resources. GIS are being used to evaluate the biogeographic distributions of the marine biota from the perspective of the biological, physical, economic, and social factors that impact marine ecosystems. Man's influence with fisheries needs to be separated from environmental and habitat related factors.

High-end GIS are now being developed that can be used in a systems framework to support establishing quantitative sampling of habitats, stock assessments, fisheries oceanography, spatial decision-making, and fisheries management. The future use of GIS tied to models and SDSS is envisioned to be more focused on maintaining biodiversity, balance, and long-term productivity of marine natural resources. The information in GIS data bases, maintained by various levels of government, universities, and the private sector can be shared over networks to promote consensus building in support of stewardship of marine natural resources and ecosystem management.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

The Data Management Subcommittee's Role In Sponsoring The Symposium

Henry G. "Skip" Lazauski

Chairman, Data Management Subcommittee
Gulf States Marine Fisheries Commission

The Data Management Subcommittee (DMSC) reports to the Technical Coordinating Committee (TCC) of the Gulf States Marine Fisheries Commission (GSMFC). Its mission is to provide for the planning and coordination of fishery data collection, processing, analyses, and other data issues and activities among the five Gulf States and the federal government. In response to changing management demands in the Gulf of Mexico which require analyses on widely different types of data, from many sources, from both a local and regional perspective, the DMSC resolved to explore how fisheries science in the Gulf was utilizing Geographic Information Systems (GIS).

This decision resulted in a symposium that was held in Palm Beach, Florida on March 18, 1993. The symposium drew in fishery researchers using GIS from the Gulf Coast, other coastal states, and Canada. These papers addressed topics which included the basics on GIS (What is it?), species specific applications of GIS (How to use it) and the future of GIS as an analysis tool in fishery science (Where it is going and what you need to do about it).

These papers point the way to a future of interconnected information that is already upon us. With increasing demands for more complex and broad ranging analyses, less time to do it in and less money to do it with, GIS offers hope that these tasks can be accomplished. Ecosystem analysis looms on the horizon and it will require more than the traditional fishery information. Data on land management practices, habitat in the entire watershed, trends in urban and rural development, regional climatic variations, and a host of other types of information will need to be incorporated.

Once the need and utility of GIS is embraced as a concept; the twin demons of compatibility and standardization will appear. Standards for hardware, software and data formats will be required before an interconnected reality of ecosystem wide information is possible. Compatibility with existing GIS data bases will need to be closely considered. Coordination of region wide GIS development is imperative. Without this coordinating function required data might not get into the system, data could be entered in non-compatible formats, essential data might not be collected at all and researchers might not be made aware of existing data sets.

If this brief statement has stimulated an interest, then you should find the rest of this publication fascinating. In addition to this symposium, there are a few primers that you might find enlightening to read on marine resource mapping (Butler et al. 1987), remote sensing (Butler et al. 1988) and geographic information systems and remote sensing (Meaden and Kapetsky 1991) in relation to fisheries.

The Data Management Subcommittee hopes that you find this publication useful in your fisheries work in the Gulf of Mexico, or anywhere people seek to better understand the marine environment. If you have any comments on this publication please direct them to me through the Gulf States Marine Fisheries Commission.

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Uses of the Marine Resources Geographic Information System (MRGIS) For Coastal Resource Research and Management In Florida

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The Division of Marine Resources has been developing a Marine Resources Geographic Information System (MRGIS) as a primary tool for marine research and management. The primary MRGIS goals are to: 1) develop a quality management and research database for GIS analyses; 2) interact with managers and researchers to assess the potential for GIS to facilitate spatial data needs; 3) develop new GIS applications relative to marine resources; 4) facilitate an ecosystem approach to coastal resource management; 5) provide MRGIS data to government agencies and the public to further promote informed decision-making on coastal matters; 6) develop the MRGIS as a component to a Departmental and State network of spatial data systems; and 7) become the primary source of synthesized marine resources information in the State.

The Coastal and Marine Resource Assessment (CAMRA) Program at the Florida Marine Research Institute (FMRI) has been responsible for the development of GIS capabilities within the Division through the MRGIS. However, significant MRGIS activities are also being instituted in the Office of Protected Species and the Bureau of Sanctuaries and Research Reserves.

The MRGIS Background

The MRGIS initially was developed in 1981 with a Coastal Zone Management (CZM) grant as a raster-based image processing system using LANDSAT Thematic Mapper data and aerial photography to map estuarine and marine fisheries habitat (Haddad and Carter 1979, Steidinger and Haddad 1981, Haddad 1982, Harris et al. 1983, Durako et al. 1985, Haddad 1985, Haddad and Harris 1985a&b, Jones et al. 1985, Haddad 1986, Haddad and Harris 1986, Haddad and Hoffman 1986, Durako et al. 1987, Durako et al. 1988, Haddad 1989, Carder et al. 1991, Orth et al. 1991, Haddad 1992a&b, Friel and Haddad 1992, Durako et al. 1992, Klemas et al. 1993, Friel et al. 1995, Leary and McGarry MacAulay 1995a&b, Leary et al. 1995, Leary and Sargent 1995, Murphy et al. 1995, Sargent et al. 1995, Zieman et al. 1995). The success of the MRGIS implementation strategy was recently recognized with an award from the JFK School of Government, Innovations Award Program and the Ford Foundation. CAMRA's staff reflects the complexity and diversity of marine resources issues. The core staff of 23 includes experts in marine biology, geography, marine geology, cartography, environmental planning, petroleum exploration, aerial photograph interpretation, coastal management, GIS, and remote sensing. In addition, the CAMRA staff taps

1. Symposium speaker

the collective expertise of over 200 scientists at the Florida Marine Research Institute.

The system consists of a collection of complementary technologies for data input, analysis, storage, and output tied together by a server and a local area network (Haddad and Harris 1986, Haddad and Michner 1991, Michner and Haddad 1992a,b). GPS units, digitizing tablets, and tape drives input to Sun workstations and PCs that run ARC/INFO, ERDAS, and Oracle software. Apple Macintosh systems are being tested as management oriented tools to access pre-synthesized GIS data summaries. Output hardware includes a variety of printers and large-format pen and electrostatic plotters. Data storage, back-up, and archiving are accomplished with a variety of devices ranging from tape cartidges to a 28-gigabyte optical jukebox.

The CAMRA Approach - Mapping the Coastal Zone

The mandate of CAMRA is extremely broad and includes the entire State of Florida. Although many resource issues in the coastal zone could be addressed using a GIS, data for marine environments are relatively scarce. The availability of spatial data in the United States reflects our country's preoccupation with land-based mapping. The ubiquitous United States Geological Survey (USGS) quadrangle map series, which forms the basis of data base development efforts at many GIS installations, is simply not available for offshore areas. GIS specialists charged with analyzing marine resources must face the fact that their study area begins where most existing map products end. Land-based features are emphasized on the quads. However, coasts are the dynamic junction of land and water. National Oceanic and Atmospheric Administration (NOAA) nautical charts are the only comprehensive United States map survey that depicts marine features from the shoreline seaward with an acceptable level of accuracy.

Information on the NOAA nautical charts forms the functional basis for coastal zone and marine resource GIS applications. Critical features include shoreline, cultural and navigationally important landmarks, critical soundings and depth curves, shoals, wrecks, obstructions, boundaries of regulated areas, and fixed and floating aids to navigation. When the charts are converted to vector files, these features become available for sophisticated spatial queries in the GIS. When the charts are scanned into raster files, they can be used as a visual backdrop to add value and relevance to the project-specific data under investigation. Together, the two map representations form a powerful data base for managing the coastal zone. Therefore, staff efforts have been mainly focused on the development and integration of critical data bases for Florida's coastal areas.

CAMRA uses data bases at a variety of scales. A target scale of 1:24,000 is a goal. However, depending on the data theme, actual scales range from 1:10,000 to 1:40,000. Great care is taken when integrating data bases of varying scales for analyses. Though CAMRA has a strong bias toward making data available immediately, with the best quality and accuracy possible, it continually augments or replaces less precise data to assure the highest standards needed for GIS analysis. For example, a data base of benthic resources (e.g. coral, seagrass, bottom type) is critical for managing the Florida Keys. CAMRA staff automated the only available benthic resource data base by digitizing and merging three existing map series of varying scales and classification schemes. This data base proved valuable for a variety of mapping projects, but has shortcomings.

To replace the data base, the Florida Department of Environmental Protection (FDEP) and NOAA conducted a state-of-the-art mapping effort using GPS-controlled aerial photos and analytical stereoplotters. The data base, completed in 1996 at a cost of more than $500,000, will be the long-term information base for managing marine resources in the Florida Keys National Marine Sanctuary (Miller 1995). By developing quality GIS data bases of fundamental data themes, CAMRA is preparing to perform the more sophisticated analyses required for managing the area.

Every effort is made to develop multi-agency partnerships with state, federal, and local government agencies in addition to private sector and non-profit organizations to share GIS database development costs. GIS coordination at the "executive" level of these organizations translates into focused data collection efforts, cooperative data base development arrangements, and data exchange. Discussed below, you will find a brief description of some data bases that have been developed or assembled by the CAMRA group at the FMRI. The Marine Mammals Section of the Institute also maintains ARC/INFO databases of manatee migration, mortality, and distribution. Not all data bases have been completed for the entire state, however, that is the long-term goal. CAMRA is actively pursuing working agreements with local and regional agencies to verify or augment existing data bases and develop additional data bases. Therefore, the data bases are only a sample of the entire MRGIS holdings.

Using the Technology Effectively

The philosophy of making data available rapidly fills a critical need in marine resource management. More than 500 requests for information were filled by CAMRA last year. The products delivered include maps, tabular output, images, prints, digital data in a variety of media, and articles related to GIS and marine resource management authored by CAMRA staff. Providing simple GIS output often leads to more sophisticated requests and ultimately to new strategic alliances, data base development arrangements, and analytical projects for CAMRA.

Most simple requests for information can be satisfied with a Resource Impact Map (RIM). Managers statewide use the RIM series of eight chart-sized maps in making resource decisions. Each map includes a section of Florida's shoreline and critical marine structural habitats that support ecosystem integrity. These communities are the equivalent of terrestrial land cover and include mangroves, saltmarshes, seagrasses, oyster reefs, coral reefs, hard bottom, and bare bottom. Bathymetry (or bottom depth) also is shown. Bathymetry is the equivalent to terrestrial elevation, and is an important controlling factor for human and marine resources. In addition, channels and navigation aides such as markers and buoys are displayed to help users orient themselves, much like road networks on land-based maps. The combination of features on the RIM is not available on any other map series, hence their popularity. Once users become familiar with RIM, they usually inquire about additional system capabilities, leading to more sophisticated analyses and derivative products from the basic RIM databases.

The following examples provide a small but representative sample of the GIS support that CAMRA provides to coastal decision-makers, while fullfilling its long-term goal of data base development and management, and research-oriented analysis. The examples center on using GIS to address resource damage, and illustrate how the MRGIS is used to minimize damage before it happens, monitor long-term damage, and assess catastrophic damage after the fact.

Site Selection For Testing of Explosives

The U.S. Navy is considering a variety of offshore sites in the United States to set off underwater explosions to gather test data for mine-clearing in the Persian Gulf. One area under consideration is off of Key West, Florida, due to the proximity of Boca Chica Naval Air Station. An environmental impact assessment is conducted before any explosive testing takes place, and the Navy hired Water and Air Research, Inc. to conduct phase one of the assessment. The Governor's Office asked CAMRA staff to use the MRGIS for preliminary analysis of the Navy's proposal. A preliminary set of site-selection criteria was compiled based on the assumption that site-specific investigations would be mandatory after initial screening. It was recommended that potential sites be: 1) within a 60 nautical mile radius of Key West; 2) in water approximately 25 feet deep; 3) outside the Florida Keys National Marine Sanctuary (FKNMS); 4) outside the jurisdictional boundary of the State of Florida; 5) in areas with non-critical benthic resources (e.g., sand bottom); and 6) a significant distance from cultural resources (shipwrecks).

The appropriate data bases were compiled, and in the first round of analysis, plots were generated with vast areas of complex benthic resources shown on the 60 NM radius, resulting in information overload. To reduce visual "clutter" and to focus analysts' attention on waters 25' deep, a "depth corridor" analysis was conducted by creating a polygon of the 18' and 30' depth arcs. The polygon was used as a "cookie-cutter" to extract just the resource information that was contained in the depth range of 25 feet. Several different versions of the maps were created for the Navy contractor, from which they selected a rectangular study area for further review and ultimately identified 25 candidate test sites. If explosive testing is eventually conducted near Key West, the MRGIS analyses will have provided information of areas in which mimimum resource impact could be expected.

Marine Mammal Research

The manatee is one of the most endangered marine mammals in the United States. There were 2,639 manatees enumerated in Florida during February 1996, prior to the deaths of 415 animals (Ward et al. 1996). The Marine Mammals Section of the FMRI established the Manatee GIS, for use as a primary tool in research and management efforts to understand and conserve the species (Reynolds and Haddad 1990, O'Shea and Kochman 1990, Weigle and Haddad 1990, Osborn 1990, Gilbrook 1990, Kautz 1990, Houhoulis 1990, Reynolds et al. 1991, Ward and Weigle 1993, Clifton and Ackerman 1994, Flamm et al. 1994a,b,c; Ward et al. 1994a,b, Wright et al. 1994, Ackerman et al. 1995, Broddery et al. 1995, Fitzgerald et al. 1995, Flamm et al. 1995, Pennington et al. 1995, Weigle et al. 1995, Wright et al. 1995, Ward et al. 1996). The Manatee GIS is a functional node of the MRGIS and integrates manatee distribution, mortality, and migration data with several databases that were created from NOAA nautical charts and satellite imagery. In particular, shoreline and bathymetry are key data bases for the manatee research and management efforts.

To acquire a statewide shoreline base map, the FMRI contacted the U.S. Fish and Wildlife Service to refine several 1:40,000-scale digital shoreline files created by the National Ocean Survey and convert them to ARC/INFO format. In addition, a data conversion firm was contracted to convert bathymetry from paper NOAA charts to digital ARC/INFO format for the entire state of Florida. These core data sets are used with diverse data bases such as manatee distribution, mortality and migration, and aquatic vegetation, and marinas. Preliminary findings have been used to delineate manatee protection zones. Tests are being conducted to combine environmental layers such as water temperature, vegetative cover, salinity, and bathymetry to create predictive models of travel routes and to identify high-use migration corridors.

Fisheries Management

CAMRA created the Resource Impact Map (RIM) series of eight chart-sized maps to assist managers statewide in making resource decisions. Each map includes coastline, depth contours, and aids to navigation digitized from NOAA charts. Benthic communities such as mangroves, saltmarshes, seagrasses, oyster reefs, hard bottom, and bare bottom are included, as are managed area boundaries (Haddad and Eckberg 1987, Haddad and Hoffman 1987, Durako et al. 1988, Haddad and McGarry 1989, McGarry et al. 1989, Haddad 1990, McGarry and Haddad 1990, Haddad 1991, Haddad and McGarry 1991, Friel and Haddad 1992, Haddad and Sargent 1994, Leary and Sargent 1995, Sargent et al. 1995, Flamm et al. 1996). Bathymetric depth curves are shown because depth is an important factor for human and marine resources. Channels and navigation aids such as buoys are displayed to help users orient themselves, like road networks on land-based maps.

The Florida Marine Fisheries Commission (FMFC) and the FMRI are using GIS and RIM information to enhance Florida's fisheries. For instance, the basic RIM data bases were augmented with shrimp nursery data to assist in the complex process of developing a shrimp management plan that includes closure areas (Haddad et al. 1993, Steele and Norris 1995). Issues relative to habitat protection, user conflict, and seafood quality vary among regions, and the maps provide a geographic presentation of these differences for policy analysis (Haddad 1991, Haddad and McGarry 1991, Weigle et al. 1991).

The Fisheries Dependent Monitoring Program at FMRI uses the Trip Ticket System with fishery landings data obtained from seafood dealer sites and facilities. Creel interviews that determine what anglers sought and caught started in 1987 in selected counties. FMRI also utilizes the Marine Recreational Fishery Statistical System (MRFSS) creel data gathered by a contractor for NMFS. The dockside Trip Interview Program (TIP), which interviews commerical fishermen, is a cooperative program with NMFS. A pilot project was initiated by FMRI in Tampa Bay during 1995; which includes creel surveys of anglers interviewed at shoreline localities and in boats throughout the bay, as well as aerial surveys of boat distributions. These data are being evaluated and visually displayed using the All Points Software FIELD-NOTES GIS.

Oil Spill Planning and Response

Since early 1992, the FMRI has been developing the Florida Marine Spill Analysis System

(FMSAS), a GIS-based application to assist oil spill planning, response and clean-up (Lamarche et al. 1996, Rubec et al. 1996), and damage assessment (FDEP 1996, Friel et al. 1996). The FMSAS integrates a variety of information (digitized maps, scanned images, remote sensing imagery, tabular data, and photographs) with targeted analytical routines needed to implement an oil spill response strategy focused on resource protection. Most of the data shown on nautical charts has been included in the FMSAS as vector databases. In addition, scanned nautical charts (250 dots-per-inch) have been integrated to provide a familiar visual backdrop for displaying the twenty other data sets in FMSAS. Coast Guard, NOAA, and state response officials specified this need because all responders are familiar with nautical chart format.

On August 10, 1993, three vessels collided in Tampa Bay, Florida. A vessel transporting aviation fuel burst into flames with another vessel before leaking #6 oil into the bay. Eventually, over 350,000 gallons of oil would leak out and a 10-mile stretch of popular beach would be covered in thick oil. The oil spill initially was carried westward from the mouth of Tampa Bay, then turned due to changing wind direction onto St. Petersburg Beach, and entered Boca Ciega Bay through St. John's Pass (Figure 1.)

The FMSAS in conjunction with GPS, was used to analyze the changing boundaries, logistical alternatives, resources-at-risk, and environmental sampling strategies to manage the spill (Friel et al. 1993, Leary and Friel 1994). Some key features that all oil spill responders requested on the maps came from NOAA charts; shoreline, bathymetry, and aids to navigation. The RoxAnn echo sounder and ARC/INFO GIS were used to map the distribution of oil after it sank to the bottom (Caddell et al. 1995). The FMSAS was critically acclaimed by the response community and made a significant contribution to minimizing resource impacts from the spill.

Pipeline Contingency Planning

The FMSAS was used to support pipeline contingency planning when a consultant contacted CAMRA about developing a facility contingency plan for a large oil tank near Boca Chica Naval Station in Key West. The Coast Guard mandated plan required an analysis of the natural and cultural resources that would be damaged if the oil tank or pipeline ruptured. Preliminary engineering analysis estimated the tank and pipeline would impact resources within a 30-mile radius. The plan was due in two weeks and the results were required immediately. The FMSAS did not contain terrestrial infrastructure data bases, so the tank and pipeline had to be entered. Once entered, the FMSAS was used with ten different data bases including marinas, habitats such as wetlands and coral reefs, and threatened and endangered species, to generate a resources-at-risk report. The report and related maps provided a clear depiction and quantification of the threatened resources such as the number of bird nesting sites, miles of sandy beach, or acres of wetland that would be damaged.

The advantage of having an existing GIS data base to provide timely information, became apparent when the Coast Guard changed the estimated radius of impact from 30 miles to 18.2 miles, a few days before the plan for the Boca Chica facility was due. Using the FMSAS, it took only one hour to run the resources-at-risk analyses again to reflect the new area of influence. The consultant stated that it took eight weeks to assemble and analyze similar data for a facility in Louisiana.

Trajectories of the August 1993 Tampa Bay oil spill

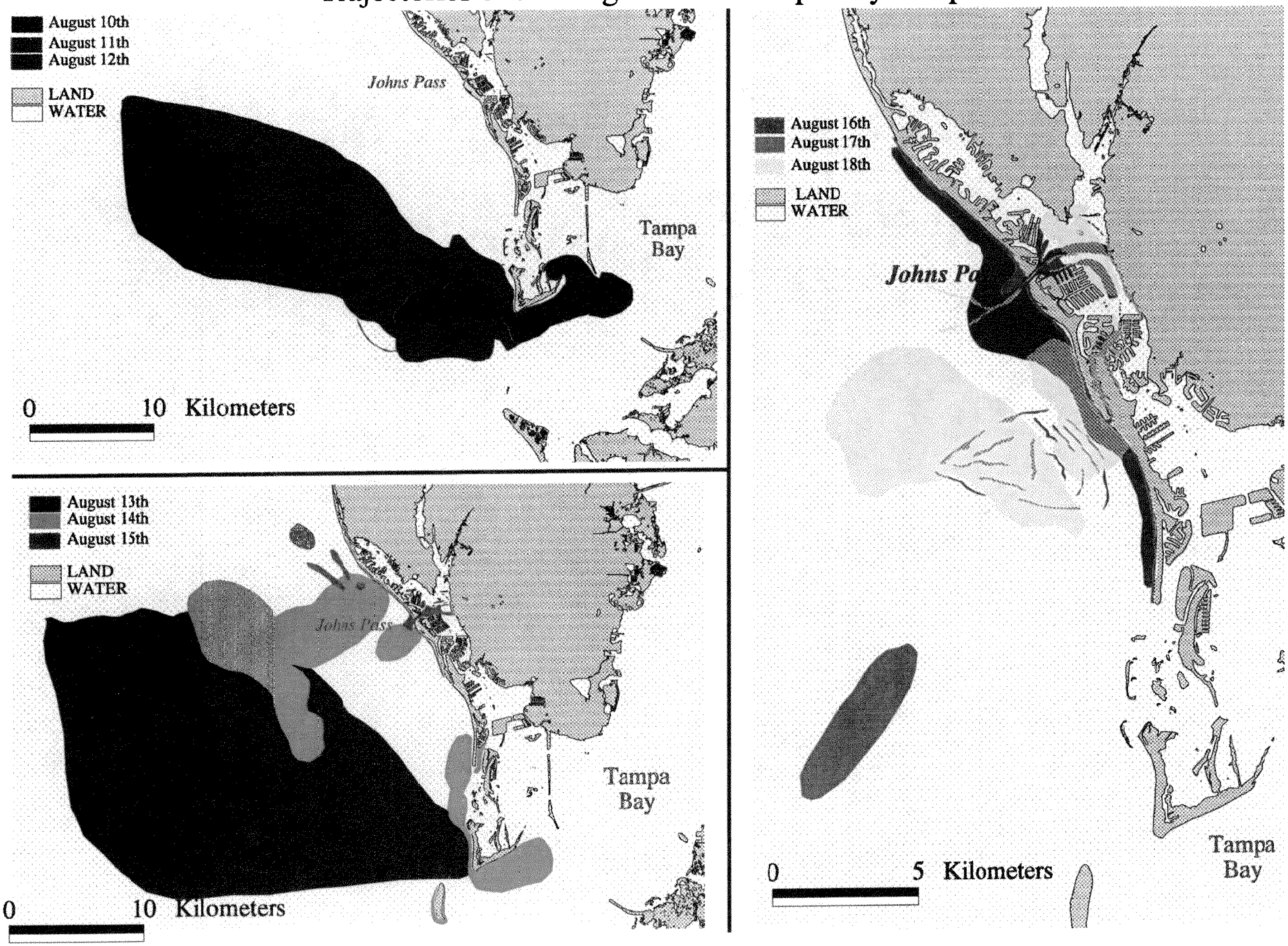

Figure 1. Trajectories of the August 1993 Tampa Bay oil spill. C. Johnson, FMRI.

Underwater Photogrammetry

Coral reef scientists at the FMRI need to document disease, discoloring, and physical changes on the reef (Jaap 1986, Jaap and Sargent 1993). CAMRA staff were asked to explore scanning and /or GIS technology to aid in these studies. The premise is that photographs of coral taken over a period of time can be interpreted; the coral outlines can be delineated, digitized, and precisely overlaid in digital form to record change between time periods (Friel and Haddad 1992). A transportable camera platform was manufactured to ensure that identical photos are taken during each visit. If platform shifting occurs between visits to a site, the photos will not align precisely and it will be difficult to accurately measure relatively minor changes in the coral.

Field ecologists simulated three separate visits to three sites, resulting in nine test photos. Two sets of control points were identified on each photo and were digitized. Statistical and visual measures of platform shift were created. The results indicated minimal shifting at two sites, but the third demonstrated considerable "tie-down"error and platform shifting. Another test set of photographs was taken, and the complete cycle of interpretation, delineation, and overlay will be conducted to refine the research design. The MRGIS was used to test the registration accuracy of the camera platform and, ultimately, the potential for GIS analysis of other aspects of coral change.

Boat and Diver Use Patterns in the Florida Keys

For many, boating and diving are the main attraction of the Keys. The FDEP-South Florida Regional Lab and The Nature Conservancy conducted a year-long study to estimate the number of boats and divers that utilize the FKNMS, and specifically the level of use on individual reefs (Friel and Haddad 1992, Norris and Flamm 1994). The study relied upon a combination of aerial fly-overs, surface surveys, and GIS (Figure 2). The CAMRA staff are supporting the collection, storage, analysis, and display of the boat-use data.

To facilitate the effort, CAMRA staff designed a data collection atlas of 26 maps that display land, reefs and hard bottom, aids to navigation, and a sampling grid. The number of boats observed during the aerial and surface surveys were recorded directly on the atlas, and entered by unique grid cell into a MRGIS data base. Sixty aerial surveys were conducted on different days of the year to count and classify boats. These data were supplemented by ground surveys to validate the aerial survey counts and to estimate the amount of specific boating activities (diving, fishing etc.). A separate map atlas was used for each day, and the data will be stored as a distinct "layer" of information to allow comparisons between different days and/or different areas of the FKNMS. The database will be used for a variety of spatial and statistical analyses to explore correlations between boat-use patterns and benthic communities, bathymetry, boat ramps, marinas, or mooring buoys. These analyses ultimately will support the determination of carrying capacities, the creation of use zones, and a revision of the FKNMS management plan. The methodology employed in this effort proved so succesful that CAMRA supported a statewide extension of the study in 1994.

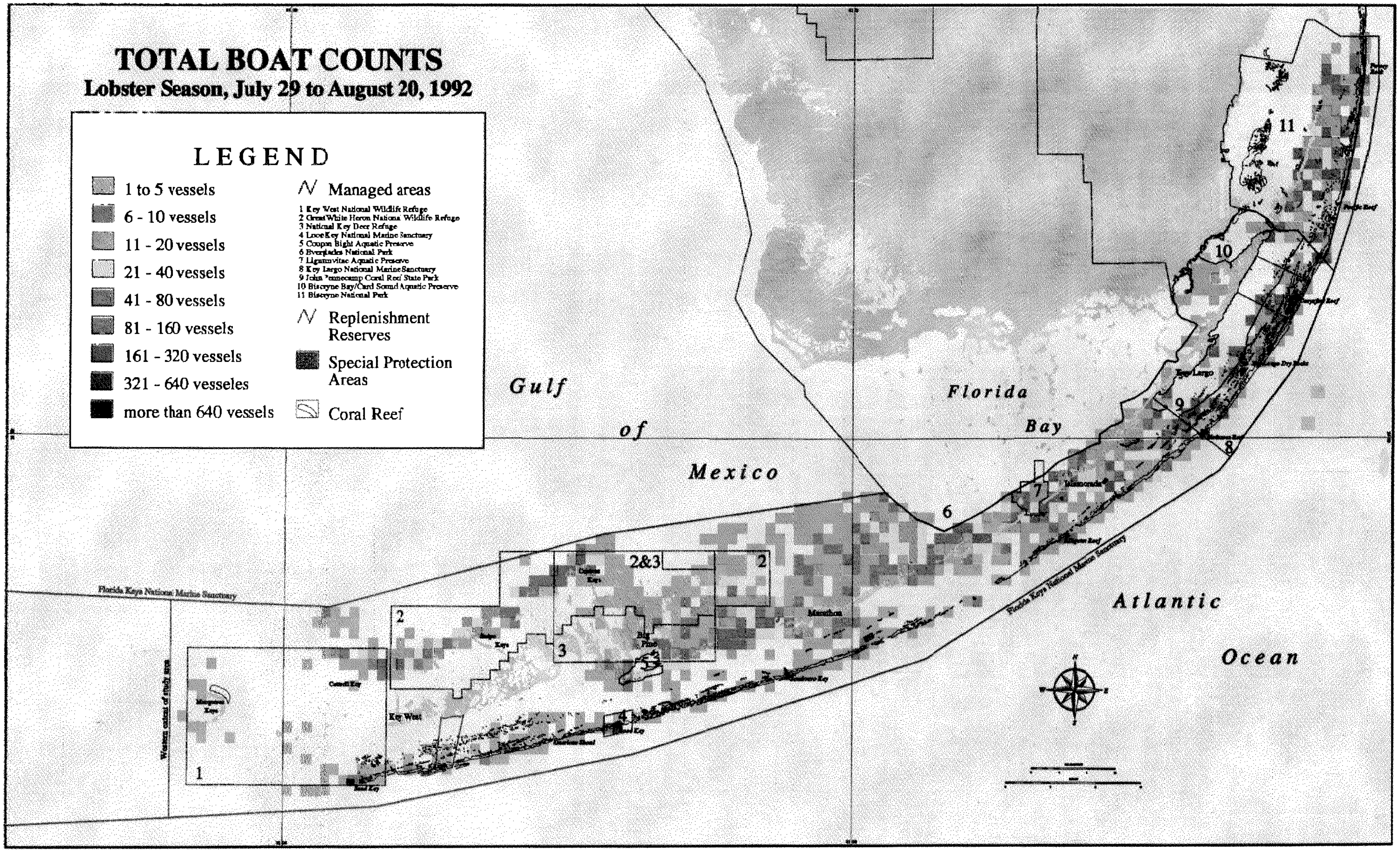

Figure 2. Quadrats depicting the intensity of boating activity in the Florida Keys (Norris and Flamm 1994).

Information Where It's Needed

Developing sorely needed marine resource data bases is only half of the solution for implementing GIS technologies. The remaining challenge is to ensure that resource managers have access to the information in usable formats. Sophisticated GISs do not necessarily accomplish that goal. CAMRA is working with NOAA's Strategic Environmental Assessments Division on the development of a Florida version of COMPAS (Coastal and Ocean Management, Planning, and Assessment System) as a potential approach. COMPAS is a unique and powerful microcomputer-based information system that brings a wide range of data and information management capabilities to the desktops of coastal resource managers.

Similar to Environmental Systems Research Institute's (ESRI) ARCVIEW Version 1 in concept, COMPAS provides a user-friendly view of many disparate data sets. It is designed not only to manage a variety of related coastal resource information, but also to present it in many different forms, including maps, data tables, graphics, and even hydrologic models. NOAA's goal is to develop a generic COMPAS that can be refined and used by other coastal states. Florida's goal is to develop a vehicle for translating GIS data and other data to the management information level. COMPAS Florida is primarily focused on the Florida Keys, and many of the data bases to be included are being developed by CAMRA staff in support of the FKNMS planning process.

COMPAS was originally configured to run on Apple Macintosh microcomputers using Apple's HyperCard software as its foundation. HyperCard is configured to seamlessly access data stored in an Oracle database and to analyze and display it using Microsoft Excel and Strategic Mapping's ATLAS Pro. The implications of porting COMPAS to MS-Windows compatible computers has been examined by NOAA and FMRI. CAMRA created COMPAS Florida applications in ARCView 2 operating on PCs, and is presently moving the system to ARCView 3, as part of the implementation of COMPAS in Florida (Westlake et al. 1995).

Summary

In practice, GIS is becoming a pivotal technology for managing almost every facet of the coastal and marine ecosystems in Florida. The continuing process of data base development and updating is never over, and as new data bases are brought on-line the GIS applications in Florida become more robust. As marine resource managers in Florida develop an appreciation for the potential of GIS, the technology is being integrated at a more fundamental level of research design and management. CAMRA will continue to provide the support necessary to utilize the emerging technologies of GPS, GIS, and remote sensing for coastal and marine research and planning.

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GIS And Fisheries Management

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Introduction

Florida's marine resources are being stressed by a multitude of problems related to growth of the human population; these problems include loss of wetlands, drainage alterations, urbanization, boating impacts, and fishing pressures. As pressures on marine resources continue to increase, it has become evident that data needed to make informed management decisions are either lacking or are inaccessible. Gathering this needed information through monitoring and research is an important step towards better informed management; however, simply gathering this information will not solve the problems associated with managing that information and making it readily available. Unless advanced information-management technologies are instituted in resource management agencies, effective utilization of the information to better manage our resources will not occur. Geographic Information Systems (GIS) technologies may provide the tool needed to translate and synthesize geographically oriented marine resources information in Florida.

A GIS is a data-management and information-analysis system that is able to capture, synthesize, generate, retrieve, analyze, and output spatial information. GIS technology is revolutionizing geographical analysis and has applications in many scientific fields (Cowen, 1988; Parker, 1988; Peuquet and Marble, 1990). Haddad and Michener (1991) foresee Geographic Information Systems evolving into the primary tools for addressing coastal resource-management issues, and published articles and workshops related to GIS technology are now evident in almost every field of science and management. A field in which GIS has not had adequate exposure or use is fisheries management.

Issues facing Florida's fisheries include stressed fish stocks, user conflicts, and impacts to fish habitat. The Florida Marine Fisheries Commission (FMFC) and the Florida Department of Environmental Protection (FDEP) (formerly the Florida Department of Natural Resources-FDNR)

3. Symposium speaker

are working together to advance GIS applications so that they can be used in managing Florida's fisheries.

Fisheries Management

Florida Marine Fisheries Commission

The FMFC was created in 1983 by the state legislature and consists of seven commissioners, who are appointed by the Governor and confirmed by the Senate, and a support staff. The FMFC is charged with the management and preservation of Florida's renewable marine fisheries resources. Chapter 370.027, Florida Statutes, grants the FMFC exclusive rule-making authority in the following areas relating to marine life (with the exception of endangered species): gear specifications, prohibited gear, bag limits, size limits, species that may not be sold, protected species, closed areas (except for public health purposes), quality control of seafood (except for oysters, clams, mussels, and crabs), fishing seasons, and special considerations relating to egg-bearing females. Rules that are adopted by the FMFC are subject to approval by the Governor and Cabinet.

Marine Resources Geographic Information System

The FDEP is mandated through Chapter 370, Florida Statutes, to manage, protect, and enhance Florida's marine resources in the best interests of the resources and the public. The FDEP Division of Marine Resources' Florida Marine Research Institute (FMRI) has implemented the Marine Resources Geographic Information System (MRGIS) as a tool to more effectively understand and manage coastal and marine resources. The MRGIS consists of an array of computers, software, and regional and statewide data bases. The primary MRGIS software includes ARC/INFO and ERDAS. Computer hardware and software are the essential technological components of a GIS, but the power of a GIS lies in its stored data bases. One of the greatest obstacles to effectively managing Florida's fisheries is the lack of a consolidated information base that can be manipulated and synthesized to provide timely assistance and guidance on research and management issues. We believe that the MRGIS can be used to overcome this obstacle. The MRGIS is being developed as the primary tool to be used in translating and synthesizing geographically oriented marine resource information in Florida. The MRGIS can take information from a variety of independent research programs, data-collection efforts, and management policies of federal, state, and local agencies and integrate it for correlated multi-disciplinary analysis and presentation, thus initiating the rudiments of an ecosystem approach to resource management. This approach to effectively utilizing information and managing data will serve the long-term goals of fisheries managers.

Shrimp Management: A Case Study

The integration of GIS capabilities and information into the decision-making process of fisheries managers has been an arduous process because of the difficulty in assembling the necessary basic information, on a statewide basis, to address the many complex issues associated with Florida's marine fisheries. However, advances are being made, and the use of the information integrated by the MRGIS in developing a plan for the long-term management of shrimp lays the foundation for using GIS technologies in fisheries management.

Shrimp Management

Shrimp is the most important invertebrate marine animal harvested in the state, with an estimated 1990 ex-vessel value of $41,531,527. Florida has three main targeted species of penaeid shrimp: pink shrimp, *Penaeus duorarum*; white shrimp, *P. setiferus*; and brown shrimp, *P. aztecus*. Another penaeid, the seabob, *Xiphopenaeus kroyeri*, is seasonally targeted in certain northwest Florida areas. Rock shrimp, *Sicyonia brevirostris*, and the royal red shrimp, *Pleoticus robustus*, are also landed in Florida; however, the harvesting of these species occurs exclusively in federal waters.

The FMFC has been developing a statewide shrimp management plan since 1987 with the following goals: maintaining healthy stocks, ensuring fair and optimal distribution among user groups, protecting habitat, minimizing bycatch, standardizing regulations, minimizing conflict with other fisheries, and ensuring a high-quality product. The shrimp fishery was divided into three user groups: recreational, live-bait, and food production. To account for habitat and gear differences, five contiguous management regions in Florida were designated: the northeast, Big Bend, southwest, southeast, and northeast regions.

The schedule for completing the shrimp management plan calls for two phases of rule-making. The first phase has been completed, and the rules became effective January 1992. Rules developed for Florida's extensive inshore shrimp fishery during this phase of the plan addressed allowable gear specifications, mesh size of nets, and shrimp count for harvesting activity inside the International Regulations for Preventing Collisions at Sea (COLREGS). In the first phase of the plan, numerous local laws were repealed, which simplified inshore and nearshore shrimp regulations and standardized the fishery on regional and statewide levels. The Big Bend region of Florida is the only area where these new regulations include harvest in all state waters. The second phase of rule-making will address the finfish bycatch associated with shrimp trawling and also the adoption of a zone management plan to determine allowable shrimp-harvesting areas.

MRGIS Data Base Development

Because of the complex process involved in developing the shrimp management plan and the goals of the FMFC to address user conflict, maintain a high-quality shrimp population for harvest, and protect habitat, the information requirements are substantial. Basic information identified as important to the planning process includes nautical chart coastline, depth contours, aids to navigation, benthic communities, managed areas, shrimping areas, and, in some cases, potential shrimp nursery areas. All of these data bases are geographically layered in the MRGIS so that any combination of information can be analyzed and produced on maps (Figure 1).

Each of the data layers obtained during development of the shrimp management plan had unique purposes as well as unique problems. Much of the data were from external sources and required varying levels of verification and quality control. Problems in the digital data ranged from errors in digitizing to errors introduced in converting the data to make it compatible with the MRGIS. When data were not available, MRGIS and FMFC staffs collected the needed information or the data gathering was contracted. Cooperation in data collection has been essential in our effort to develop an extensive MRGIS data base.

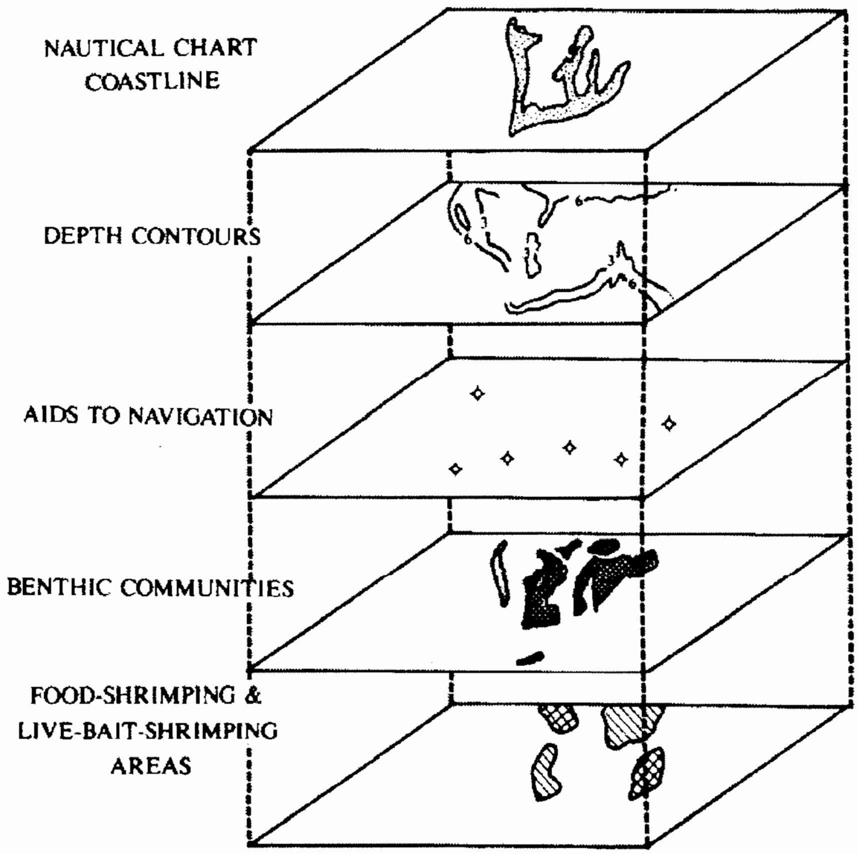

Figure 1. Conceptual view of the relationship among several GIS data layers used to assist in shrimp management planning.

Nautical Chart Coastline

The nautical-chart coastline data base is a generalization of the Florida coastline digitized primarily from National Oceanic and Atmospheric Administration (NOAA) nautical charts. A coastline from nautical charts was selected after numerous options were presented to the FMFC and the public at a FMFC meeting. It was determined that because both the public and the FMFC used NOAA nautical charts as common reference maps, the presentation of MRGIS information would be best understood in that format. The majority of the digitized charts were at a map scale of 1:40,000, but some charts ranged in scale depending on their availability. The U.S. Fish and Wildlife Service developed this database for FDEP from digital line data provided by NOAA.

Benthic Communities

Benthic communities, including seagrass, mangrove, saltmarsh, non-vegetated bottom, oyster reef, and coral communities, play a significant role in supporting Florida recreational and commercial fisheries.

The areal distribution of these communities is important to many issues facing the FMFC and FDEP. Shrimp and other commercial and recreational species utilize seagrass, saltmarsh, and mangrove areas as habitat and nursery areas. The seagrass communities are primary fishing grounds in the bait-shrimping industry. Shrimp managers require information on habitat impacts, bycatch, gear use, and zoning relative to benthic communities.

The benthic-community data used in developing a state-wide data base were compiled from a myriad of sources. Where possible, existing data, which were developed and verified by other agencies, were utilized. For areas about which existing, reliable data were not available, standard remote-sensing techniques utilizing satellite imagery and aerial photography were employed.

Depth Contours

Depth contours are common features on NOAA nautical charts and represent common features of orientation considered important to map presentation. In addition, using depth ranges to isolate areas of interest (e.g., the location of seagrass in depths of less than 3 ft) allows managers to analyze the relationships between shrimping activities and the resources.

Depth-contour data were automated for the following depths: 3 ft, 6 ft, 12 ft, 18 ft, 30 ft, and 60 ft. In addition, channels and spoil areas were identified. Data were digitized from NOAA nautical charts (primarily 1:40,000 scale) by an independent contractor and are compatible with the coastline data layer. All depth-contour data were required to carry attributes as both lines and polygons for maximum usage in the GIS. This requirement allows the flexibility of highlighting individual contour lines as well as providing polygons to query other layers on the basis of depth range. For example, although the data are generally depicted as lines in maps, we have found it useful to extract seagrass areas that occur within specific water depths. Problems encountered during the development of this data base included incomplete contour lines, differences in lines on overlapping charts, and a single line representing several depths. Data were interpolated to complete contour lines and a labelling methodology was developed to allow selection of contours for a specific depth when a single contour segment represented several depths.

Shrimping Areas

The bait-shrimp-fishing industry maintains live shrimp in holding tanks for distribution as live bait, whereas food shrimp are usually frozen onboard the shrimping vessels prior to processing. The locations of live-bait-shrimping and food-shrimping areas are critical to the development of the shrimp management plan. The FMFC is using this information to assess the location of potential habitat impacts, develop an understanding of potential user conflicts, maximize habitat protection, and minimize impact to the fishing industry.

Locations of live-bait-shrimping and food-shrimping areas were determined by a team of FDEP and FMFC staff, who met with shrimpers and their representatives. Shrimpers identified those areas where they fished by drawing polygons on NOAA nautical charts. When appropriate, references were made to the seasonality of these shrimping areas. The marked-up nautical charts were returned to the FMRI for digitizing into the MRGIS as a separate data layer. The accuracy of this particular data layer was dependent on the cooperation of the shrimpers.

Aids to Navigation

Landmarks that can be used in determining position are called aids to navigation. Channel markers, lighthouses, buoys, water tanks, piers, marinas, and shipwrecks are examples of navigational aids that appear on NOAA nautical charts. Channel markers and buoys were determined to be the most important features for inclusion in the aids-to-navigation data layer. Both provide a visual reference for location, and the FMFC and other marine resource managers use them as zone-boundary references for regulatory and management purposes.

Aids-to-navigation data to be entered into the MRGIS data base were purchased from the NOAA National Ocean Service (NOS). Data for the entire country were provided to the FMRI as an ASCII text file. The data were searched for features that fell within the minimum and maximum latitude and longitude values for Florida. The data presented numerous problems that proved difficult to correct. Labeling inconsistencies (e.g., buoys were abbreviated several different ways) made sorting of the data difficult. In addition, multiple entries for a given location and the inclusion of outdated information (e.g., positions of channel markers were given even if they were no longer at that location) were recorded. In some cases, extraneous items from the charts, such as compass roses, were included in the digital data base. Inconsequential data were eliminated from the data base and errors were corrected.

Managed Areas

Managed areas have also been included in the data base for some regions of the state, which provides an understanding of jurisdictional boundaries and existing management zones relative to resources and issues of regulatory responsibilities. Existing state and federal jurisdictional boundaries and existing shrimp management zones have been utilized. Boundaries for managed areas were either interpreted from legal descriptions or were digitized from NOAA nautical charts. It is expected that the locations of additional managed areas (e.g., National Marine Sanctuaries and Florida Aquatic Preserves) will be required for future planning.

Applications Of The Shrimp Management Plan

The identification, collection, control of quality, and integration of geographic data into the MRGIS have been difficult and time-consuming. Information provided to the FMFC to be used in planning for shrimp management has been in the form of maps that depict various combinations of data layers and in the form of results of simple analyses designed to geographically relate different data layers.

Map Making

Until the users fully understand the analytical power of the MRGIS, they will continue to request primarily information in the form of maps that portray all or different combinations of the data layers. Several layers of information for a portion of the Tampa Bay region of Florida are depicted (Figure 2). These maps are produced in color on an electrostatic plotter in large-scale format to enhance the visual presentation of the information.

The FMFC staff uses these maps in formulating the management plans for a given region.

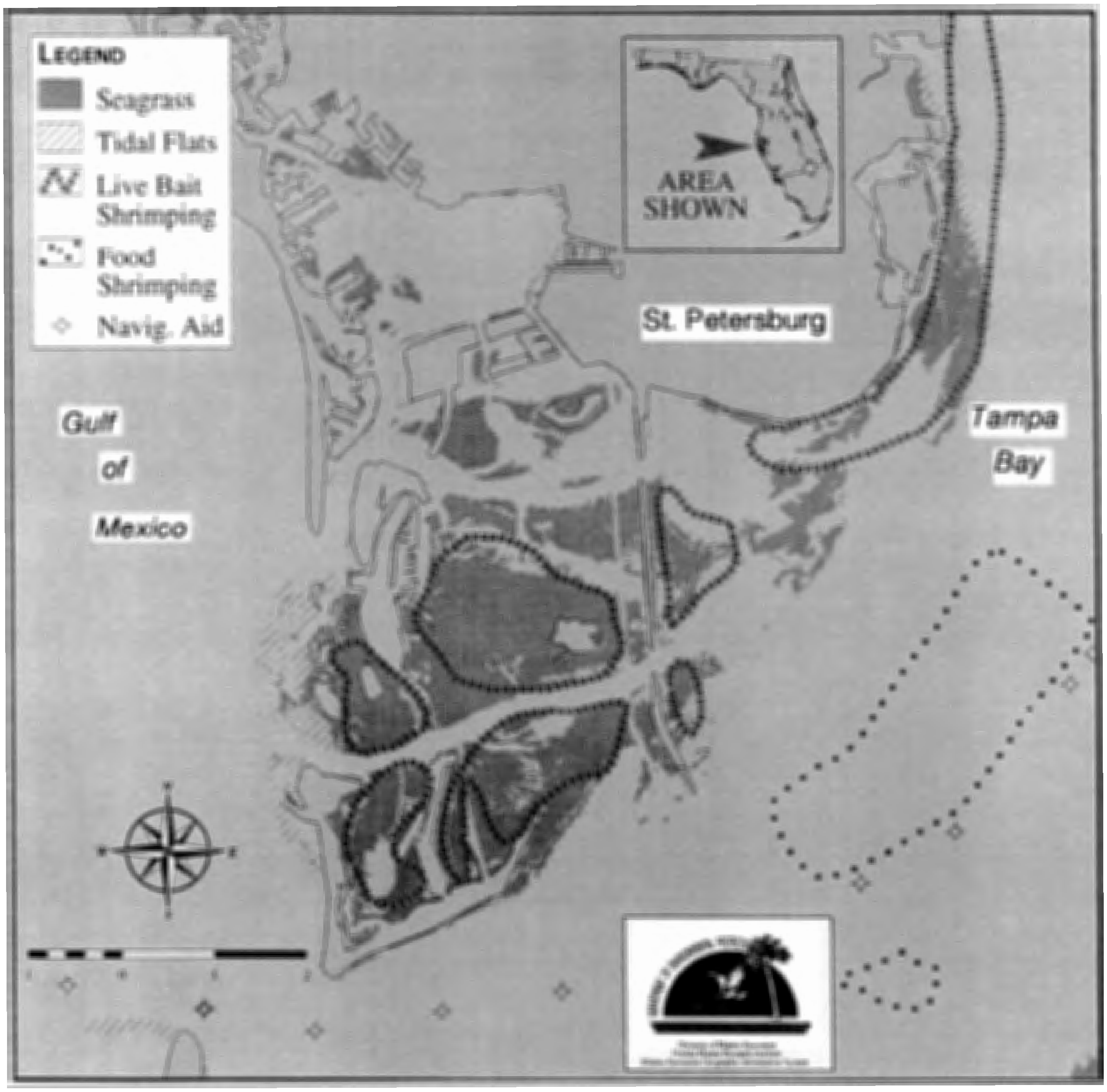

Figure 2. A MRGIS map of a portion of the Tampa Bay region showing the overlay of coastline, benthic communities (seagrass and unvegetated tidal flats only), live-bait-shrimping, food-shrimping areas, and aids to navigation. D. Wilder, FMRI.

Issues relative to habitat protection, user conflict, seafood quality, and the like, vary among regions, and the maps provide a geographic presentation of these differences. Maps are of particular importance in the development of potential zones for managing user conflicts and maintaining harvestable yields of shrimp. The FMFC staff developing the management plan also uses maps to support their recommendations and present them to the commissioners of the FMFC. In addition, maps are used at public hearings and workshops to present components of the management plan to the public. It is expected that in the long-term, maps will be one of the more tangible types of information used in public presentations and will provide the focus for public understanding and feedback on many of the issues.

The combination of different layers of information for presentation is rudimentary from the perspective of advanced GIS applications. However, when the result is the visualization of information in a form and content that previously was not available, the advantage is significant.

Information Analysis

The FMRI and FMFC are determining acreage (e.g., acres of seagrass and shrimping areas) and investigating the relationships among some of the layers of information. Results of an analysis of the Tampa Bay region to determine the depth and acreage of seagrasses that occur within live-bait-shrimping or food-shrimping areas are shown (Table 1). Habitat-impact and bycatch issues are better addressed with this type of information because the impacts of management options can be assessed. For example, if resource managers were designing shrimp zoning in Tampa Bay to minimize impacts to seagrass, they could see from the information in Table 1 that the live-bait-shrimping areas are the only areas that include seagrass. In fact, 8,464 acres (44%) of the total live-bait-shrimping area is seagrass. However, 7,582 acres (90%) of the total seagrass found in the live-bait-shrimping areas are in depths of less than 3 ft, and only 10,413 acres (54%) of the total area shrimped is in less than 3 ft. This implies that zoning options minimizing shrimping in depths less than 3 ft would protect 90% of the seagrass areas shrimped but would reduce the primary shrimping areas by 54%.

A visual presentation of the results of the geographic analysis depicting the areas of seagrass in depths less than 3 ft that are shrimped in a portion of the Tampa Bay region is shown (Figure 3). Any combination of map layers and results from Table 1 can be geographically depicted to enhance the understanding of the information. Of course, results of shrimping-bycatch and seagrass-impact studies, economic values, resource allocations, and many other factors contribute to the final determination of shrimping zones. The real achievement of the MRGIS analyses is that this level of information and the ability to look at hypothetical management options have never been available in this way before.

Conclusions

There are many issues facing fisheries managers in Florida. We have demonstrated that GIS technology can be a valuable tool in developing fisheries management plans. Because much of the information used by fisheries managers is of a geographic nature, it is expected that the application of GIS technologies will continue to expand. However, fisheries managers must realize that the

Table 1. Result of a MRGIS analysis to determine the amounts of seagrass found in different depth ranges within live-bait-shrimping and food-shrimping areas in the Tampa Bay region.

LIVE-BAIT SHRIMPING			
DEPTH	SEAGRASS ACRES SHRIMPED	NON-SEAGRASS ACRES SHRIMPED	TOTAL AREA SHRIMPED
< 3 Feet	7,582	2,831	10,413
3 to 6 Feet	347	4,556	4,903
> 6 Feet	535	3,313	3,848
TOTAL	8,464	10,700	19,164

FOOD SHRIMPING		
DEPTH	SEAGRASS ACRES SHRIMPED	NON-SEAGRASS ACRES SHRIMPED
< 3 Feet	0	40
3 to 6 Feet	0	575
> 6 Feet	0	32,209
TOTAL	0	32,824

power of the GIS is in the data. Analyses are easy. Most failures in using GIS technology result when managers and GIS experts fail to properly identify the need for, plan for, and commit to data collection, acquisition, and quality control. If these data issues are not addressed, GIS technologies will not prove successful in the long-term.

The process of adapting GIS techniques to the needs of the FMFC staff developing the shrimp management plan has not always been easy. The expectations of the FMFC regarding the the availability of data layers necessary for the shrimp management plan and the FMRI's ability to properly develop them were occasionally different. Schedules for public hearings and workshops had to be adjusted to accommodate for the time required to enter accurate data bases into the MRGIS. The outcome of this interactive process between FMFC and FMRI staffs, however, has been a successful application of GIS for fisheries management.

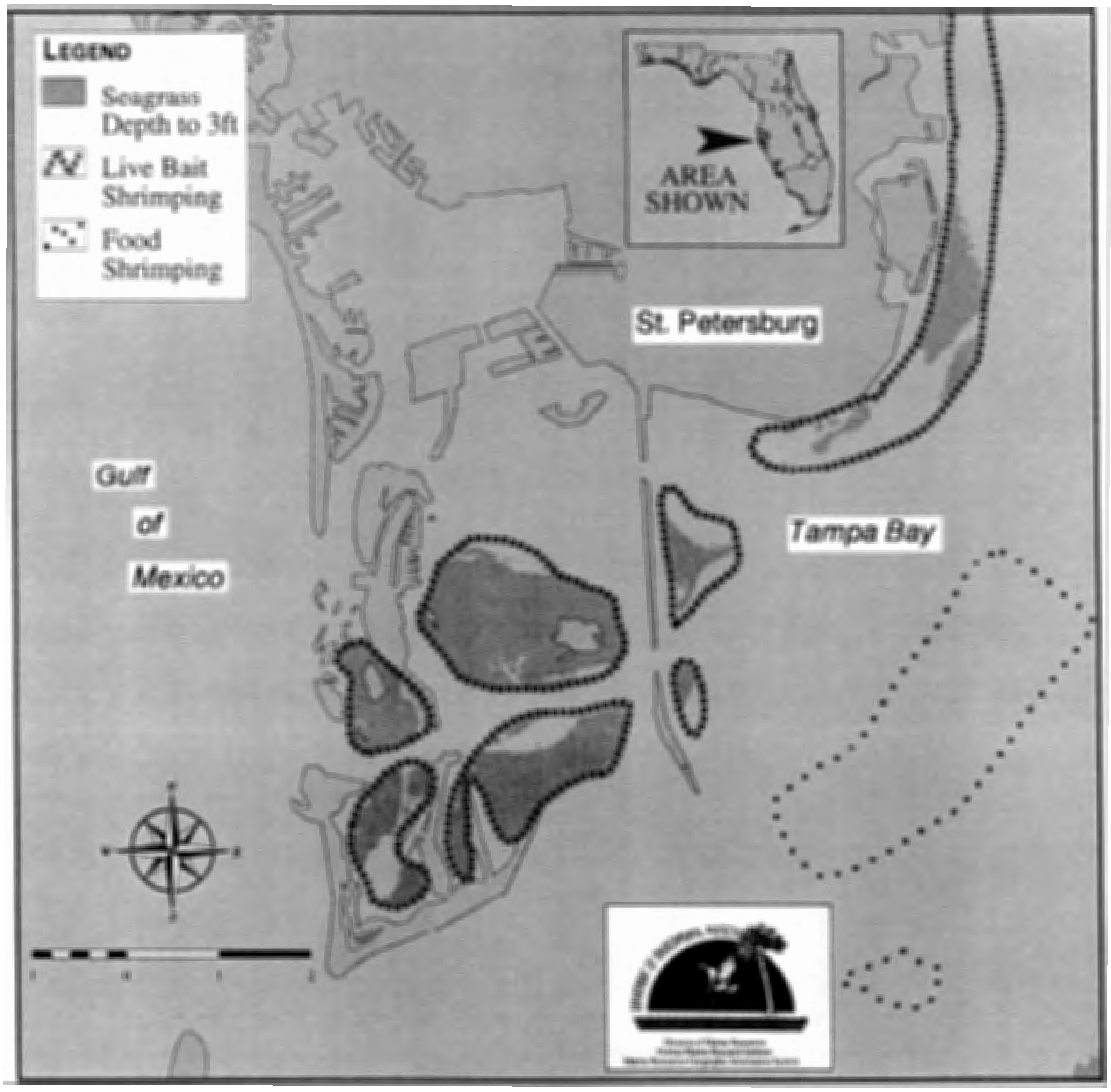

Figure 3. A MRGIS map of a portion of the Tampa Bay region showing the location of seagrass areas in less than 3-ft depths found in the live-bait-shrimping or food-shrimping areas. D. Wilder, FMRI.

If properly implemented, GIS technology can become more valuable every year in managing Florida's fisheries. By including water-quality, physical, meteorological, socio-economic, and species information, management options can be explored with a better understanding of the potential results of a management decision. The next technological advancement will be to transfer the ability to manipulate the information to the FMFC staff. The FDEP and FMFC staffs are beginning work to provide the FMFC with the capability to display different combinations of map layers and the results of analyses. The goal is to make these capabilities available not only for technical analyses but also for low-cost, interactive displays at public workshops, hearings, and meetings. Only then will the maximum value of the technology be fully realized.

Acknowledgements

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Influence of Inter-Annual Temperature Changes on Redfish (*Sebastes spp.*) Catch Rates In The Gulf Of St. Lawrence

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Abstract

Commercial catch rates of redfish (*Sebastes fasciatus* and *S. mentella*) exhibited an anomalous drop in the Gulf of St. Lawrence during 1983. The present study examined the influence of year, depth, and temperature categories on catch rates using research survey data from 1983-1988. Maps were created to examine the spatial distributions of juvenile, recruit, and adult redfish catch rates. Kriging was used to map the coverage of 4 temperature ranges from bottom temperature data. Categorical data analysis using log-linear modeling determined that recruit and adult catch rates were highest in a preferred temperature zone ranging from 5.8 -7.9°C. Juvenile catch rates were highest in Depth Class 2 (183-274 m). The preferred temperature zone shrank to 0.2% of the total survey area in 1983 and expanded to 25.7% in 1986 and 29.2% in 1987. A drop in catch rates during 1986 and 1987 was associated with the dispersion of the population in the preferred temperature zone. Population estimates were determined using the trawl area swept method extrapolated to the total area: for 41 depth strata; for 4 depth strata; and for 4 temperature strata. Abnormally cold conditions caused a 50% drop in total population biomass during 1983. Summing population numbers and biomass across temperature strata facilitated the best assessment of the influence of climatic change on interannual trends in redfish total population abundance.

Introduction

Gulf based fishermen and processors from Quebec and New Brunswick which exploit redfishes (*Sebastes spp.*) from the northern Gulf of St. Lawrence, Canada (Figure 1) expressed concern during the summer of 1983 about declining catch rates (CPUE's). Non-Gulf based fishermen from Nova Scotia and Newfoundland were less concerned about declining CPUEs of redfish. These trawl fisheries were primarily directed during the early 1980's on the deepwater redfish (*S. mentella*) in the Esquiman Channel at depths greater than 250 m (Rubec et al. 1986, 1991). The Acadian redfish (*S. fasciatus*) and the golden redfish (*S. norvegicus*) are usually found at depths from 183-274 m (100-150 fathoms) (Trottier et al. 1989, Rubec et al. 1991).

An analysis of the geographic distribution of commercial fishing effort by Gulf and non-Gulf based vessels revealed marked differences in fishing patterns (Rubec et al. 1986). Gulf based vessels fished throughout the summer and fall months, while non-Gulf based vessels concentrated their fishing effort during the fall and winter months off of SW Newfoundland near the mouth of St. George's Bay and east of Beauge Bank during 1984 and 1985. Gulf based vessels fished over a wider area. Quebec vessels from the Magdalen Islands localized their fishing between the east end of Anticosti Island and the Port au Port Peninsula, Newfoundland from 1979-1982. From 1983-1985, the area fished by Gulf based vessels expanded. Analyses of both commercial and research vessel CPUEs indicated that redfish (*Sebastes spp.*) had declined in abundance in the Esquiman Channel. The decline was not predicted through stock assessments.

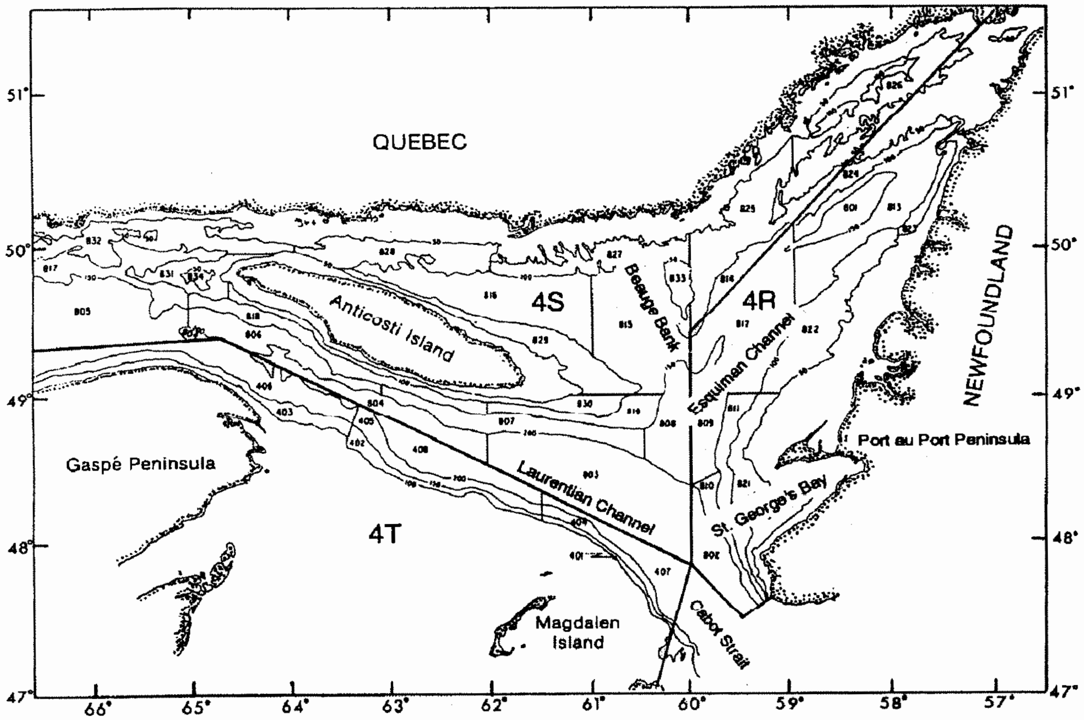

Figure 1. Northern Gulf of St. Lawrence indicating 41 depth strata used on trawl surveys.

Despite considerable analyses of 1983-1987 data, it was difficult to quantify the factors determining redfish abundances and distributions (Rubec 1988). It was proposed that the decline in commercial catch rates might be related to changes in environmental conditions. A four way analysis of variance (ANOVA) indicated that temperature was a highly significant factor explaining redfish CPUEs. This suggested that changes in the distribution of preferred temperature zones could have caused the redfish to change their geographic and depth distributions making them less vulnerable to the commercial fishery.

Fishery independent research vessel (R/V) survey data can be used in models to explain redfish abundance because environmental data is usually collected along with the fish by the Canadian Department of Fisheries and Oceans (DFO). Trawl surveys in the northern Gulf of St. Lawrence (GSL) date back to the late 1940's. However, because of changes in trawl survey sampling schemes, vessels, and gear this study is only concerned with fishery and hydrographic data collected during July-August from 1983 to 1988 by the R/V Lady Hammond.

The present analysis has examined redfish catch rates for three size classes of redfish (*Sebastes spp.*) in relation to depth, bottom water temperature, time of day, and year.

Materials and Methods

Using a random stratified survey design with 41 strata, the northern GSL was surveyed for redfish during August from 1983 to 1988. The R/V Lady Hammond used a Western IIA bottom trawl to conduct 0.5 h tows at a speed of 6.48 km/h (3.5 N mi/h). The CPUEs were standardized to a distance of 3.24 km. The strata were distributed over 4 depth ranges of 91.5 m (50 fathoms). There were 1044 sets (200 in 1983, 102 in 1984, 180 in 1985, 176 in 1986, 166 in 1987, and 220 in 1988).

An effort was made to obtain a Sippican expendable bathythermograph (XBT) profile at each station. However, for various reasons not all stations were sampled resulting in missing temperature data. CPUEs lacking corresponding bottom temperature data were excluded from the 1017 trawl sets used in the statistical analyses.

Trawl CPUEs (no./tow) were partitioned according to 3 size classes of redfish: juveniles ≤15.9 cm, recruits 16-24.9 cm, and adults 25-52 cm. It has been demonstrated that redfish change their spatial distributions in the GSL from year to year as they grow to become adults (Atkinson 1984). Consequently, the study was designed to determine the relative importance of temperature and/or depth in explaining redfish CPUEs and distributions for each of the 3 size classes over the 6 year sampling period.

Categorical data analysis using log-linear modeling was utilized to determine the importance of the factors and their interactions (Freeman 1987). Catch rates ranging from 0-9916 redfish per standard tow, and bottom temperatures ranging from -1.5 to 7.9°C being continuous variates were partitioned into quartiles (Legendre and Legendre 1983, Frechet 1990). Since the sampling design on the groundfish survey is based on 4 depth strata of 50 fathom steps, this was maintained as the basis of delimiting depth intervals. Preliminary categorical analysis, without year in the model, found that time of day (day/night) was less important than catch rate, temperature and depth in terms of the factors which appeared first in the model. Hence, time of day (H) was excluded from further analyses.

The various parameters were ranked from low to high using the Statistical Analysis System function PROC UNIVARIATE. The date were then partitioned into quartile categories. Juvenile numbers /tow were partitioned into four classes: 1 =0, 2 >0 & ≤10.2, 3 >10.2 & ≤114.1, 4 >114.1 & ≤9756.2. Recruit no./tow classes were 1 ≥0 & ≤3.9, 2 >3.9 & ≤24.1, 3 >24.1 & ≤129.6, 4 >129.6 & ≤6173.6. Adult no./tow classes were: 1 ≥0 & ≤12.4, 2 >12.4 & ≤111.3, 3 >111.3 & ≤360.3, 4 >360.3 & ≤5426.5. The total no./tow classes were: 1 ≥0 & ≤78.3, 2 >78.3 & ≤285.5, 3 >285.5 &≤ 845.1, 4 >845.1 & ≤9916.6. The depth classes (DC) in meters were: 1 >91 & ≤183, 2>183 & ≤ 274, 3 >274 & ≤366, 4 >366 & ≤530. The temperature classes (TC) in °C were: 1 >-1.5 & ≤4.3, 2 >4.3 & ≤ 5.3, 3 >5.3 & ≤5.8, 4 >5.8 & ≤7.9.

A multiway cross tabulation (4 X 4 X 6 X 4) of the observed frequency of temperature (T), depth (D), year (Y) and catch rate (C) of redfish was used in the log-linear analyses (Table 1). This type of analysis was preferred because the catch rate variable showed a biological response that reached a maximum for intermediate values of the response variable depth. Data were analyzed using the STATGRAPHICS package from Manugistics Inc. Since some cells had zeros, a constant value of 0.5 (Delta) was added to the multidimensional matrix to allow calculation of the log-linear parameters. The Categorical option was used to build the models by means of forward progression (Freeman 1987).

Table 1. Categories used in log-linear categorical analysis of redfish trawl survey data from the Gulf of St. Lawrence.

[Y]	Years	6 years	1983-1988
[C]	Catch rates 3 size classes	4 quartiles	no.'s/tow
[D]	Depth	4 depth ranges	50 fathom intervals
[T]	Temperature	4 quartiles	degrees centigrade

SURFER (Golden Software Inc.), a low cost Spatial Data Analysis System (SDAS), with some features of a Geographic Information System (GIS), was used to map the 4 depth zones depicted in Figure 2. Plots of the geographic distributions of redfish were created by size classes using different symbols for abundance categories by year to produce 18 maps (not presented).

SURFER was also used to contour bottom temperature data using simple punctual kriging (Webster et al. 1991). About 200 temperature values, obtained from an oceanographic survey in September 1984, were used to supplement 102 bottom temperatures from the August 1984 R/V survey. The data were used to contour temperatures by categories to produce 6 annual maps. An electonic planimeter was used with the temperature maps to determine percentages of the total survey area (99,927 km^2) occupied by each temperature zone.

The area swept method, usually used for estimating fish population numbers from R/V survey data, involves multiplying the mean CPUE within each stratum by the area of the stratum divided by the area swept by the trawl, and then summing all the strata estimates (Doubleday 1981). The present analysis has determined population numbers and population biomass from 1983 to 1988 using area swept calculations with three different stratification schemes. The first determined the populations and associated variances according to the regular 41 depth strata. The second used survey data allocated to the areas of 4-50 fathom depth ranges. The third method estimated population trends of redfish population according to the 4 temperature zones determined from mapping and planimetry. Depth strata areas stayed the same, while the areas of temperature strata changed from year to year.

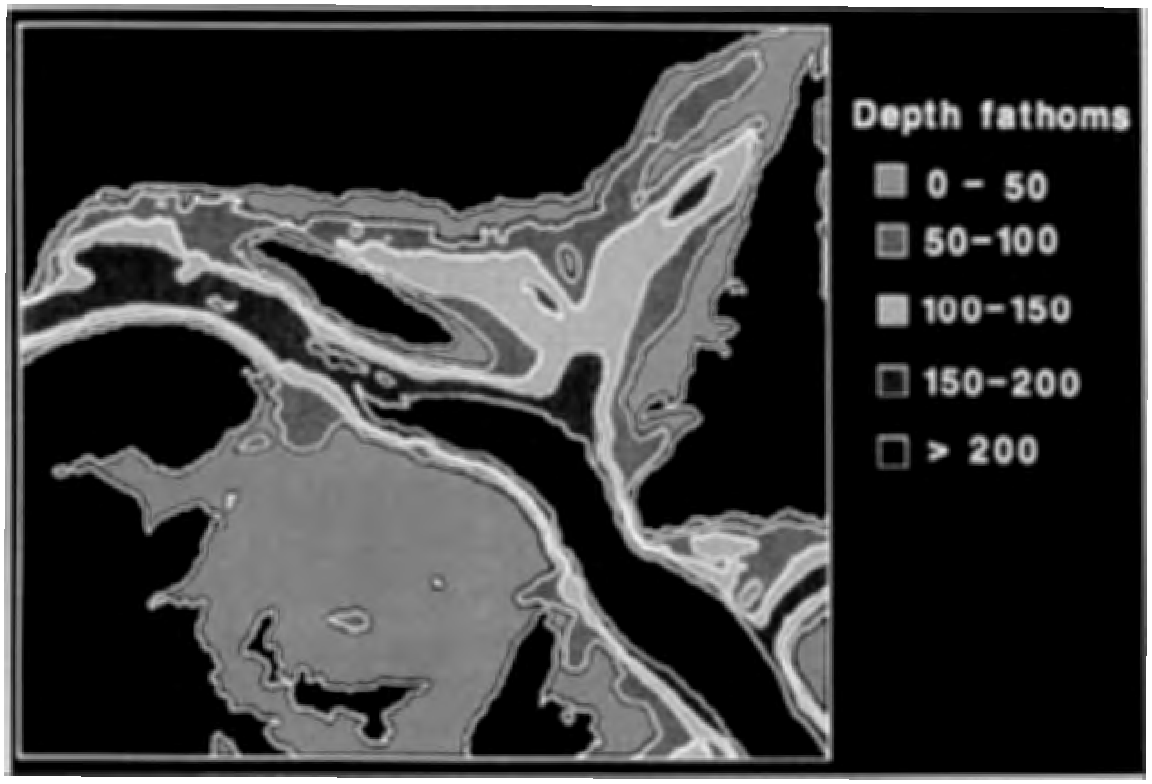

Figure 2. Depth ranges in fathoms used for research vessel surveys of redfish in the northern Gulf of St. Lawrence.

Results

Mean temperature tends to increase with increasing depth in the GSL (Table 2). However, inspection of mean temperatures indicated that DC-2 (183-274 m) became warmer across years, increasing from 4.5°C in 1983 to 5.5°C in 1986 and then declined to 5.3°C in 1988. Depth classes 2 to 4 became warmer in 1986 in comparison to the earlier years, and declined somewhat to 1988. This indicates a warming trend in bottom temperatures, at depths greater than 183 m (100 fathoms), which peaked during 1986.

Mean CPUEs according to the 4 depth strata for juvenile, recruit, and adult redfish were determined from 1983 to 1988 (Table 2). Juveniles exhibited the highest CPUEs in Depth Class (DC) 2 from 1983 to 1986. High recruit CPUEs were spread over DC-2 and DC-3 (183-366 m) during 1987 and 1988. The adult CPUE in DC-2 was highest in 1983, 1985 and 1986; while DC-3 had the highest mean CPUEs in 1984, 1987, and 1988.

Table 2. Mean temperature and mean juvenile, recruit, and adult numbers per tow or redfish by depth classes in the Gulf of St. Lawrence.

Depth Class	1983	1984	1985	1986	1987	1988
			Mean Temperature °C			
DC-1	2.8	2.3	2.1	1.9	1.5	1.7
DC-2	4.5	4.9	5.3	5.5	5.4	5.3
DC-3	5.4	5.4	5.6	6.0	5.9	5.7
DC-4	5.2	5.6	5.5	5.8	5.8	5.2
			Mean Juvenile No./Tow			
DC-1	367.0	550.5	48.9	6.3	39.7	32.6
DC-2	1084.0	1159.5	210.4	40.1	283.0	133.4
DC-3	169.5	192.0	45.7	5.7	3.2	4.6
DC-4	7.8	27.3	8.4	0.3	0.1	0.0
			Mean Recruit No./Tow			
DC-1	35.1	21.3	37.6	16.6	77.6	64.0
DC-2	59.2	161.2	503.1	724.4	375.0	249.3
DC-3	35.6	41.2	174.6	226.6	584.1	192.0
DC-4	0.6	3.6	42.2	17.3	25.5	11.2
			Mean Adult No./Tow			
DC-1	155.4	83.0	47.5	17.1	63.1	167.7
DC-2	245.9	509.9	374.1	391.2	298.8	449.8
DC-3	188.9	701.4	361.4	335.1	486.2	756.0
DC-4	112.4	368.8	340.2	118.2	270.8	402.1

Mean numbers per tow according to the 4 temperature strata were also determined from 1983 to 1988 (Table 3). There was no apparent preference for any one temperature stratum by juvenile redfish over the six year period. Recruits had no marked temperature class (TC) preference in terms of higher CPUEs during 1983 and 1984, had highest CPUEs in TC-4 (5.8-7.9°C) from 1985 to 1987, and had high mean CPUEs over TC-3 and TC-4 (5.3-7.9°C) during 1988. Adult CPUEs showed no TC preference during 1983, and exhibited the highest mean CPUEs in TC-4 from 1984 to 1988.

Table 3. Mean temperature and mean numbers per tow for juvenile, recruit and adult redfish by temperature classes in the Gulf of St. Lawrence.

Temperature Class	Year 1983	1984	1985	1986	1987	1988
			Mean Temperature °C			
TC-1	3.3	2.8	2.1	1.9	1.6	1.6
TC-2	5.0	5.1	5.1	5.1	5.0	5.0
TC-3	5.5	5.5	5.5	5.6	5.6	5.6
TC-4	6.1	7.1	6.1	6.2	6.1	5.9
			Mean Juvenile No. /Tow			
TC-1	658.9	885.7	74.3	7.2	65.4	32.9
TC-2	677.7	521.5	85.8	21.0	349.7	57.4
TC-3	120.5	240.4	72.9	10.0	160.9	38.3
TC-4	0.0	146.6	102.3	24.8	34.3	17.6
			Mean Recruit No./Tow			
TC-1	49.9	42.7	79.0	18.4	87.1	50.4
TC-2	44.9	81.6	110.4	445.4	394.1	79.0
TC-3	37.9	88.6	142.9	156.0	134.9	227.1
TC-4	0.0	45.4	437.7	566.6	517.6	218.2
			Mean Adult No./Tow			
TC-1	222.2	150.1	65.3	23.2	72.2	100.3
TC-2	227.5	386.1	143.5	237.2	191.5	388.9
TC-3	157.1	861.5	318.1	148.0	299.2	599.8
TC-4	0.0	938.8	486.3	434.1	459.8	992.8

The temperature maps (Figure 3) have been shaded to highlight the spatial extent of TC-3 (5.4-5.7°C) and TC-4 (5.8-7.9°C). The temperature zone preferred by recruits and adults (TC-4) was almost non-existant occupying a small patch along the SW Newfoundland coast during 1983. Two patches occurred in the middle part of the Laurentian Channel and in the mouth of the Esquiman Channel during 1984. The warming trend is indicated by the expansion of zone TC-4 during 1986 and 1987. The contraction of the area occupied by TC-4 demonstrates a cooling trend in 1988.

The percentages of the total area determined by planimetry occupied by the 4 depth, and 4 temperature strata are summarized (Table 4). The areas of temperature zones changed markedly between years. The preferred temperature zone (TC-4) occupied only 0.2% of the total area during 1983. The TC-4 zone increased to occupy 25.7% of the total area during 1986 and 29.2% during 1987 (Figure 4). It occupied 10.3% of the total area during 1988.

Table 4. Percentage of total area of 99,927 km^2 for depth or temperature strata determined by planimetry.

Depth Class	Depth Strata 1983-1988	Temperature Class	Temperature Strata 1983	1984	1985	1986	1987	1988
DC1	29.3	TC1	37.6	38.0	34.3	37.9	33.6	34.1
DC2	31.4	TC2	48.6	43.0	30.0	18.7	17.6	28.6
DC3	22.9	TC3	13.6	14.3	27.2	17.7	19.6	27.0
DC4	15.9	TC4	0.2	4.7	8.5	25.7	29.2	10.3

Simplified log-linear models derived from the categorical data analyses are presented (Table 5). In this type of model all the parameters being modeled are dependent variables. The ordering in the interactions in the model indicate the relative importance of the factors. All the models for juveniles, recruits, adults, and total for all sizes combined start with the interaction term DT, which indicates the auto-correlation of temperature with increasing depth.

The next interaction term (Table 5) indicates the relative importance of depth (D) or temperature (T) with catch rate (C). Juvenile redfish exhibited an interaction term (CD) which indicates that high catch rates were depth dependent. The mean juvenile CPUEs were highest in DC-2 for all years. Recruits, adults, and the total of all size classes exhibit interaction terms CT followed by CD. This indicates that recruits and adults had catch rates which were more temperature than depth dependent. The mean CPUEs demonstrate a preference for higher

TEMPERATURE

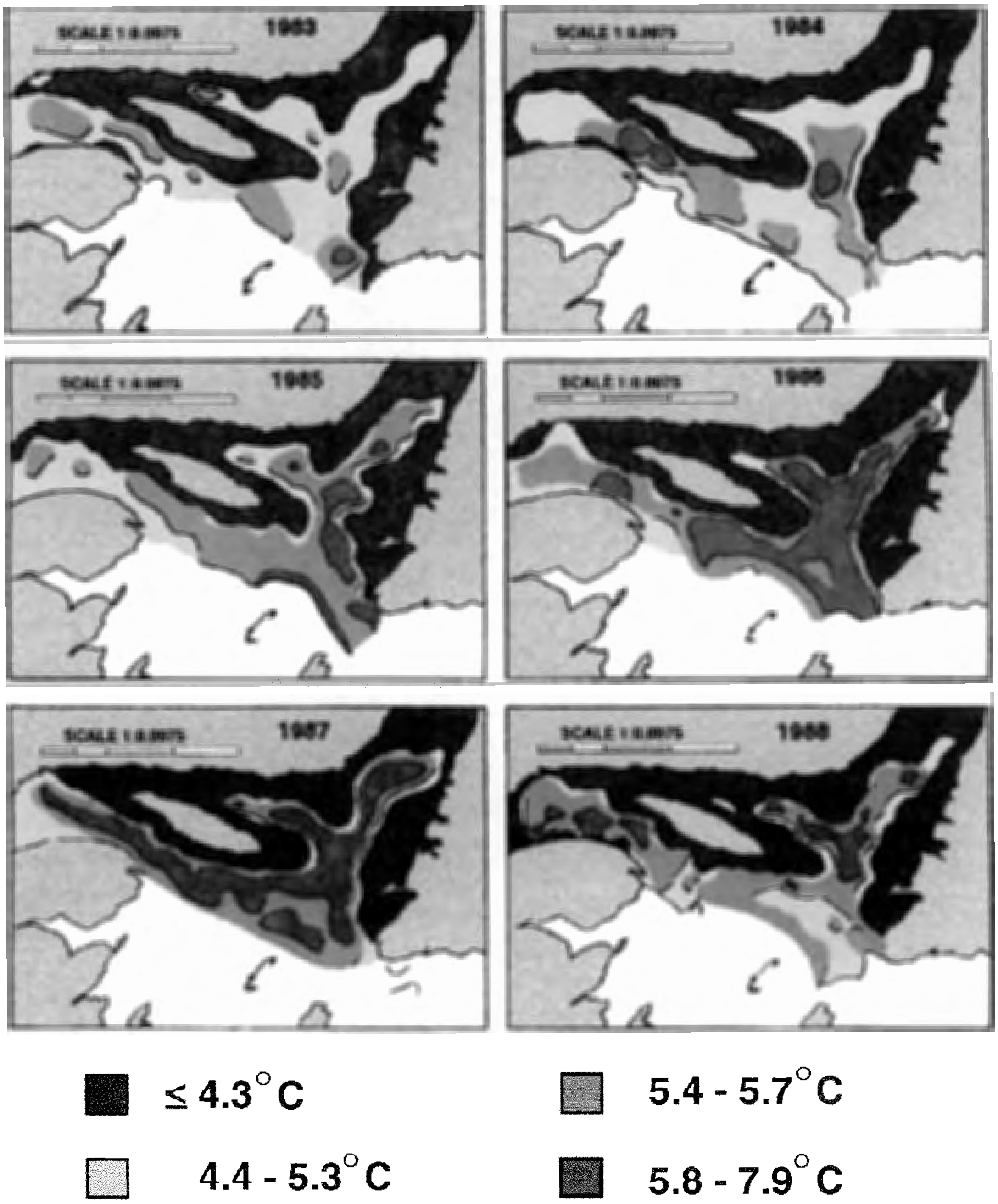

Figure 3. Changes in the areal extent of bottom temperature zones in the northen Gulf of St. Lawrence from 1983-1988.

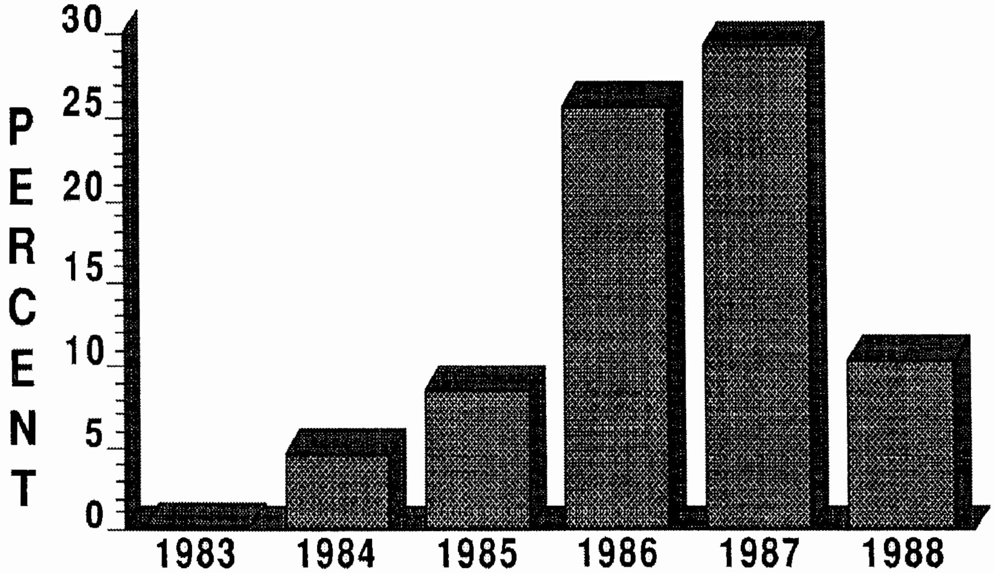

Figure 4. Relative changes in redfish preferred temperature areas (5.8-7.9°C) in the Gulf of St. Lawrence from 1983 to 1988.

Table 5. Simplified log-linear models derived using categorical data analysis of redfish Catch rates [C] in relation to Depth [D], Temperature [T]and Years [Y]. E = expected cell frequency, ϕ = average of the logarithms of the expectations.

Models	
Juveniles	$\ln(E) = \phi + Y + C + D + T + DT + CD + YT + YC + YD + YDT$
Recruits	$\ln(E) = \phi + Y + C + D + T + DT + CT + CD + YT + YD + YC$
Adults	$\ln(E) = \phi + Y + C + D + T + DT + CT + CD + YT + YD + YDT$
Total	$\ln(E) = \phi + Y + C + D + T + DT + CT + CD + YT + YD + YDT$

temperatures in TC-4 (5.8-7.9°C) for most years. The CT interaction also outwayed CD for the total catch of all size classes combined.

Of interest are the interaction terms involving year (Y). Juveniles have interaction terms YT, followed by YC, YD, and then YDT (Table 5). For recruits, adults, and all sizes combined the YT interaction follows CD. These terms with Y reflect the bottom temperature changes occurring between years.

Trends in population biomass estimates (Figure 5) derived from 41 depth strata, 4 depth strata, and 4 temperature strata from R/V surveys have been compared with trends determined from a non-linear production model from commercial CPUEs (Laberge and Hurtubise 1989). The 1983 population biomass estimate derived from temperature strata was only about 50% of the biomass estimated from commercial CPUE data. Lower population biomass estimates were calculated between 1985 to 1987 from the R/V stratification schemes compared to the commercial estimates. While the R/V population trends look similar, there are considerable differences in the estimated biomass for years such as 1985 and 1986. The estimates derived from the 4 temperature strata are believed to more accurately reflect the actual trends in population biomass.

The 95% confidence intervals (CI) associated with total population biomass R/V estimates (juveniles+recruits+adults) for the four depth strata ranged from 22-34% over the 6 years (Figure 5). The 95% CI associated associated with 41 depth strata ranged from 20-55% of the population biomass estimates for 1984-1988 (Laberge and Hurtubise 1989). The 95% CI derived from 4 temperature strata in the present study ranged from 20-38% of the population biomass estimates for 1983- 1988.

Discussion and Conclusions

Maps created by kriging bottom temperature data with SURFER (Figure 3) indicated anomalously cold conditions in 1983 and warmer than normal conditions in the GSL during 1986 and 1987. The temperature zone ranging from 5.8-7.9°C preferred by redfish contracted to 0.2% of the total area during 1983; then expanded to 25.7% in 1986 and to 29.2% in 1987.

There is a consistent DFO time series of oceanographic data collected in the GSL since the early 1950's during September of each year (Bugden 1989). Bottom temperatures (200-300 m) in the Cabot Strait off of SW Newfoundland (Figure 6) indicate a cooling trend from the early 1950's to the late 1960's. The mean bottom temperature rose from a low of about 4.0°C in mid-1967 to 6.1°C in late 1986. Mean bottom temperatures in the Cabot Strait during the mid-1980's reached the highest sustained values attained over the last half century. The temperature changes are largely density compensated through changes in salinity. Oceanic water was found to be forced up the Laurentian Channel by varying proportions of Labrador and Western Atlantic current water.

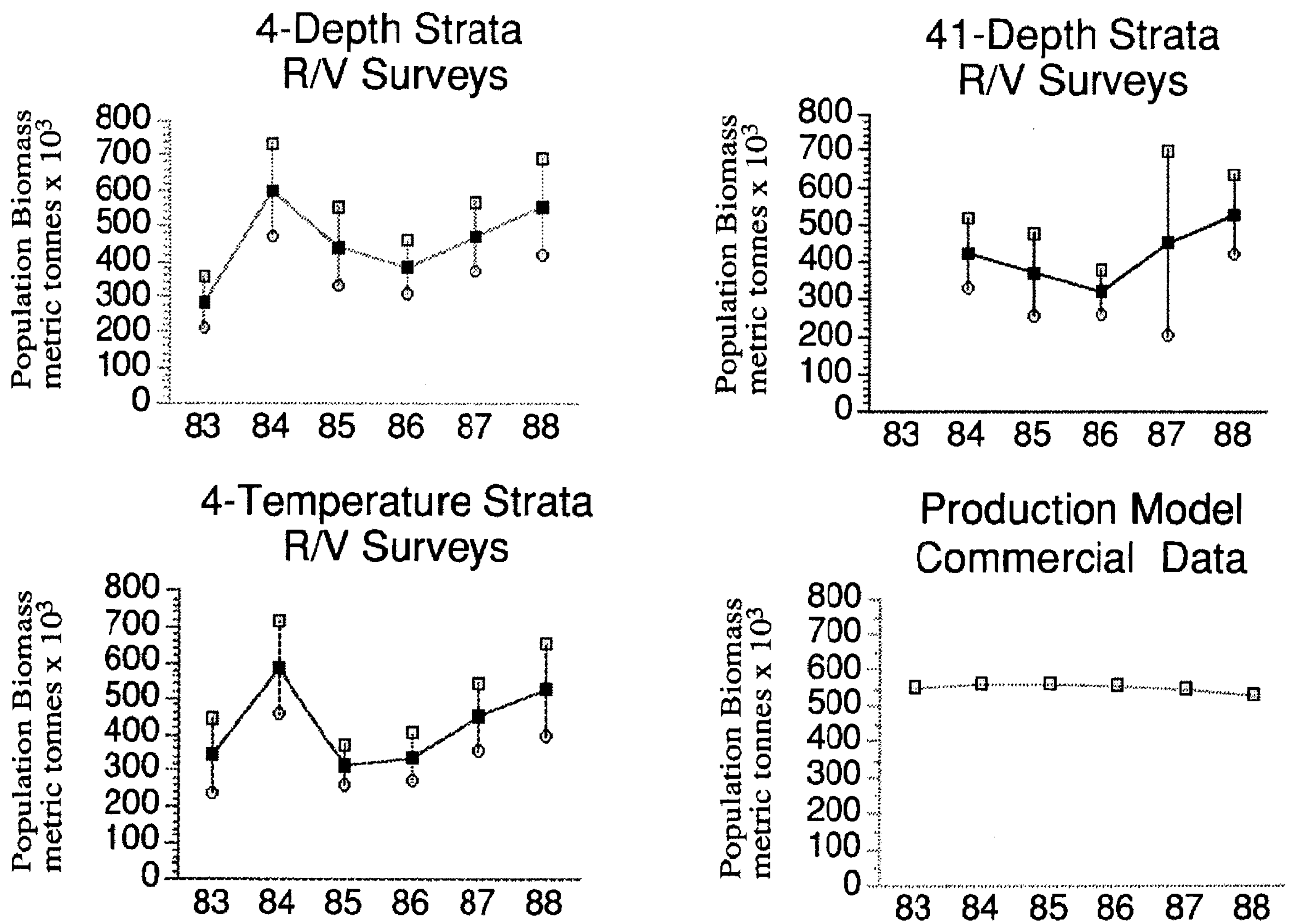

Figure 5. Trends in population numbers of redfish in the Gulf of St. Lawrence determined from research vessel stratification schemes and commercial data.

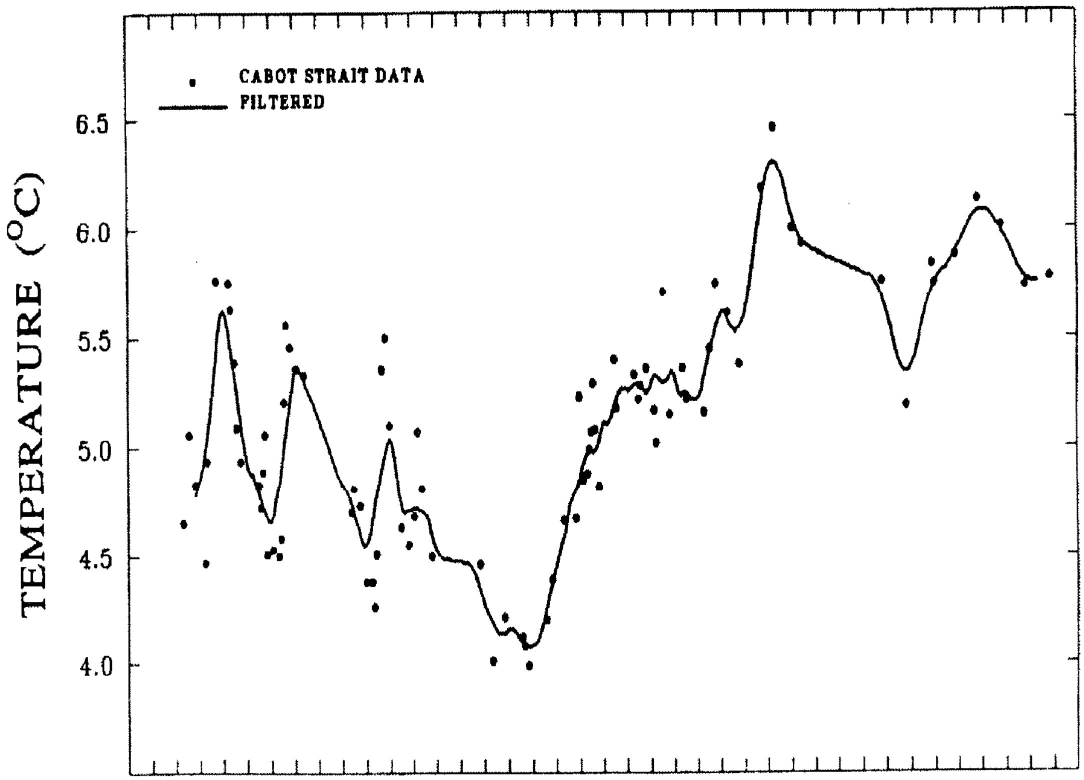

Figure 6. Trends in mean bottom water temperatures in the Cabot Strait area of the northern Gulf of St. Lawrence since the 1950's (Bugden 1991).

The bottom temperature changes during the 1980's in the Cabot Strait (Bugden 1989) appear to be related to atmospherically induced climatic change. A marked decline occurred in 1983, then bottom water temperatures increased during 1986 and 1987. These water temperature changes in the Cabot Strait tend to track global mean annual surface air temperature (Figure 7) changes during the 1980's (Easterling 1989, Smith 1990, Kerr 1990). There was a marked drop in mean air temperatures worldwide during 1983, which has been related to a strong El Nino/Southern Ocillation (UNESCO 1992, McPhaden 1994). The average global surface air temperature for 1987 was the warmest temperature recorded in this century. The record warmth in air temperatures during 1987 also appears to have been partly the result of an unusually strong El Nino/Southern Ocillation (Easterling 1989).

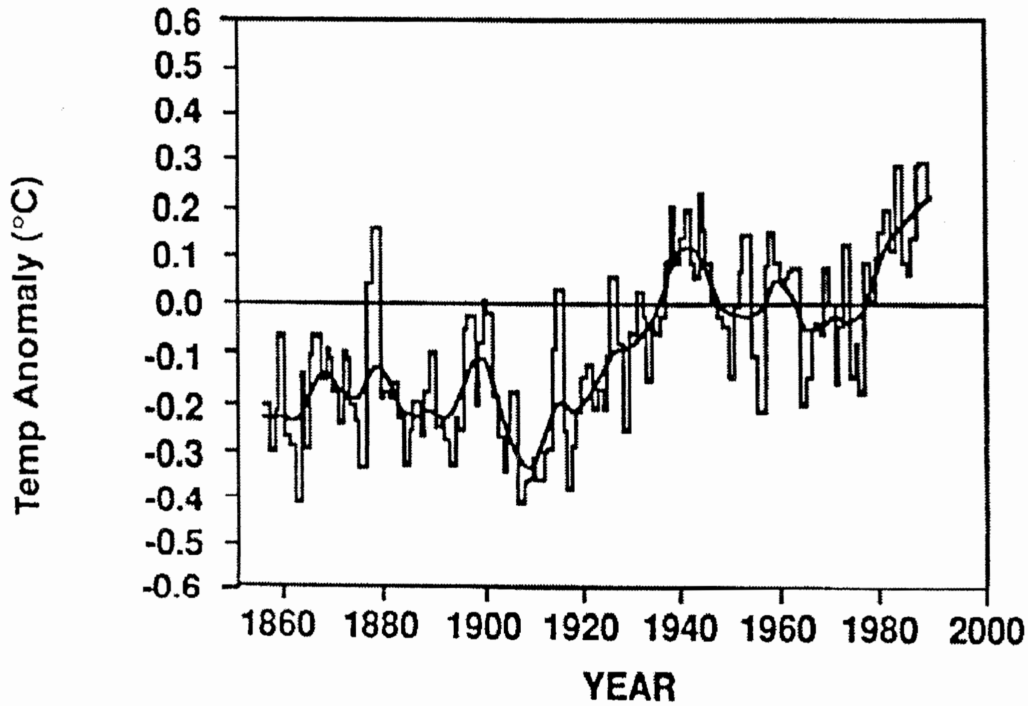

Figure 7. Changes in average global mean air temperatures from 1859-1989 (Kerr 1990).

While it is apparent that increases in atmospheric temperatures can induce changes in oceanographic water temperatures, the situation in the North Atlantic is more complex than that in the North Pacific (UNESCO 1992). The Atlantic can be characterized as an overturning ocean. Further studies are needed to understand the relationship between climatic variability and deep ocean current patterns in the Atlantic (Broecker 1995).

Catch rates (no./tow) were examined in the present study for three size classes of redfish in the GSL (Tables 2 and 3). Categorical data analysis indicated that juvenile redish catch rates were highest in DC-2 (184-244 m) for all years from 1983-1988 (Table 5). Recruits and adult redfish CPUEs were highest in a preferred temperature zone (TC-4) ranging from 5.8-7.9°C. Hence, the distribution of juveniles was primarily depth dependent, while recruits and adults were more abundant in the areas with the preferred temperature range.

Similar temperature preferences have recently been found with Pacific ocean perch (*Sebastes alutus*) on the west coast of Canada (Scott 1995). It was found that ocean perch prefer a temperature range of 4.8°C to 6.7°C and that their movement patterns were linked to the movement of water masses with these temperature zones being influenced by wind patterns. Scott discussed the fact that the catchability rarely remains constant and has been found to vary inversely with stock abundance and the area occupied by the stock. Catchability varies because the probability of catching fish is not dependent solely upon the amount of time spent fishing but also upon the probability of fish being present where one is fishing. Therefore effort should be redefined as the amount of preferred habitat sampled, such that the catchability represents the probability of catching fish per unit of preferred habitat.

Smaller estimated population variances were found in the present study by reducing the number of strata from 41 depth strata to either 4 depth or 4 temperature strata. Further reductions in population variances could be achieved in future surveys by increasing the number of stations in the preferred temperature zone associated with higher densities of redfish.

The mean CPUEs from the R/V surveys, averaged across depth strata or the entire area, did not appear to be directly proportional to population biomass. The shrinkage of the preferred temperature zone in 1983 was associated with a decline in the R/V CPUE, and about a 50% decline in the estimated total population biomass in comparison to 1984. It is believed that a large part of the redfish population avoided abnormally cold bottom temperature conditions by remaining outside the GSL during 1983. A limited amount of port sampling during 1983, in which the redfish species were discriminated by means of anal fin ray counts (Rubec et. al. 1991), would indicate that a large part of the deepwater redfish (*S. mentella*) population did not return to the GSL during the summer of 1983.

During 1986 and 1987, the redfish population was present in the GSL. However, mean CPUEs determined by depth strata may have been biased. The population dispersed over a larger area associated with the expansion of the preferred temperature zone. Population estimates derived by summing across the 4 temperature strata are believed to more accurately estimate inter-annual trends in population biomass.

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SEA's Use of Computer Based Tools: GIS to Spatial Decision Support Systems

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Introduction

This paper is for those who are considering putting a GIS facility in their agency. It is along the lines of a how-to do it. The Strategic Environmental Assessments (SEA) Division has evolved an elaborate GIS network by which it carries out digital mapping and produces a range of products. It interacts with other divisions within the National Oceanic and Atmospheric Administration (NOAA) as well as with other agencies to bring together digital data which are published in a variety of formats. SEA developed its present GIS related network by a trial and error process. It did not evolve from a predetermined plan. The present paper presents information, which may be useful to your agency.

This is for automechanics on how to create a GIS network. What did NOAA do? The agency is fairly typical. The GIS did not evolve because a group of wise men sat down three or four year ago and decided that this is the way it was going to be. In fact, that is not the way to do it. A GIS is loaded with pitfalls. SEA's GIS network developed through a process of evolution, in which we made mistakes, back-tracked a little bit, and looked a little ahead. This paper in introductory automechanics will describe SEA's use of GIS, technically and by example. While we want to describe SEA's use of GIS, that is not the priority right now. We want to emphasize that institutions are not hardware configured computers. *Institutions are primarily people doing jobs.* This is such a technical area that often this common sense principle is lost. We want to get beyond the technological jargon. The paper will focus on people doing projects, and projects that require certain spatial analytical skills The GIS network should be viewed in that context.

The SEA Division Approach

Points To Keep In Mind

We want to accent three things which are listed in Figure 1.

4. Symposium speaker

1) *Wise Software Selection* .

We have all had vendors come into our agencies, who have led us to believe that their point-and-click software on our screens will solve all of our problems. It is not going to happen. There is a need for making wise choices in acquiring software for work groups in an agency. However, it takes more than software.

2) *User-friendly data.*

If the data being analyzed is not user-friendly, few people in the agency are going to use it. It is just that simple.

3) *Modest Planning.*

Data processing staff and those who work on large computer systems, such as mainframes, are used to long range planning. Long range planning makes sense where the costs of the central system and its associated software are high.

Introduction

- Describe SEA's use of GIS and Networks, technically and through examples
- Focus on People, Projects, and Skills
- Accent: Wise Software Selection
- Accent: User-Friendly Data
- Accent: <u>Modest</u> Planning

Figure 1. The emphasis on people, projects and skills by NOAA SEA Division.

The software and computer technologies associated with desktop machines are changing rapidly. The costs for desktop hardware and software are modest in comparison to the central system. Hence, shorter time frames and modest planning can reap benefits in productivity and work efficiency. This is discussed later in the paper.

Distinctions Between High and Low End.

The high-end discussed in this paper refers to "Workstations" which use one of the UNIX operating systems. The low-end refers to the use of "Desktop" computers such as Macintosh and/or IBM-PC compatible machines running respectively either the Macintosh, or Microsoft's MS-DOS and/or the MS-Windows operating system.

A common mistake in creating a GIS system in an agency is to put most of the emphasis on the central data base(s) and the creation of high-end applications. The agency makes a large investment in converting data from the traditional hierarchical data base on a mainframe computer to a relational data base management system (RDBMS) such as Oracle, Sybase or Ingres. The latter may be associated with a series of servers that replace the mainframe. This migration to distributed computing has been termed "client/server".

The agency creates a central GIS laboratory facility using workstations, which are linked to the RDBMS. The system is expensive and requires highly trained personnel. Little thought is given to how staff outside the central GIS laboratory are going to use the RDBMS and GIS .

Description of SEA's GIS Network

SEA does a lot of mapping and data synthesis, but little modeling. The high-end and low-end applications being utilized at SEA have developed in parallel (Figure 2). That happened naturally early-on because they were different platforms. As such, SEA's office has a central GIS laboratory, called GeoCOAST, that feeds geographic files to SEA's main working-level staff, who are the main priority. The central GIS facility is not the priority. SEA's general staff are the priority.

The office has two branches, which emphasize electronic data capabilities. The first branch has the central GIS laboratory conducting data management and GIS utilizing high-end workstations running GIS software such as ARC/INFO and programming/statistical analysis software such as the Statistical Analysis System (SAS) tied to Oracle and SAS data bases (Figure 3). The second branch controls spatial decision support systems (SDSS) using low-end desktop machines. In SEA the low-end has been primarily Macintosh desktops. However, with recent improvements in graphical user interfaces (GUIs) (e.g. MS-Windows 3.1 and OS/2) more IBM-PC compatible microcomputers are being purchased.

How does SEA benefit from that? We didn't want to be slaves to GIS. In many offices that is what has happened. The working level people at the low-end, who need tools on their desk to do analyses, end up becoming slaves to the high-end GIS. We don't think that is the way to do it.

General Environment

- High-end and desktop approaches <u>in parallel</u>
- Look to desktop first (now changing)
- Flexibility to project managers on selection of computer tools

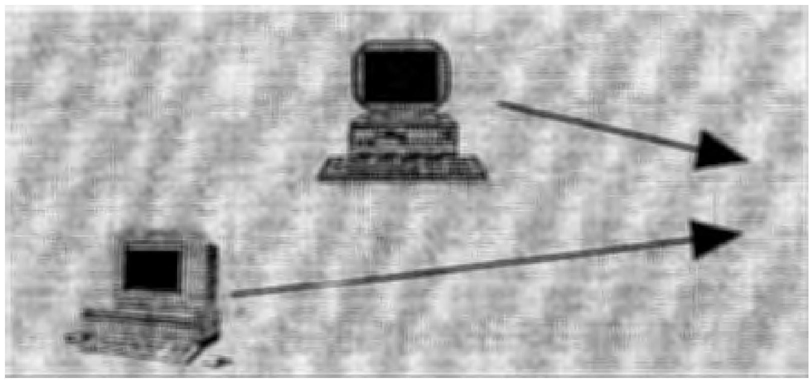

Figure 2. High-end and desktop approaches working in parallel.

The Office

- Central GIS Laboratory (GeoCOAST)
- Each staff member with one computer
- Emphasis on mapping and data synthesis
- Two branches emphasizing electronic capabilities
  - data management and GIS (high end)
  - decision support systems (low end)
- Electronic products include:
  - high resolution digital geographies
  - desktop information systems
  - simple spreadsheet-type files

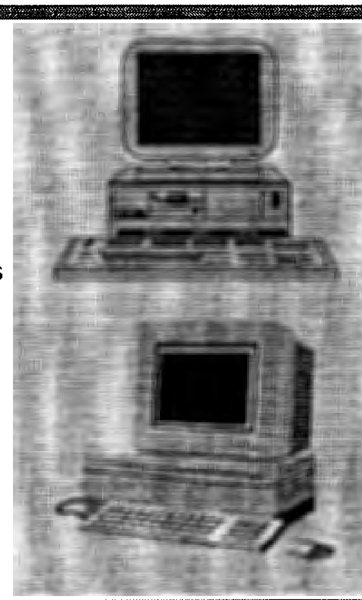

Figure 3. The main components of a GIS network in use by the SEA office.

The emphasis for the whole division is put on the timely production of information (Figure 4). This includes electronic products and printed materials derived from the digital information. This can include high resolution digital geography such as detailed base maps, and more simplified maps, graphics, and tabular data produced by the general staff. The emphasis is on making the best use of human resources. This involves taking advantage of their skills and knowledge.

Programmatic Considerations in Software Selection

- Timely information delivery and products
- Human resources
    - specific skills and knowledge
    - numbers/locations of people
- Work process
    - basic/raw data development
    - analysis and/or synthesis
    - presentation
    - electronic distribution

Figure 4. Software selection in relation to human resources and the work process.

The SEA Division work process (Figure 5) involves four steps including: 1) basic raw data development; 2) analysis and/or synthesis of that data; 3) presentation of that information; and 4) electronic distribution. The flow of work is planned by sharing map files and data over the network. Different staff carry out different phases of the work, and there are different tools and different people involved in each of these activites. A large part of this work is done on the desktop microcomputers by 65 to 70 general staff.

Wise Software Selection

There are practical considerations in software and hardware selection (Figure 6). The high-end GIS systems are wonderful machines. They are multifunctional, flexible, and allow high-level analyses. Their disadvantage is that they require highly skilled personnel, and are not very interactive. The workstations and associated UNIX-based software are expensive ($10-50K). There is generally a slow turnaround.

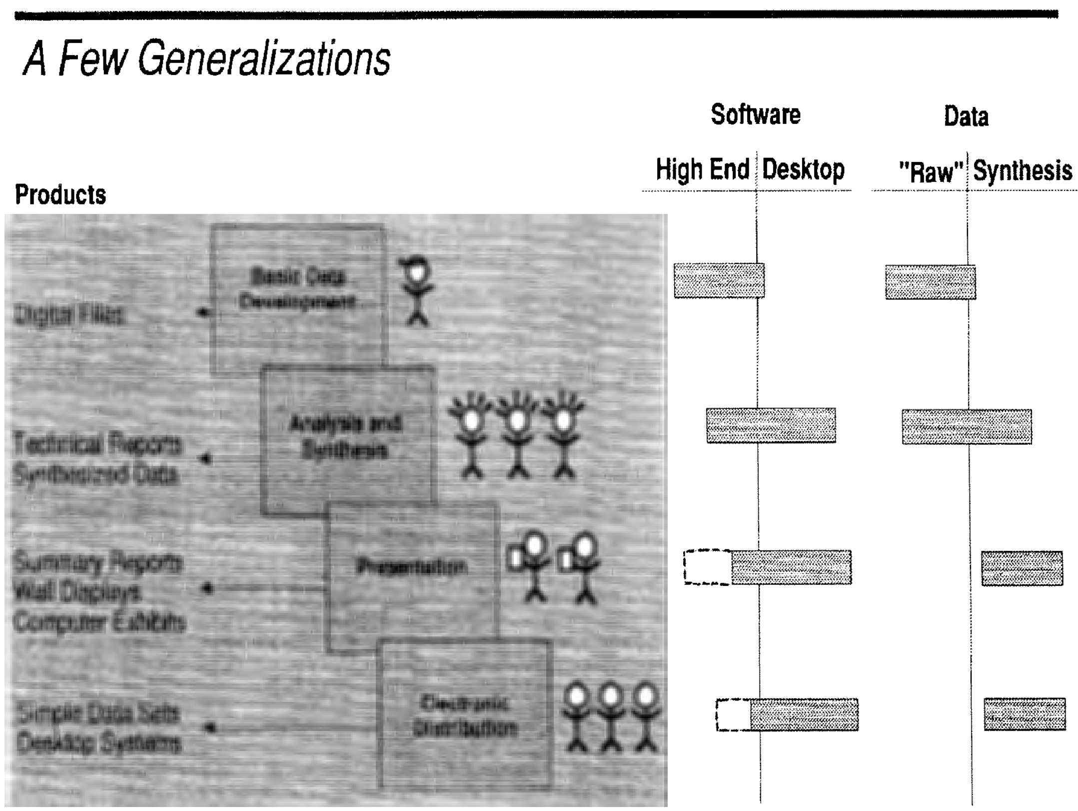

Figure 5. People at SEA sharing spatial data to develop products.

Generally speaking, GIS staff are specialists with degrees in geography, remote sensing, image analysis and/or data processing. A person trained in the use of a GIS system, such as ARC/INFO, needs to use it on a regular basis to maintain his or her skills.

On the other hand, if some of the spatial analytical tools are made available at the working level, one can get static but functional analyses done on desktop machines (Figure 6). This software is highly interactive, and can be used by many personnel. There is no reason why an expert fisheries biologist has to go to a fancy workstation to do multilevel mapping, contouring, or simple spatial analyses. This type of software is available on both Macintosh and PC-based desktop machines. An example is the spatial analyses of redfish (*Sebastes* spp.) done by the first author using SURFER. There is a faster turn around, and a much lower cost associated with the hardware and software for the desktop machines.

Both workstations and desktops are necessary when planning the creation of a GIS network for an agency. Yes, there is overlap between the two approaches (Figure 6). Is the area of overlap getting bigger? Relatively speaking, we don't think so. The whole pie is expanding. High-end GIS systems are getting even more powerful. We are getting high-level capabilities on the workstation, that we wouldn't have thought of several years ago. The desktop is also expanding both in the speed of the machines (Pentium, Power Macs) and their software capabilities. We can now do more types of spatial analyses on the desktop. Making some investment in desktop spatial analytical software tools early-on is going to pay off.

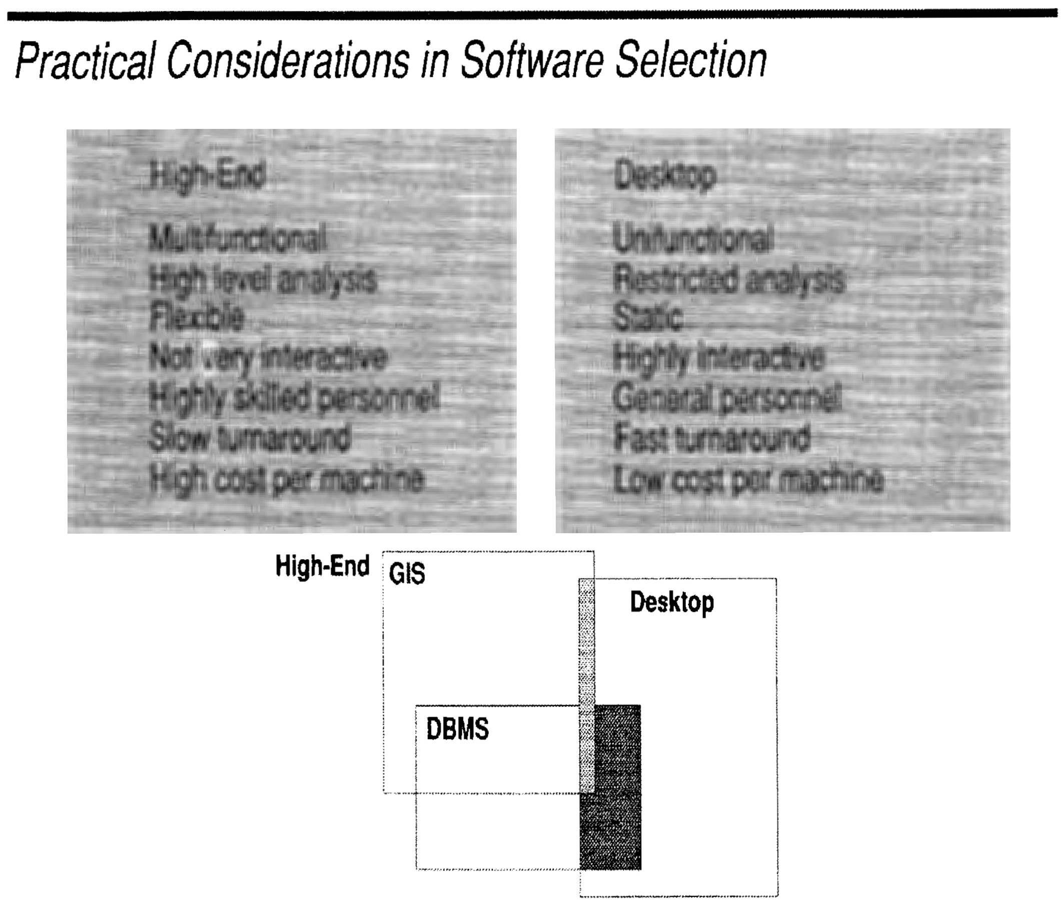

Figure 6. Relative capabilities of GIS workstations and spatial desktops tied to a data base management system (DBMS).

User-friendly data

Raw data is unusable to many legitimate users (Figure 7). Many people cannot deal with raw data. An example is world-class geophysicists in England who were terrified of GIS. They thought that the workstations locked them into a very formal approach. SEA staff sent them some simple Macintosh mapping software packages. The geophysicists were soon entering their own data; and doing many spatial analyses on their desktop Macintosh computers.

Raw data has little use for many purposes (Figure 7). If there is peer support and people want to synthesize data, one can convert data to a useful form. Raw data can be organized to a user-friendly form. Much of what you see in reports is summarized data. It can also be stored in a database in electronic form.

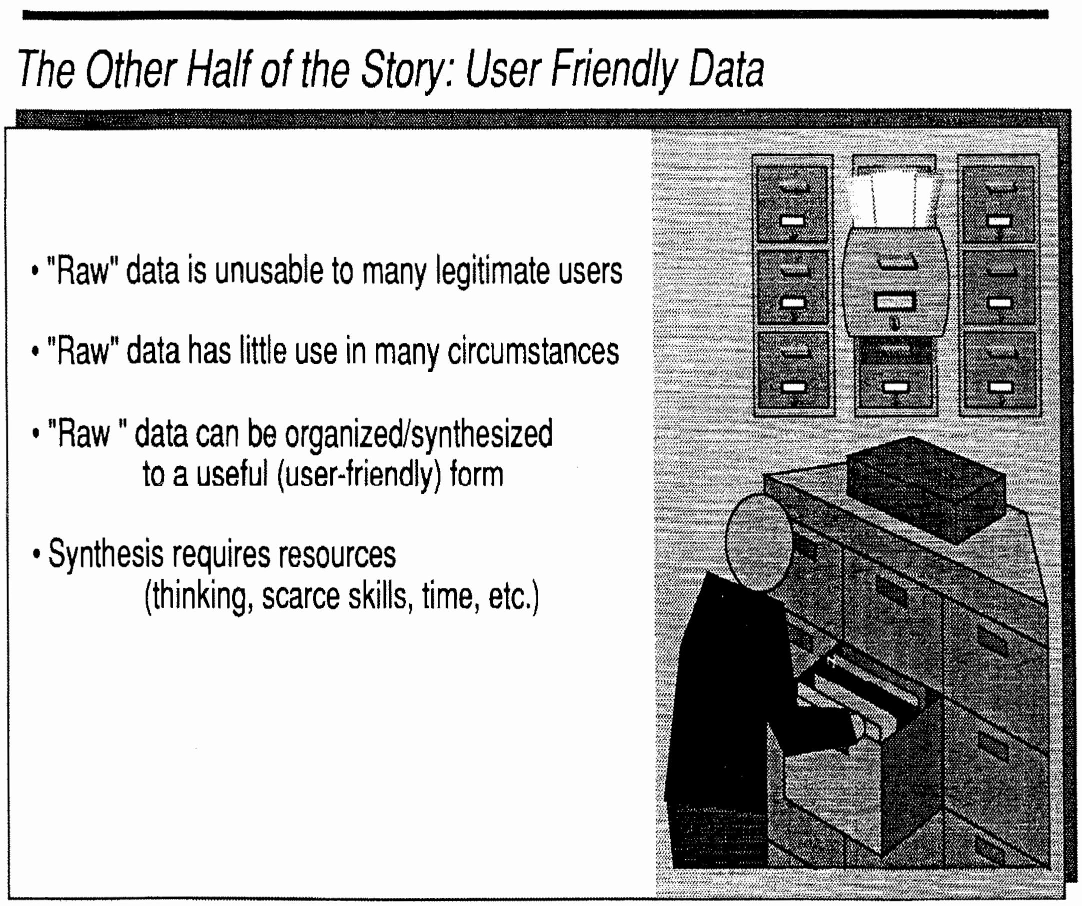

Figure 7. Disadvantages of raw data for many potential users.

Synthesis requires a source of raw data. One must enter the raw data, and store it in an appropriate computer format. Considering the time and large sums of money expended on monitoring programs; it is necessary for agencies to spend the relatively modest amounts needed to convert raw data into summary information. While the whole process does not come cheaply; institutions must commit themselves to producing synthesized information.

Basic Data Development

Some examples of basic data development and syntheses being conducted by SEA include the following: 1) The division has been developing maps at 1:250,000 scale of the coastal drainages of the United States. This is a major project of the office. The product is being distributed on CD-ROM in a variety of formats; 2) Temperature maps off the northeast coast of the United States and Canada were developed from raw temperature data obtained from the Northeast Fisheries Center in Woods Hole and the Canadian Department of Fisheries and Oceans. A gigabyte level raw data base was processed in SPANS to produce user-friendly vectors, which were exported to the desktop; 3) Salinity data was contoured to produce vectors from point measurements. Salinity contours from U.S. estuaries were mapped under high and low freshwater inflow conditions. These contour maps are being used with forcing functions and as a habitat parameter in analyses of species distributions on desktops.

The kriging functions to do the contouring of temperature or salinity data are available on desktop computers for about $250. Data that occupied gigabytes on the mainframe can be reduced to one or two megabytes for analysis on the desktop. It can then be distributed on floppy disk and used for a variety of projects.

Productivity Benefits

If an agency does not make some investment in analyzing its data and converting it into usable information; it will under-utilize its human resources. By planning the work flow, less time and money is wasted on activities that don't lead to useful products. In SEA's office, there are more than 50 users doing thematic mapping on desktop computers.

Personnel familiar with the main data bases use SAS and Structured Query Language (SQL) programming to access the original data in order to produce summary statistics. This summary information is then made available to other staff over the network, who work with it on the desktops. Point source information is overlaid on digital base maps to produce a variety of map products.

Put the common sense points together. Different people at separate stations producing different products. Every project is different and the data requirements differ at different phases. A manager seeking to establish a GIS installation should think about who is going to benefit. Is it going to help this or that group?

SEA's Hardware Configuration

How is it done? Here's SEA's configuration (Figure 8). The division has moved to a client/server environment. It's main GIS is ARC/INFO with ARCVIEW Version 2 presently (1994) being implemented on the desktops. There are 15-20 high-end users associated with the GeoCoast facility and 65-70 users at the low-end sharing files over the network. SEA has a large GIS facility with Macintosh desktops and UNIX-based workstations. The end-user community obtains a considerable amount of information over the network through data administrators. Standard applications such as standard geography files, synthesized data files, and shared data files are available to all staff on the server. Everybody in the SEA office can do multilayered, very complex maps.

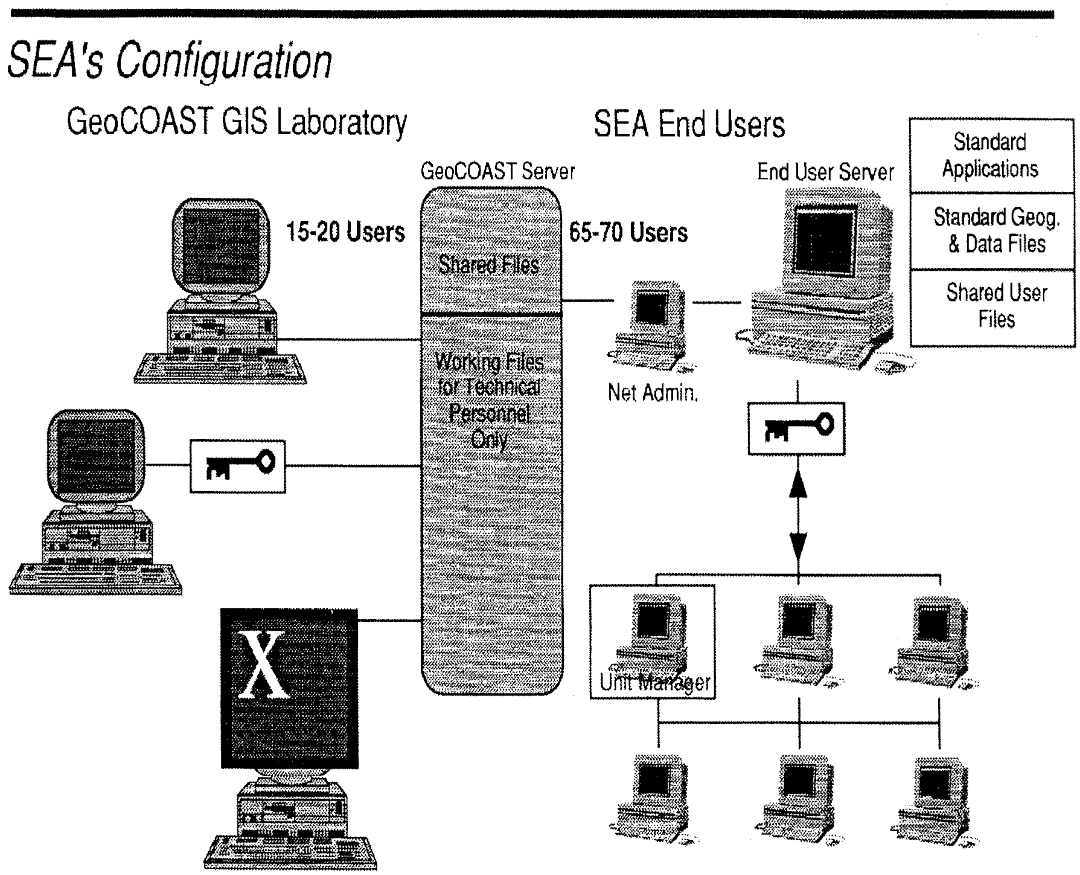

Figure 8. The hardware configuration of the SEA Division GIS network.

User-friendly desktop mapping and desktop spatial analysis software became available on the Macintosh several years ago. The GUI facilitates carrying out complex operations. Most people can learn to do it.

The division keys all of its software. It buys multiple copies of certain software applications to ensure that it is restricted at the user level.

Network administrators are responsible for supervising 6 to 7 end-user machines. Some staff spend 20% of their time as network people, since nobody wants to do it full time. They do it as a break from their regular work. It is not a dead-end network management position. Network administrators are recommended to oversee work and maintain system integrity.

Applications and Files

Here is the software and files that have been put up (Figure 9). Notice the difference between the low-end, where there is a wide software suite, including statistics, desktop mapping, graphics, and word processing packages. While at the high-end, a very restricted high level package is maintained to store standard geographies and project specific maps.

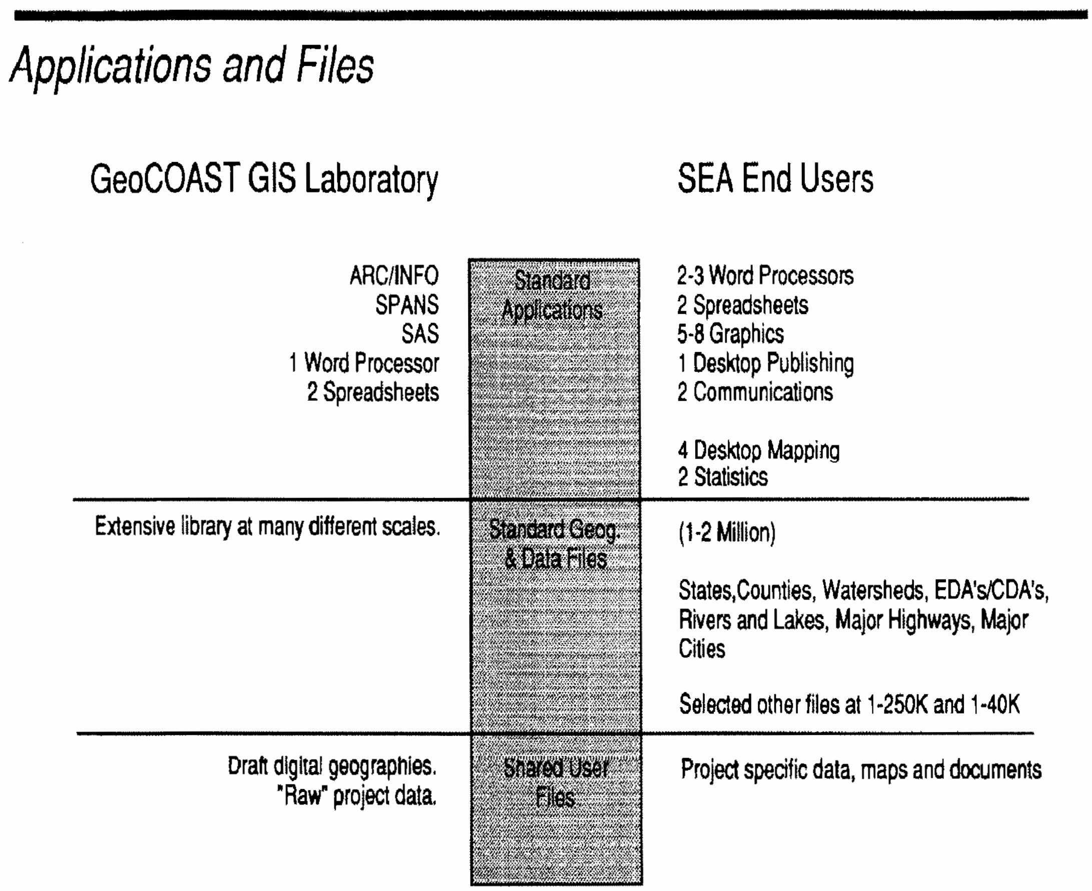

Figure 9. The applications and files in use by the GeoCoast laboratory and SEA end users.

Costs of GIS Network

What is the cost to set all of this up? Anywhere from $200,000 to $500,000 (Figure 10). It cost the division about $12,000 for the main server using Macintosh equipment, which is a little higher than for PCs. The standard geographies, standard data files and shared user files for all 65 users cost about $15,000. The cost of each end-user desktop with associated software and Ethernet card was $3,500. This includes a wide selection of user-friendly software.

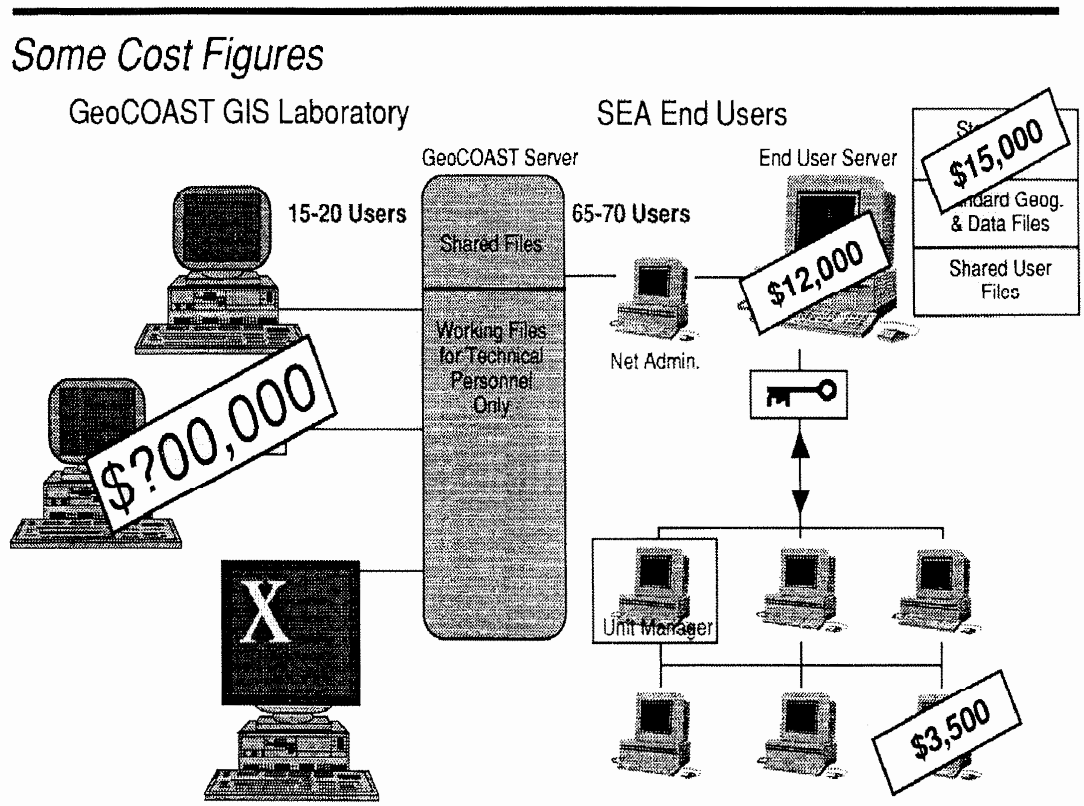

Figure 10. Relative costs of the SEA GIS network at the high and low ends.

Modest Planning

Your agency is going to spend three to four years planning the implementation of the high and low ends of a GIS network to suit its needs for managing marine resources (Figure 11). That is what it took the SEA Division. If you go to various GIS installations; they will tell you the same thing.

Reorient your planning from first considering the high-end (Figure 11, top) to the low-end (Figure 11, bottom). Ask. Where am I now? Where can I be in six months that is totally under my control? Can I have my people doing maps at their desk? Can I make investments in software that will allow them to do spatial analyses right now? Can I put machines together in a simple way to allow people to share and store files? These are attainable goals.

The first thing you should ask when setting up a major GIS installation is; how is this going to benefit the staff six months from now? What are they going to be able to do six months from now that they can't do now? We don't mean the people in the GIS laboratory; we mean the general staff.

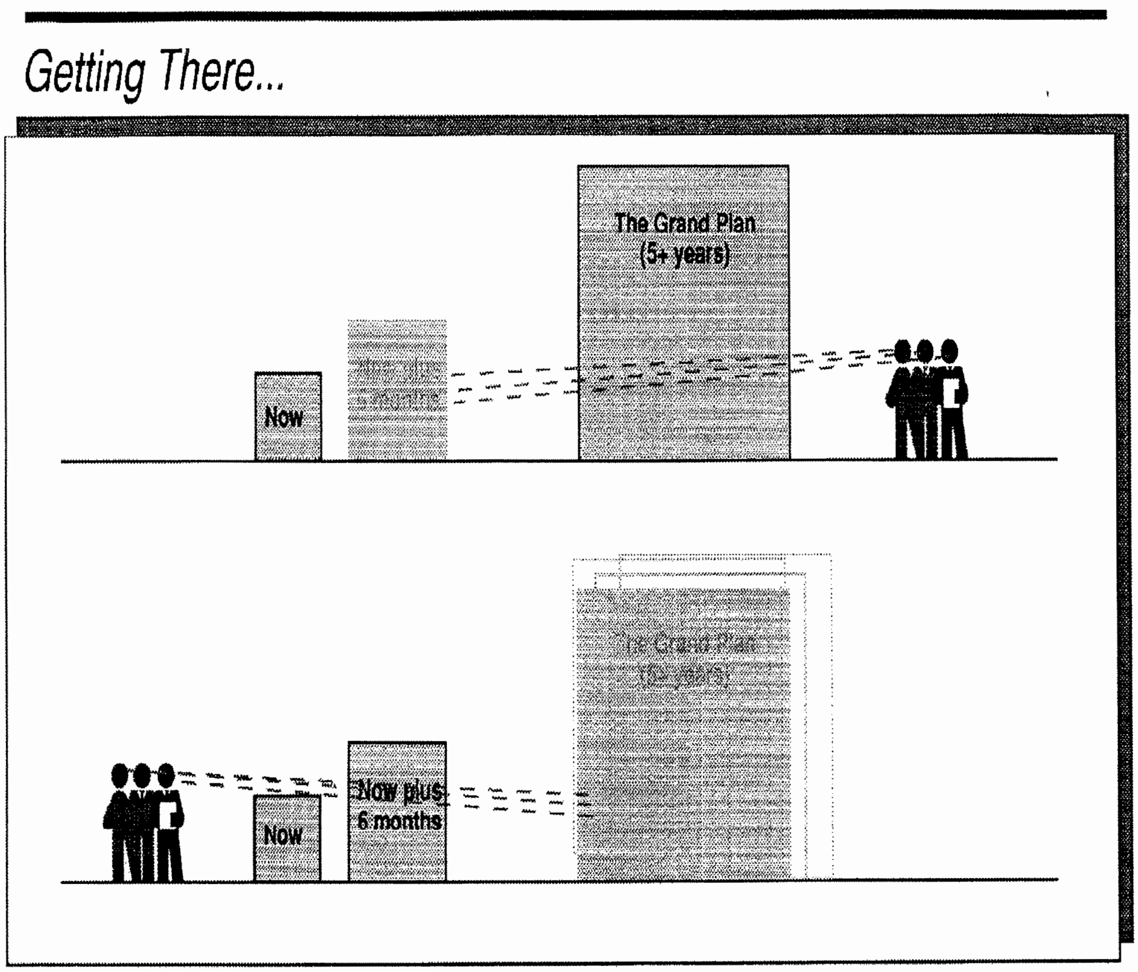

Figure 11. The GIS planning horizons from the high and low ends.

Conclusion

We recommend that any agency seeking to establish a spatial analysis network should first consider purchasing the low-end (Figure 11, bottom). If you start with a network of desktops with spatial software, your general staff will be more productive sooner. The initial cost is lower than starting at the high-end. The emphasis should be on acquiring hardware and software to start producing a product in the short term.

Once the work force for the short-term is operational, the planning horizon can shift to the long term. Having done some spatial analysis projects on desktops will enhance your agency's credibility. That will help your group to obtain funding for larger programs that require the use of high-end equipment. Maybe, it is good that the grand long term high-end plan (Figure 11, bottom) is hazy. You are not going to make any big mistakes. The high-end will be considerably better and cheaper three to four years from now.

COMPAS and the Evolution of SEA's Desktop Information System Program

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Introduction

Five years ago, the Strategic Environmental Assessments Division (SEA) began a limited program to explore the usefulness of desktop information systems to improve the delivery of information for coastal and ocean resource management decisions. This paper describes the lessons SEA has learned in the evolution of COMPAS, the Coastal Ocean Management, Planning, and Assessment System, from its inception in 1989 to the present. The COMPAS Program and other similar efforts have produced a wide range of information, techniques, and tools for Federal, State, and local institutions.

The Problem

The problems of effectively managing conflicting resource uses within the coastal zone of the U.S. continue to frustrate environmental resource managers and decision-makers. One of the many reasons often cited for these problems is the poor application of our existing information base to specific management needs. All too often information well-suited to assisting in a particular management question is not accessible to those charged with the management responsibility. The COMPAS program was designed to specifically address this information delivery dilemma. COMPAS is a desktop information system designed to bring information to state resource managers responsible for oversight and guidance of coastal resource use. The program is part of continuing Federal/State partnership activities of the National Oceanic and Atmospheric Administration (NOAA). COMPAS is funded in part by NOAA's Coastal Ocean Program.

Development of Desktop Information Systems

For the past decade, SEA has been developing national data sets and information on various coastal and ocean resource use topics. In the mid-1980s, SEA began to evolve a series of microcomputer-based information systems designed to provide its own staff with greater access to these data when performing program-related analyses or responding to inquiries from outside

1. Symposium speaker.

sources. The success of these early systems among its own staff and encouraging comments from individuals outside SEA led to the creation of an exploratory program in 1987. The simple goal of the program was to experiment with new ways to provide information and capabilities affecting decisions on coastal and ocean resource use. The program was conceived as a limited effort, primarily experimental. There was no master plan nor fixed directions; initial emphasis was on flexibility. Program strategy was allowed to evolve as circumstances changed, technology advanced, and new opportunities arose.

Original Concepts

Two concepts guided initial efforts. The first was straightforward in both concept and execution: microcomputers could be used to enhance access to information pertinent to coastal resource decisions. Even in these relatively early days of microcomputer technology, the potential benefits of desktop computing were quite clear. The second concept was that to be effective in resource management, information must be simple and easily understood. Raw data is of little use in most contexts. Creating simple and easily understood information directed to various possible uses may require a considerable investment in data analysis, data synthesis, and data base design. It is a *knowledge-engineering process* (Basta and Ehler 1993).

Initial Efforts

To evaluate these initial concepts, SEA developed two desktop Spatial Decision Support Systems (SDSS) for external distribution to interested users. These systems had three operational characteristics. First, they focused on standard regional (i.e., multi-state) data sets gathered and supported by government institutions; second, they contained only a single data type (e.g., commercial harvest of specif ic species); and third, application software was custom-designed.

The first system, the Computer Mapping and Analysis System (*Cmas*) for Gulf of Mexico Shrimp Harvest, which was a cooperative effort between the National Marine Fisheries Service (NMFS) Galveston Laboratory and SEA, took about 18 months to develop (SAB 1988). It contains 30 years of monthly catch statistics for seven shrimp species, 13 size categories, 21 statistical areas, and 11 depth zones. Data is updated every year. Capabilities include menu-driven query, schematic mapping (Figure 1), tabular summaries, and simple graphs. The system has become a principal management tool of the fishery and is used by scientists of NMFS, resource management agencies of Gulf states, and by several universities in research projects.

The second system, Colonial Seabirds of the West Coast of North America (SAB 1990a), was requested by scientists of the U.S. Fish and Wildlife Service who participated in a cooperative development effort. Released in 1990, the system contains best estimate numbers of 50 seabird species at 2,400 colonies along the west coast from Siberia through California. It contains an extensive on-line bibliography for researchers, high resolution mapping (Figure 2), simple query, and simple spatial analysis. This system has been distributed to Federal and State agencies, universities, and private sector companies and individuals. Uses have ranged from research analysis

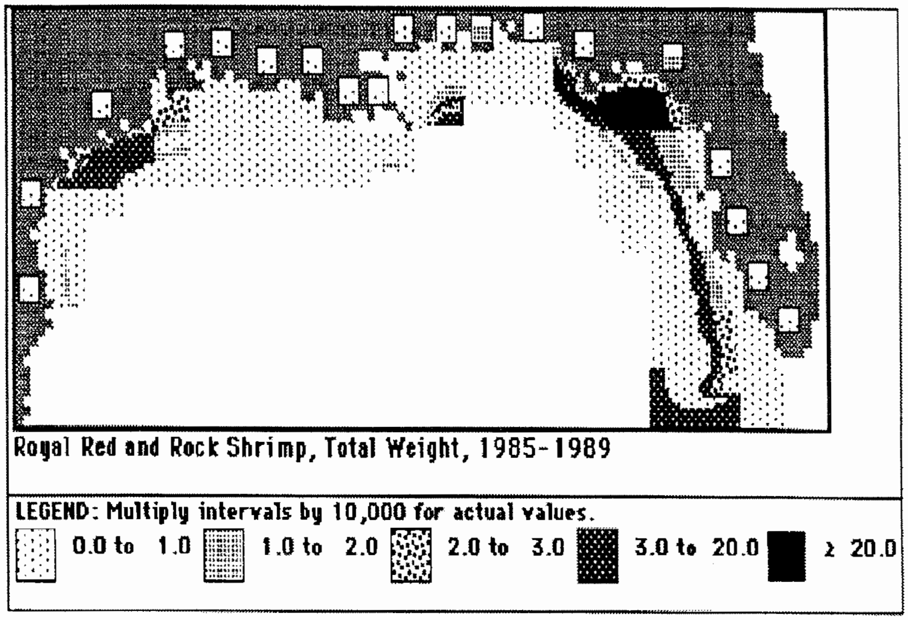

Figure 1. A schematic map of Royal red and Rock shrimp commercial harvest.

to oil spill litigation and land purchases. The modest success of these experimental systems encouraged SEA to expand and formalize these efforts. In 1989, COMPAS, a new SDSS program, was conceived.

COMPAS Program: New Concepts

The COMPAS program added two important concepts to those previously discussed (SAB 1989). First, information should be targeted to state and local institutions to effect coastal resource decisions. Most resource management decisions are made at the state level. From its inception, COMPAS was designed as an extension of NOAA's Federal/State partnership program. COMPAS products would be focused to individual states; product development would be a cooperative effort between NOAA and state personnel. Second, information provided in COMPAS products should cover various topics to affect decisions. Unlike previous products, COMPAS was not designed as a single dimension or single-use product. It was designed to meet uses considered important to NOAA's cooperating state partners. The multi-dimensional design of COMPAS was completely consistent with SEA's program of strategic assessments of the Nation's coasts and oceans (SAB 1990b).

Information from one of SEA's strategic assessments, the National Estuarine Inventory (Alexander and Monaco 1993), was synthesized and crafted into a schematic COMPAS prototype system (Figure 3) which was previewed to several states to gauge interest. NOAA's Coastal Ocean Program provided a multi-year partial funding base, and Texas was selected as the first COMPAS state. Work on the first COMPAS product began in late 1989.

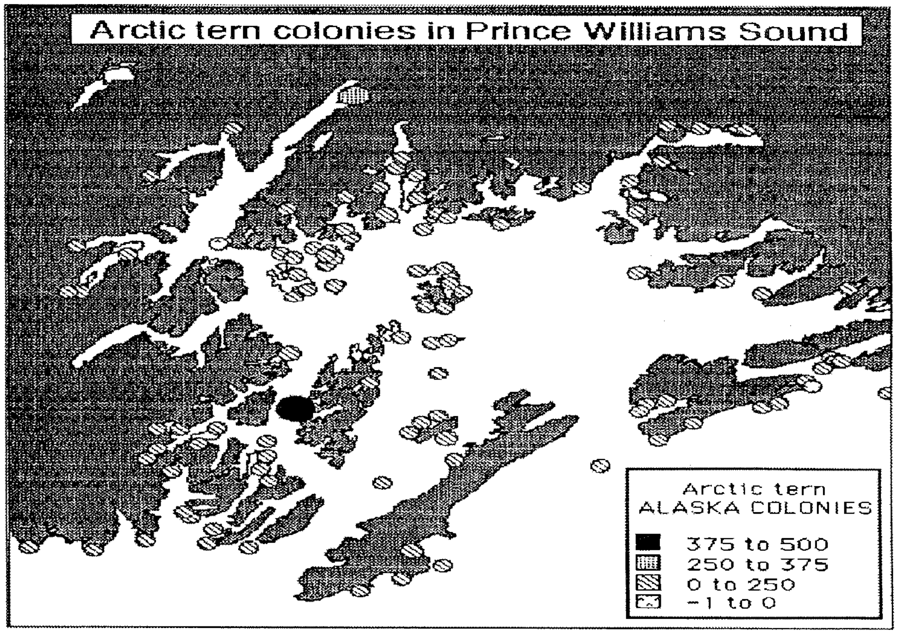

Figure 2. A map of arctic tern colonies in Prince William Sound (map resolution is 1-250k).

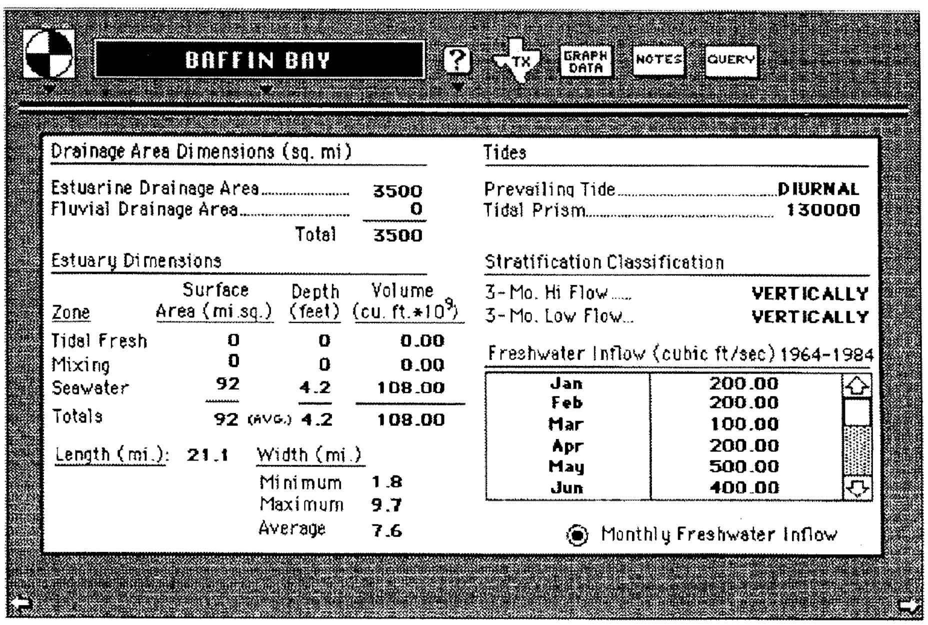

Figure 3. Physical and hydrographic data for Baffin Bay estuary from initial COMPAS prototype.

COMPAS Texas: The COMPAS Process

Although SEA's desktop system program has tried to maintain flexibility, this flexibility was seriously challenged in the development of COMPAS Texas. Early in this project, the state of Texas (and it turns out, other states as well) placed the highest priority on the development of synthesis, user-friendly information from their own data sets. In the case of Texas, these data sets consisted of massive amounts of raw data. While it is one thing to evolve synthesis information from a single data set, it is quite another to expand this process to multiple data sets in several institutions, and to coalesce them into a single desktop product.

SEA did not anticipate the scope of this task. To accomplish this the Texas project devoted its principal focus to crafting the raw data into useful and *easy-to-use information*. This required a deliberate process that included identifying priority issues, inventorying data sets, establishing data set priorities, determining relevant spatial aggregates, winnowing and consolidating data to the most salient features, and controlling data quality. The process resulted in identifying water-use management and coastal tracts important issues to the state. Data sets related to these issues (e.g. water rights, water-quality monitoring, and stream segment standards) became the focus of the analysis data sets (Figure 4).

Additionally, since many of these data sets even in synthesis form were very large (tens of thousands of records), a decision was made to build COMPAS around a powerful relational data base management system. Oracle was selected as the data base foundation of COMPAS because of its multi-platform compatibility and its use of Structured Query Language (SQL), the industry standard. Once the data were synthesized, the process continued with the development of data

COMPAS Texas

Lead State Institution:	Texas Water Commission
Other Cooperating Institutions:	Texas General Land Office Texas Railroad Commission Texas Natural Resource Information System Texas Water Development Board Texas Parks and Wildlife Department
<u>NOAA Data Sets</u> Housing and Population Land Use Marine Resources Pesticide Use Physical and Hydrologic Characteristics of Estuaries Pollution Sources Public Recreation Facilities Shellfish Wetland Habitats	<u>Texas Data Sets</u> Coastal Tracts Streamflow Gages Stream Segment Standards Wastewater Permits Water Quality Monitoring Water Rights Permits

Figure 4. Participating state institutions and data sets in COMPAS Texas Product.

structures within the data base management system and the specification of query and view capabilities for the information.

The actual product of COMPAS projects, an electronic desktop system, has a certain allure in this highly technological era. Nonetheless, the cooperative information development process--the COMPAS process begun in Texas and since refined in Florida and Oregon--has become the centerpiece of the COMPAS program. This was recognized by a panel of state and federal resource management experts that reviewed the program in the fall of 1991 as the Texas product was nearing completion.

In addition to evolving the COMPAS process, the Texas project identified several broad capabilities that served as a basis of software development. The most important of these were: 1) a simple point-and-click interface for generating complex SQL queries; 2) portrayal of information as simple screen views for immediate access; 3) map portrayal and spatial queries; and 4) directed navigation through the product.

COMPAS Texas (Figure 5) was completed in June of 1992. The state of Texas is using COMPAS for both operational programs and special projects. Applications for new water-rights permits are assessed in view of information for existing permits, water-quality monitoring data, and historic streamflow records, all of which are included in COMPAS. Wastewater discharge permit applications are evaluated against water-quality data. Information from COMPAS has been used in developing a state water bank, establishing the boundary for the state coastal management program, and assessing the impacts of changes in freshwater inflow to Corpus Christi Bay.

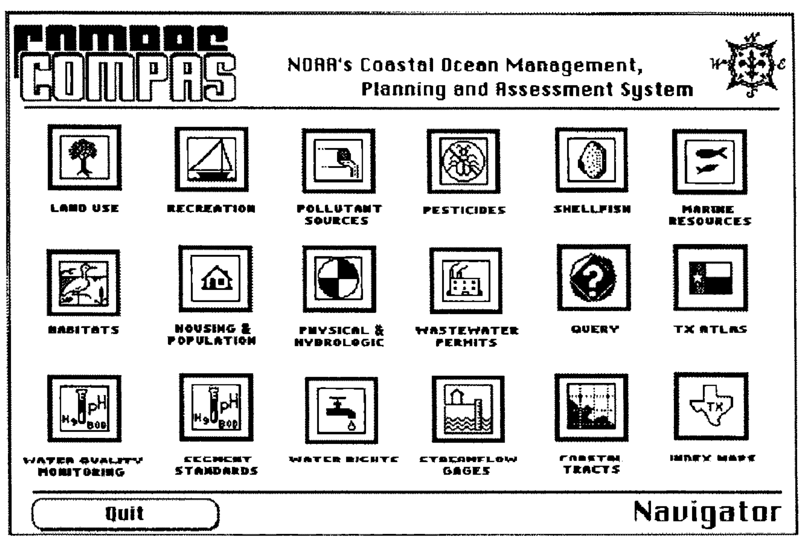

Figure 5. Navigator screen from COMPAS Texas application showing types of information in final product.

COMPAS Texas: New Program Directions

The COMPAS Texas project provided NOAA with essential experience on which to frame a series of decisions governing the program. Fundamental of those was SEA's decision to support the COMPAS process as defined in Texas with generic software (i.e., software that could be used in many circumstances and for many types of information, without the need for additional programming). This software would serve two objectives which would be planned into its design.

First, it would provide a necessary framework for the information development process (see "COMPAS Texas: The COMPAS Process"). The process of transforming raw data into synthesized information is a formal process. It cannot be done in the abstract. The production of a desktop information system product provides an important structure for assessing the appropriate delivery of this information to end users. Since the information may be of many different types *generic* software capable of accommodating various data was essential.

Second, the goal of COMPAS has always been a product that could be implemented by many states without the long-term involvement of NOAA staff. Thus, not only would the software have to be generic, but it would also have to be sufficiently easy-to-use so state agencies could develop a COMPAS product without a major investment in staff resources for a prolonged period. However, no single product can be all things to all users. To address this need, the COMPAS development team defined four types of users of COMPAS products:

- **Read-only User**. This is the most important user category. This individual uses the product and associated data to extract information, develop reports, etc., for resource management purposes.

- **Simple Database User.** This type of user adds data sets to the preloaded COMPAS data base. Additionally, this user may wish to create simple card views of this data together with data already in the product.

- **State COMPAS Database Manager.** This user manages the state COMPAS data base. He/she understands the basic principles of relational data base design and can create complex custom views and product features requiring some technical skill and/or training.

- **COMPAS Development Team.** This team provides training to the state COMPAS manager in the use of COMPAS tools, assists state managers as necessary in developing products, and manages and upgrades, as appropriate, the computer code in COMPAS software applications.

The COMPAS Florida project, the second state in the COMPAS development program, would serve as the platform for developing these capabilities. The third COMPAS state, Oregon, would be the initial test case.

COMPAS Florida: Database Design and GIS Information

The COMPAS Florida project began in 1991. At that time, NOAA was beginning a cooperative project of federal, state, and local resource management agencies to develop the management plan for the newly designated Florida Keys National Marine Sanctuary (Figure 6). To complement the management plan, NOAA and the state agreed that the COMPAS project would have a special focus on the sanctuary where both NOAA and the state had mutual management interest. This focus, however, would not be at the expense of statewide information. Both NOAA and state data for the entire state would be incorporated in the product.

The lead Florida agency was the Executive Office of the Governor. Ongoing project support and technical capabilities were provided by the Florida Marine Research Institute (FMRI), knowledge and management needs of state sanctuaries by the state Bureau and Sanctuaries and Research Reserves. Besides NOAA's principal focus of refining the COMPAS process and producing the generic application software, the project team evolved two additional areas of emphasis: relational data base design and high-level Geographic Information System (GIS) data. The Texas project provided SEA with some experience in the usefulness of relational data structures. The project team believed that a more robust relational design could be very effective. Over the past five years, FMRI has been evolving a sophisticated GIS for the entire state of Florida. The FMRI staff viewed COMPAS as a vehicle for distributing this information into a form usable by field personnel.

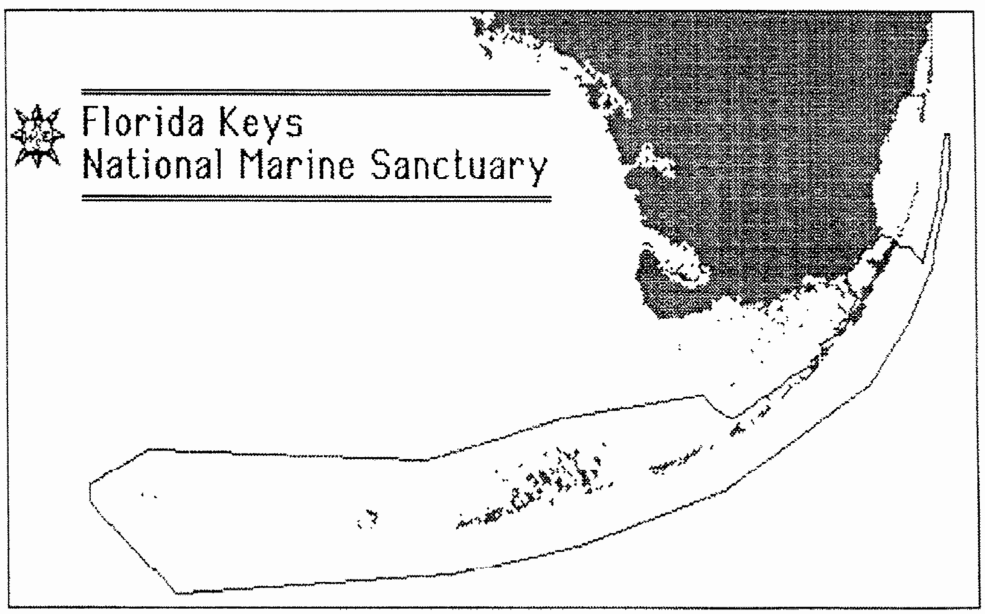

Figure 6. Area of interest for Florida Keys National Marine Sanctuary focus of COMPAS Florida project.

These two areas of concentration ultimately became one in the course of the project. The data base design was unified spatially with the following defined spatial units for the entire state of Florida: Counties, NOAA's estuarine drainage areas, and a five-minute grid established by Florida as an official reporting unit for land- and ocean-based data. For the Florida Keys, the units are: Key Segments (upper, middle, and lower), Key Tracts (17 areas based on U.S. census tracts), and a similar one-minute grid. This design allows point information (e.g., pollution point sources, shipwrecks, reefs, etc.) to be maintained as point data. Querying and/or aggregating point data by spatial units is done by the user through application software. Similarly, since the point data are normalized, revisions and updates are a single step process.

Information content of the product (Figure 7) initially focused on the Florida Keys. Priority management issues identified were: 1) loss of seagrass; 2) loss of coral reef (Figure 8); 3) diving and snorkeling activities; 4) enforcement; 5) groundwater quality; and 6) navigation. Data sets identified to address these topics included: benthic habitats, shipwrecks, natural and artificial reefs, boat-use surveys, enforcement actions, sanctuary vessels, groundwater quality monitoring, septic tanks, injection wells, boat groundings, mooring buoys, and navigational aids. Other data sets of more general use were sitings of endangered and threatened species, and protected areas. Several of these data sets have already been included in the product, while others are being investigated by SEA and Florida staff.

COMPAS FLORIDA

Lead State Institution:	Executive Office of the Governor
Other Cooperating Institutions:	Department of Environmental Protection Florida Marine Research Institute Bureau of Sanctuaries and Research Reserves
NOAA Data Sets (stationwide)*	Florida Data Sets (Florida Keys)*
Housing and Population Pesticide Use Physical and Hydrogrologic Characteristics of Esturaries Public Recreation Facilities Shellfish Wetland Habitats	Artificial Reefs U.S. Census Shipwrecks Marinas Benthic Resources Common Reefs Protected Areas Florida Natural Areas Inventory Enforcement Actions

*Interim Florida COMPAS Product

Figure 7. Participating state institutions and data sets in COMPAS Florida product.

Attention has now shifted to the entire state. Specific management issues and data sets are still being formulated. Candidates include propeller scarring in seagrass beds, recreational and commercial boating activities, and manatee/sea turtle mortalities. Besides these data sets, numerous geographic files (or coverages) from FMRI's GIS facility are being ported to a commercial thematic mapping application that will accompany the product (Figure 9). Selected coverages will be translated to SEA's COMPAS Windows Query Map application (see "COMPAS Windows") as reference maps for spatial queries.

A demonstration version of the COMPAS Florida product was completed in February 1993 and previewed to the state of Florida and Florida Keys Sanctuary personnel. Many comments from the previewers were incorporated into the final product design. The product was scheduled for completion in October-December 1993.

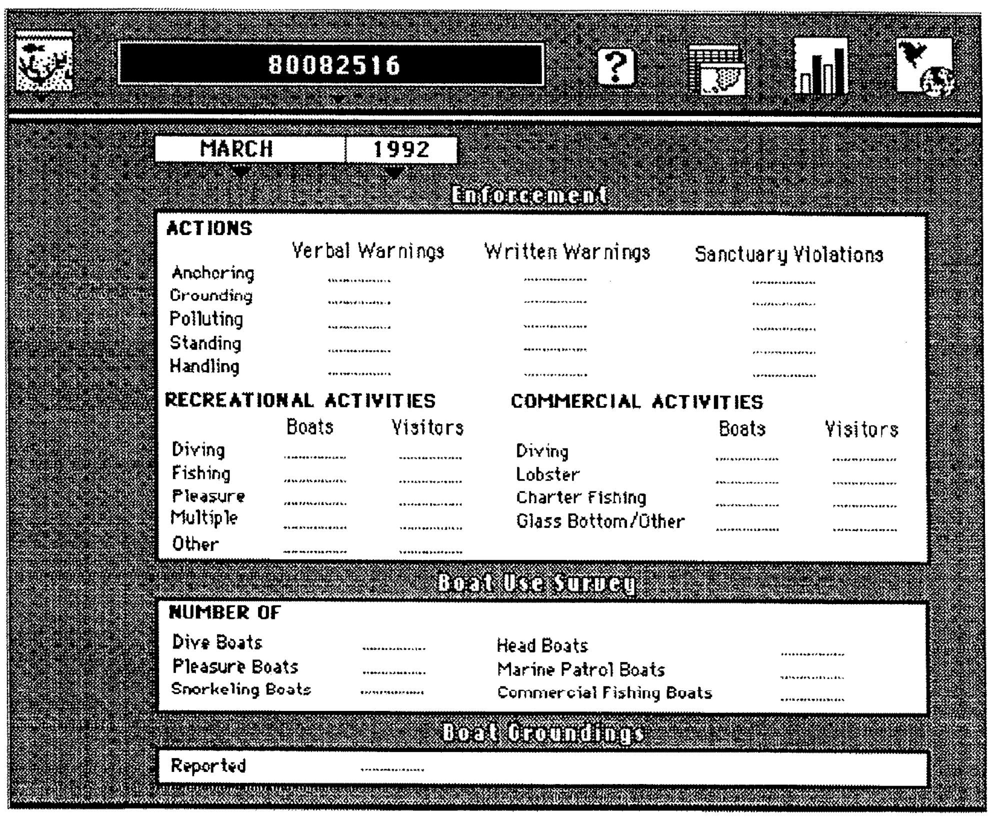

Figure 8. Screen showing data accessed to examine activities related to coral reef loss from a demonstration version of the COMPAS Florida product.

Geographic Files In Compas Florida Product

State Of Florida	Florida Keys
Counties	Tiger Files
EDAs	Protected Areas
NOAA Navigation Charts	Key Segments
Rivers and Hydrologic Units	Key Tracts
Streams and Lakes	1 Minute Grid
State Agency Jurisdictions	Bathymetry
State Waters	State Waters
Census Tracts	Draft Replenishment Zones
5 Minute Grid	Draft Sanctuary Preservation Area
	Area to be Avoided

Figure 9. Geographic coverage included in COMPAS Florida product.

COMPAS Florida: Improved Capabilities

The highly structured character of the COMPAS Florida process was an excellent development environment and allowed SEA to adhere to its plan to evolve the COMPAS software tools. Some of these tools were expanded and/or generalized versions of software developed for COMPAS Texas (e.g., the text query of COMPAS Windows); others were entirely new. COMPAS applications are also being developed so as to be independent of one another. This provides a maximum of flexibility to both future developers of COMPAS products and end users in that they can choose which applications they want or do not want to use. The three principal COMPAS applications include: COMPAS Windows, View Builder, and The Navigator.

COMPAS Windows

COMPAS Windows, an integrated application of three basic capabilities, provides a user with a point-and-click interface for managing data and querying the data base. Data Manager provides a series of data loading, editing, and data management features for enhancing and/or customizing the COMPAS data base. With Query Text (Figure 10), the user can make numerous database queries, ranging from a simple query of a single data set (or table) to a complex multi-table query with column joins. Query Map (Figure 11) is a spatial window in the data base. Spatial queries are developed directly with simple pointing tools on a map surface.

View Builder

With this application, the user can develop simple card views which combine information from various parts of the data base. This is especially useful when addressing management issues

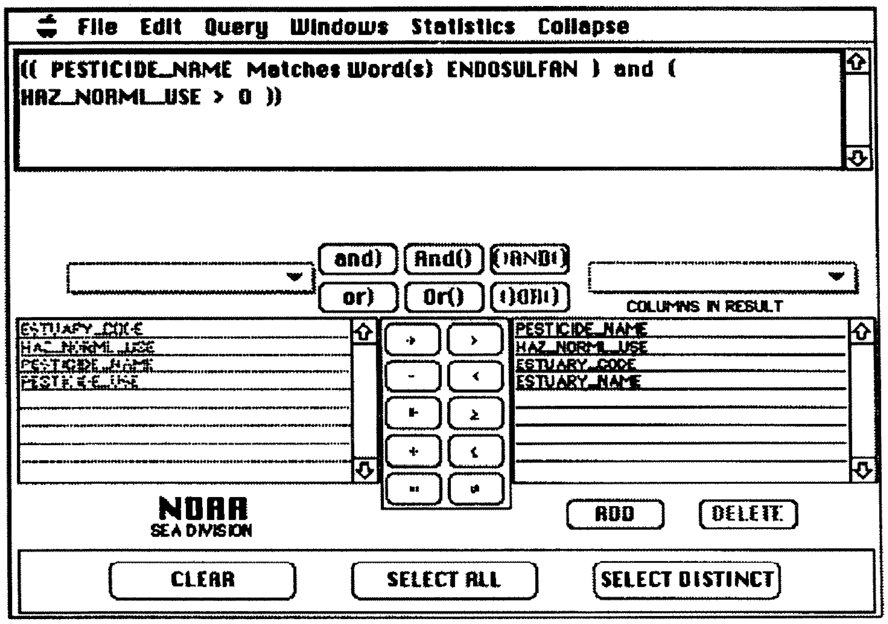

Figure 10. Example query on pesticide use from COMPAS Windows Query Text.

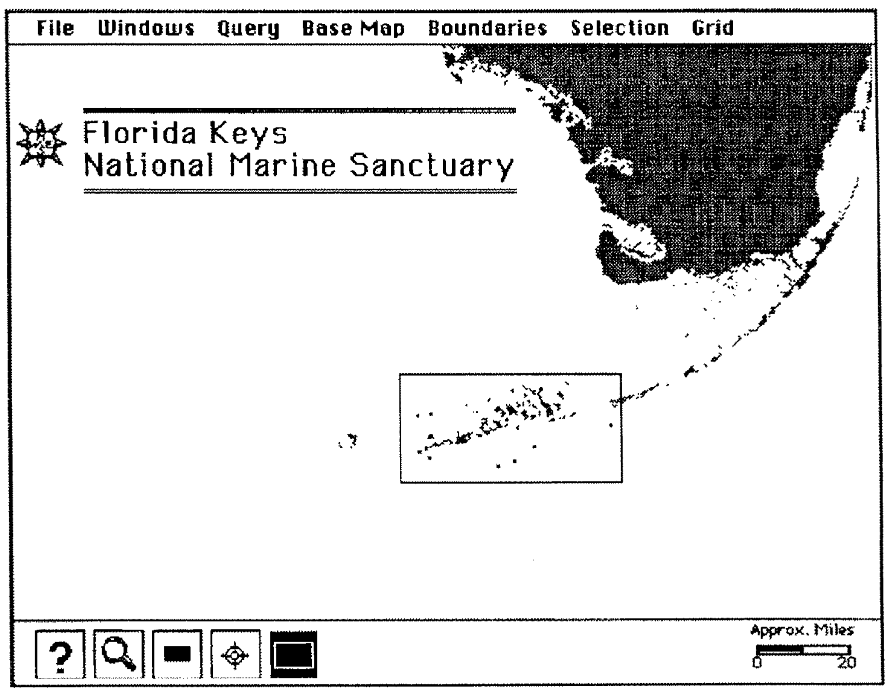

Figure 11. Spatial selection of shipwrecks from COMPAS Windows Query Map.

which may require the simultaneous display of information from several data sets. In addition to simple queries, View Builder (Figure 12) supports numerous data aggregations, and allows the user to customize the look and navigation of the view through pull-down menus, dialog boxes, and other standard interface features. Users can add associated pictures. Because views directly access the data base, they are automatically updated as the data base is revised and/or expanded.

The Navigator

The Navigator (Figure 13) is a standard entry point from which a user can access various parts of the product. Additionally, the Navigator supports on-line Help, data documentation, and a picture-based electronic atlas.

COMPAS Oregon: New NOAA Role

Oregon is the third and final state in the COMPAS developmental program. This project began in late 1992; work began in earnest the following spring. The lead Oregon institution is the Oregon Department of Land Conservation and Development, with numerous other Oregon agencies participating in initial issue and information assessment work sessions.

The Florida project provided a basic set of COMPAS process techniques and software tools to implement COMPAS in various regional, state, and substate (e.g., watershed) contexts. As COMPAS matured in Florida, the relatively small SEA staff devoted to developing these systems could not continue to work directly with staffs in many individual regional and state institutions to develop specific data and complete products. Regardless of the specific characteristics of any particular product, the concepts and skills of bringing information closer to decisions is the essence of the program. For this concept to take hold, staff in individual states must assume leadership responsibilities.

This change in roles has been the focus of the Oregon project. SEA's responsibilities are primarily technical/technique training of state personnel and providing assistance in project planning and the technical aspects of product development. This *behind-the-scenes* role is providing NOAA with key experience in assessing methods of the transferring *process* or knowledge-engineering concepts and skills. NOAA is using this experience to codify the COMPAS process with a series of guidebooks and standard forms which will be of general use in future COMPAS-type efforts.

Initial surveys of state agencies have identified numerous coastal issues including: public access, shoreline alterations, coastal hazards, water quality, and others. Work is being done to refine issues and identify appropriate data sets and geographic coverages. Plans are to complete the project within a year, a much shorter development cycle than previous projects.

With the conclusion of the Oregon project, the COMPAS program will have completed its developmental work. The result will be a suite of information, techniques, and tools that, applied thoughtfully, can assist state governments in improving the information content in coastal resource

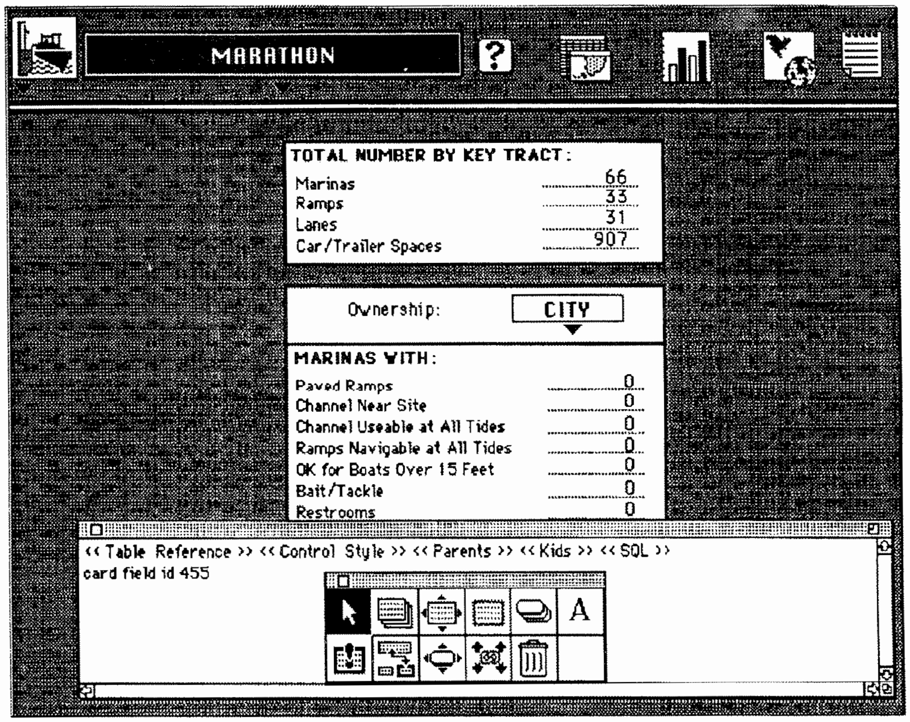

Figure 12. Constructing a card view for marine facilities in the Florida Keys with View Builder.

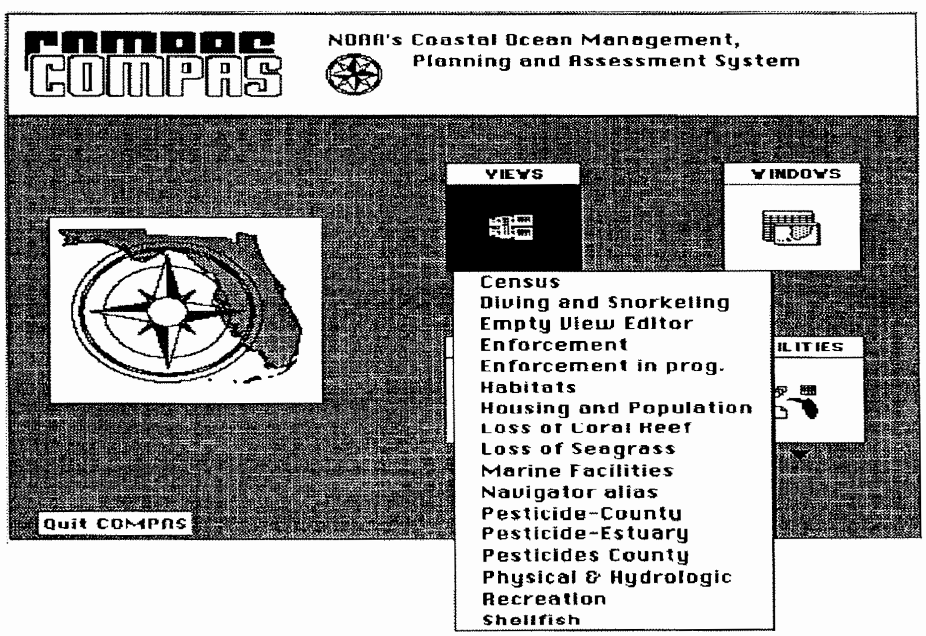

Figure 13. The COMPAS Navigator provides direct access to all elements of a COMPAS product.

decisions. Future COMPAS projects should require only limited involvement by SEA. However, to the extent feasible within resource constraints, SEA will provide continuing assistance (i.e., planning, technical training, etc.) to government agencies actively pursuing COMPAS or COMPAS-type efforts.

Other Developments

The previous discussion focused on SEA's COMPAS program. As this program was proceeding, SEA was developing several other desktop information tools which emphasize thematic mapping and spatial analysis. These tools derive from SEA's long programmatic history with mapping dating back to the regional strategic assessment atlas series initiated in 1979 (Ray et al. 1980). They are also in response to numerous conversations SEA staff had with coastal resource managers that strongly indicated a pressing need for desktop mapping capabilities.

The Mapping Toolkit

The Mapping Toolkit is a set of independent applications that emphasize simple query and direct thematic mapping. The applications, which work directly with commercial software products (i.e., ATLAS*Mapmaker [Strategic Mapping, Inc.] and Microsoft Excel [Microsoft Corp.]), are designed to take full advantage of SEA's growing library of digital geographic files resident in its GeoCoast GIS laboratory. The applications include:

- **Stackmaker.** With this tool a user can easily create HyperCard stacks from a spreadsheet data set. The created stack is automatically provided with numerous capabilities (Figure 14) including multivariate query, direct thematic mapping of exported data, and arithmetic derivatives.

- **Shellmaker.** Similar to the COMPAS Navigator, Shellmaker allows users to combine many data sets or stacks into a single product. Its features include dynamic updating, data documentation, and an on-line bibliography.

- **Map Generator.** This tool provides a point-and-click interface for the creation of complex multi-layered thematic maps.

- **Clipper.** This tool clips geographic files to any user-specified, georeferenced rectangular window. This allows users to extract a region of interest from a single geographic file of a large area.

Like COMPAS the Mapping Toolkit is generic and easily accommodates end-user data. An example product was developed by NOAA's National Status and Trends (NS&T) staff (Gottholm and Harmon 1993).

The Mapping Toolkit was partially funded by EPA's Environmental Monitoring and

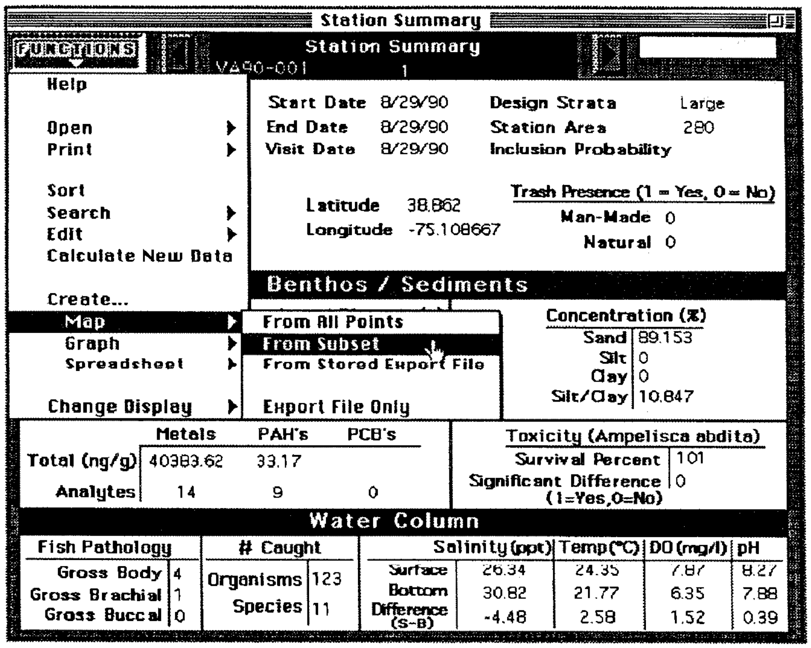

Figure 14. Capabilities provided by Stackmaker shown for data set of monitoring sites.

Assessment Program (EMAP) in a cooperative effort with SEA to develop a prototype desktop information system (called The Mid-Atlantic Mapping and Information System) for the Virginian Province demonstration project of the EMAP Near Coastal Program (NOAA and EPA 1991). Besides specific biological and chemical monitoring information from the EMAP sampling sites, the product includes:

- Monitoring data from the NS&T program
- Pollution source estimates and pesticide use from SEA's National Coastal Pollutant Discharge Inventory
- Aggregated wetlands data
- Bottom sediment distributions (Figure 15) and pollution susceptibilities from the National Estuarine Inventory
- Population and building permits from the U.S. Census
- Summary information from EPA's Toxics Release Inventory
- A full set of geographic files for nine states in the region

As in the COMPAS products, all data were carefully assessed and synthesized prior to its inclusion. The final product was released in August 1993 to selected federal, state, and regional institutions, who were either active in the Virginian Province project or whose management responsibilities directly benefited from the information.

The Mapping Framework

SEA's Mapping Framework is an attempt to bridge one gap between high-end centralized

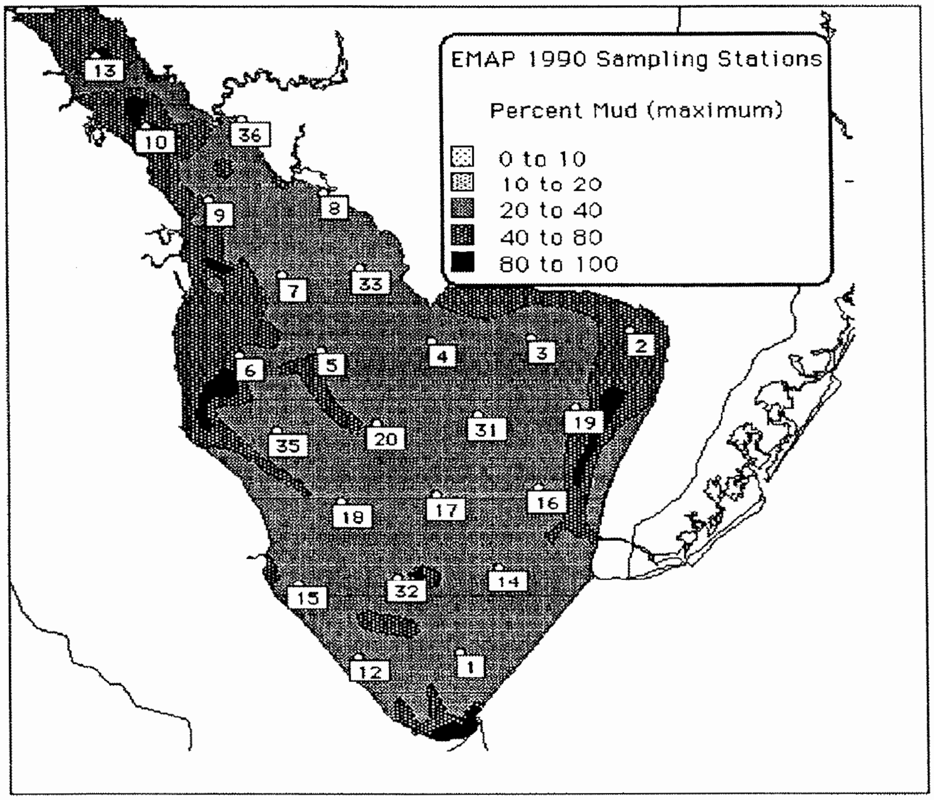

Figure 15. Sampling data and sediment contours from the Mid-Atlantic Mapping and Information System.

GIS systems and low-end thematic mapping applications: simple and advanced spatial analysis. This project, which began primarily to meet the spatial analysis needs of SEA's own programs, is now evolving to a point where a wider community might benefit. Although simple thematic mapping provides the greatest element of natural resource managers' or analysts' needs for desktop mapping, other more analytical capabilities are sometimes required. Often the only access analysts have to these capabilities are in central GIS systems with dedicated personnel. Over the past four years, SEA has undertaken a small program to integrate a powerful set of mapping and spatial data analysis system (SDAS) applications in an environment more conducive to use by those most knowledgeable of the uses and/or content of specific data. To accomplish this, SEA has worked directly with commercial, government, and academic developers. Besides the basic thematic mapping application (ATLAS*MapMaker) described above, these applications include:

- **MAPFACTORY** (University of Western Ontario, Canada) - Raster-based spatial analysis and image processing.
- **SURFACE III** (Kansas Geological Survey) - Interpolation and contouring.
- **REGARD** (University of Dublin, Ireland) - Statistical and visual analysis of spatial data.

Concluding Comments

SEA's program of desktop information systems was conceived as primarily exploratory and experimental with emphasis on flexibility. Over the past several years, combined experience with COMPAS and the Mapping Toolkit, and the numerous cooperative projects they have spawned, have provided SEA with the basic components of its desktop information systems.

Flexible Information and Tools

The early flexibility provided in the program is reflected in the varied array of components of SEA's desktop products. These components fall into five general categories and provide a broad conceptual and practical framework: 1) state and local information; 2) NOAA information; 3) data base management; 4) thematic mapping; and 5) product integration framework. A sixth category, a series of custom products on topics of special management or technical interest to NOAA, is just beginning (see "The Future"). Figure 16 summarizes these components and describes SEA's contributions to each.

Two summary points bear mention. First, SEA's desktop products have proven to be much more than application software. In fact, the largest portion of the work has been spent on the information content of the products. SEA has no intention of competing with the private sector in the development of general purpose application software. Application software will be developed only insofar as it supports and improves the provision of information for making coastal and ocean resource management decisions. Second, SEA is developing the techniques, tools and data shown in Figure 16 so as to be independent of one another. This provides considerable flexibility to both users and SEA in evolving future products. The components of future products can be selected based on their importance to a product's objectives rather than on their electronic relationship to one another. For example, SEA has developed products where mapping was the primary objective. There was little need for intricate data base design or query capability. Similarly, SEA currently is participating in a study with the state of Delaware to evaluate information needs of the state oil spill response staff. No immediate electronic product is foreseen. The study is designed as the first stage in a longer term effort by the st ate. In this effort, the techniques of data synthesis are critical.

The Future

SEA's program of desktop information systems is nearing a point of maturity where future directions can be charted in advance. SEA will solidify the base components of its desktop products including written documentation, field testing, and quality control of standard geographic and data files. For the longer term (the following two years), four major expansions of the program are planned.

Conversion of Selected Applications to Other Microcomputer Platforms.

The Apple Macintosh has been SEA's development platform. Although many of the

Status of Components of SEA's Desktop Information Systems

Category	Component	Status
State and Local Information	Codified COMPAS Process - Workbook - Electronic Forms	Complete Jan. '94
	Standard DBMS Conventions	Completed
NOAA Information	National files on numerous topics (shellfish, public recreation facilities, pesticide use, pollution sources)	Complete Jan. '94
	Standard Card Views	Complete Sept. 93
Database Application Management	Compas Windows	
	- Data Manager	Completed
	- Query Text	Complete Sept. '93
	- Query Map	Complete Jan. '94
	View Builder	Complete Sept. '93
	Stack Maker	Completed
Thematic Mapping	Standard Geographic Files (states, counties, NOAA shorelines, estuarine drainage areas, rivers and water bodies, etc.)	Completed continually updated
	Map Generator	Completed
	Clipper	Completed
	Mapping Framework	Completed, being expanded
Production Integration Framework	COMPAS Navigator	Completed
	Shellmaker	Completed
Custom Products of Management/Technical interest to NOAA		Major effort for FY'94

Figure 16. Summary of components of SEA's desktop information system program.

components of SEA's desktop system program are not sensitive to platform (e.g., the codified process, standard data, geographic files, etc.), most of the application software will require conversion to other operating systems (DOS, Windows, OS/2, etc.) now used on PC-compatible machines. Conversion of the first application, COMPAS Windows, was started early in 1994. Others will follow as time and resources allow.

Custom Applications for Management Issues of Special Concern to NOAA.

SEA's desktop products are generic--designed to accommodate the various data types associated with the myriad issues important for management of the Nation's coasts and oceans. However, a smaller set of issues and/or information exists for which NOAA has a direct management responsibility or technical involvement. SEA will develop custom desktop applications for some of these subjects. One custom application, Federal Consistency review of Federal projects and activities under state coastal zone management programs, is already underway, an outgrowth of COMPAS Florida. Possible additional topics include an easy reference guide to NOAA nautical charts, wetlands permitting, and others.

Incorporating Desktop System Components into SEA's Data Center.

In fiscal year 1994, SEA started a three year effort to establish a data center. This center will house and provide user access to the large amounts of data and information that SEA has developed over the past decade in its Strategic Assessment Program. The Center's main objective will be to provide various electronic products, ranging from simple spreadsheet-type files to complete desktop information systems. Many of the tools and techniques of SEA's desktop program will be used to support this product delivery focus.

Technical Assistance.

There is little question that the experience SEA has obtained in the past five years in developing desktop information systems could be of considerable benefit to institutions either considering or actively pursuing similar efforts. To ensure that requests for assistance receive support, SEA will initiate a technical assistance program as an integral part of its future desktop information system efforts.

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A Spatial Decision Support System For Coastal Management: A Research Project At The National Wetlands Research Center Of The U.S. Geological Survey

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Introduction

Environmental resource managers and scientists are being challenged in developing strategies to manage complex coastal systems. From an ecological perspective, there are myriad dynamic, interrelated natural and human-induced processes that affect the health and stability of coastal systems. However, the problems associated with managing coastal resources usually transcend purely ecological factors when one considers societal needs and expectations from these resources. For example, at least nine Federal, State, and local government agencies, often with widely varying responsibilities or interests, are charged with managing environmental resources and/or regulating human activities within Louisiana's coastal systems; that number may be higher in other coastal areas of the United States. In many coastal systems, a declining resource base and environmental quality combined with an expanding human population exert increased demands on those systems. This results in a number of conflicting resource management and environmental impact assessment issues. The issues include determining the most cost-effective strategies for restoring degraded natural systems, local and regional planning for future urban and commercial development in or near sensitive coastal habitats, predicting impacts from acute and chronic pollutant discharges (oil spills, fecal coliform contamination) as well as from natural hazard damages to coastal systems, and optimal partitioning of coastal resources among competing user groups (e.g., commercial and recreational fishermen).

Solving such complex environmental resource management problems often involves a multidisciplinary approach, requires computerized analytical modeling abilities to manipulate large quantities of spatial-temporal data according to a defined set of objectives or constraints, and needs a mechanism to provide quick responses for dynamic resource and environmental issues. For this, a GIS-based multifunctional Spatial Decision Support System (SDSS) is being developed at the National Wetlands Research Center of the U.S. Geological Survey (formerly the Southern Science Center of the U.S. Fish and Wildlife Service/National Biological Service).

1. Symposium speaker.

Description of Spatial Decision Support System

To meet the decision support requirements in coastal resource management, environmental impact assessment, and environmental data base management, the system is designed as a multifunctional decision-making mechanism with three subsystems: 1) a resource management subsystem (RMS); 2) an environmental impact assessment subsystem (EIAS); and 3) an environmental data base management subsystem (EDBMS). A group of functions are being developed under each of the subsystems, which will reflect the most immediate needs in coastal management (Figure 1).

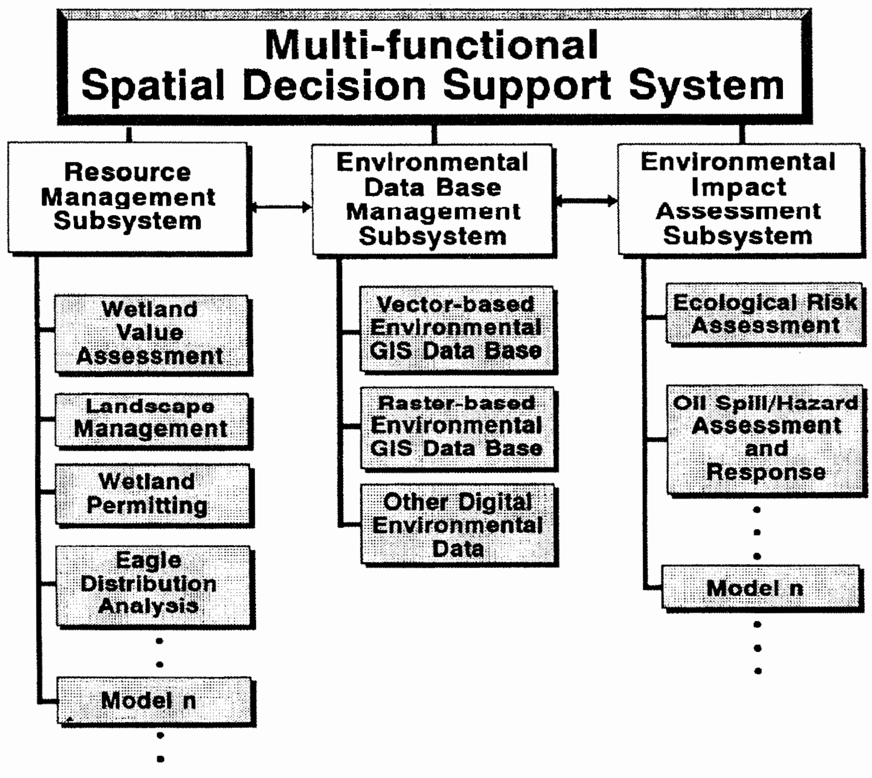

Figure 1. The various components of the spatial decision support system being developed at the Southern Science Center.

The RMS currently focuses on coastal wetland restoration planning, coastal wetland permitting, coastal eagle nest distribution analysis, and landscape management issues, which require rule-based modeling and spatial analysis; other capabilities may be included as the system evolves. The EIAS mainly aims at the following major coastal environmental impact issues: 1) coastal marine oil spill risk assessment, environmental sensitivity modeling, and contingency planning; 2) natural hazard damage assessment; and 3) coastal ecological risk assessment that emphasizes the impact of human and economic activities on the impact of human and economic activities on the coastal ecological environment. Rule-based models for these analyses as well as for the other proposed tasks will be developed. The EDBMS is designed to be composed of both vector- and raster-based GIS data bases as well as associated environmental data and to provide an interface between the modeling subsystems (RMS and EIAS) and the host GIS. Digital habitat databases in ARC/INFO (Environmental Systems Research Institute, Inc., Redlands CA) format for Louisiana as well as for some other coastal states were developed, which serve as major vector-based GIS data sources. Landsat data for large coastal areas were collected and digitally classified in terms of coastal environmental and resource features; which are major components of raster-based environment databases.

The three subsystems will be integrated as the functional complement to the host GIS, ARC/INFO. The system can be invoked in the ARC/INFO operating environment and has access to ARC/INFO modules. The coupled SDSS-GIS system will be able to share both GIS and SDSS capabilities in general GIS analysis, graphic display, tabular reporting and analytical modeling.

A customized system interface is created as a controlling component of the SDSS that provides the user with an interactive means to operate the system and perform the spatial decision-making tasks. The interface is developed as a menu-driven system created with ARC Macro Language (AML), that represents features of both GIS and SDSS in an integrated form. The system interface has the following capabilities: a) increasing ease of use of the system; b) providing a means to associate and manipulate all system resources in spatial decision-making; c) organizing the complex decision-making process into an efficient, integrated form, and; d) receiving initial modeling inputs.

A pilot system development that focuses on coastal wetland restoration planning was completed as a part of the RMS (Ji et al. 1992, Ji 1993, Ji et al. 1993, Ji and Mitchell 1995). Through this study, the approaches and techniques for further system development for other applications have been established. In this study, the model integrated into ARC/INFO GIS was called wetland value assessment (WVA) methodology (Mitchell et al. 1992). This analytical model was a habitat-based resource assessment procedure primarily used as a planning tool in prioritizing coastal wetland protection, enhancement, and restoration project proposals submitted for Federal funding. The rule-based WVA model predicts changes in wetland quality and quantity that are expected as a result of a proposed project. The output of the model, measured in average annualized habitat units, can be combined with project costs to measure the effectiveness of a proposed project.

The ARC/INFO GIS-based WVA decision support function includes four components: 1) a WVA model base that contains rule-based WVA models for swamp, saline marsh, brackish marsh, and fresh/intermediate marsh, and is integrated with the GIS database by retrieving model inputs from project coverage's attribute files; 2) a WVA GIS data base that consists of ARC/INFO coverages for project sites, WVA model variable inputs, and the project record file; 3) a model interpreter that provides strategies for automated modeling based on the project site, the wetland type, and the number of project target years for analysis; and 4) a customized user interface that consists of a series of customized ARC/INFO menus through which the decision support is performed (Ji 1993). The decision-making output is a list showing a rank of competing project proposals, with associated information such as project names, project descriptions, project sponsors, project types, hydrologic basins, and measurements of project cost effectiveness.

On-going projects include eagle nest distribution analysis, coastal wetland (environmental) permitting, oil spill response and planning, and coastal ecological risk assessment. Other planned projects will be conducted in the near future.

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A Microcomputer-Based Spill Impact Assessment System For Untreated And Chemically Dispersed Oil Spills In The U.S. Gulf Of Mexico

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Reprinted with permission from: Trudel et al. 1989. A microcomputer-based spill impact assessment system for untreated and chemically dispersed oil spills in the U.S. Gulf of Mexico. p. 533-537, *In:* Proceedings International Oil Spill Conference, held 13-16 February 1989 in San Antonio TX, American Petroleum Institute, Washington DC.

Abstract

A microcomputer-based spill impact assessment system has been developed and applied to the problem of making oil spill impact predictions and real-time dispersant use decisions for the U.S. Gulf of Mexico and the Atlantic coast of Florida. The system predicts the effects of chemically-dispersed and untreated spills on 70 important resources, including oil-sensitive habitats (salt marsh, coral reef), ecologically and economically important species, and for shorelines and property. Impact is estimated by means of a model that integrates the effects of such variables as spill conditions, oil properties, environmental conditions, oil toxicity, and resource vulnerability. When used for decision -making on dispersant use, the system computes the risk of all or a selected group of resources for a given spill when the spill is treated with dispersants (assuming complete or partial dispersant effectiveness) and when the spill is left untreated. The system produces a tabular summary of quantitative risk estimates for each resource for each countermeasure strategy. To be effective in making real-time management decisions for spills, the system completes its analysis quickly (in less than one hour for any given spill), is "user-friendly," and yields detailed information on resource-specific impact calculations that are essential for real-time verification of predicted spill effects. The system has been developed in cooperation with environmental regulation and resource management agencies in the states of Florida, Alabama, Mississippi, Louisiana, and Texas, and with federal government agencies (National Oceanic and Atmospheric Administration, Minerals Management Service, and the U.S. Coast Guard), and has been funded by the Marine Industry Group.

Introduction

This paper describes a computerized impact assessment system for calculating the environ-

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mental effects of oil spills in the U.S. Gulf of Mexico. The system simulates oil fate and movements, oil toxicity, and the vulnerability of oil-sensitive environmental resources of the Gulf, and computes the proportion of identifiable stocks of important resources that may be at risk from oil spills. When used in dispersant use decision-making, the system computes the environmental impacts of specified spills when left untreated and compares these impacts with those of the spills when treated with dispersants. This information allows the user to select the treatment option that promises the least overall environmental impact.

The system was developed as part of a project intended to identify areas in which dispersants should or should not be used in the U.S. Gulf of Mexico based on impact assessments and decision-making procedures described by Trudel et al. (1983). This project involved the analysis of hundreds of spill scenarios for the Gulf of Mexico and the east coast of Florida. Concerned with the time requirements and tedium of analyzing hundreds of spill scenarios by hand, the main task in the project was to develop a microcomputer-based Spatial Decision Support System (SDSS) incorporating models for simulating spill impacts on the environment resources of an area. This system not only served the limited purpose of speeding up the scenario analysis of the project, but also has provided regulators and resource managers with a quick, portable, highly flexible, user-friendly, spill impact assessment tool for use in real-time spill response and in planning and training.

One of the most challenging problems encountered in developing a microcomputer-based system was that of relating the spatial distribution of spilled oil to the distribution of oil-vulnerable resources. Although powerful mainframe analytical spatial analysis systems have existed for a number of years, only in the last several years have such systems become available for use in microcomputers. After a review of available microcomputer software, a uniquely powerful analytical Geographic Information System was identified and adapted for use with the spill impact modeling system.

Ecological impact models for oil spills are not new. Oil fate models have existed for more than a decade and single-resource impact models (for birds and fish) have existed for almost as long. One of the objectives of this work was to develop a system that would deal simultaneously with all major resources (not just bird and fish species, but also less studied resources, such as marshes, mangroves, and turtles) in a major ecosystem and would do so quickly and at relatively low cost.

Spill Response System Description

This paper describes the impact assessment system in general, the operation of the microcomputer-based system incorporating the Geographic Information System, and the application of this system in simulating spill impacts in the U.S. Gulf of Mexico.

Impact Assessment Model

The spill impact model estimates the impact of any spill in the Gulf of Mexico on any or all of 70 important resources in the area. The system operates as follows. For any given spill, a map of oil fate and movement is generated, showing the predicted locations and concentrations of oil at various times after the discharge. Oil fate data is combined with resource-specific toxicity data to determine the size and location of areas of toxic conditions or Areas Of Effect (AOEs) for each resource. AOEs are compared with historical spatial distributions of each resource at the time of year of the spill, to estimate the proportion of stocks and fisheries that may be at risk from the spill. This estimate is then corrected for the influence of other spatial, temporal, and biological factors (e.g., population age structure), to yield an estimate of spill impact on all resources and fisheries. The general operation of the spill impact assessment model is summarized in the flow chart depicted in Figure 1.

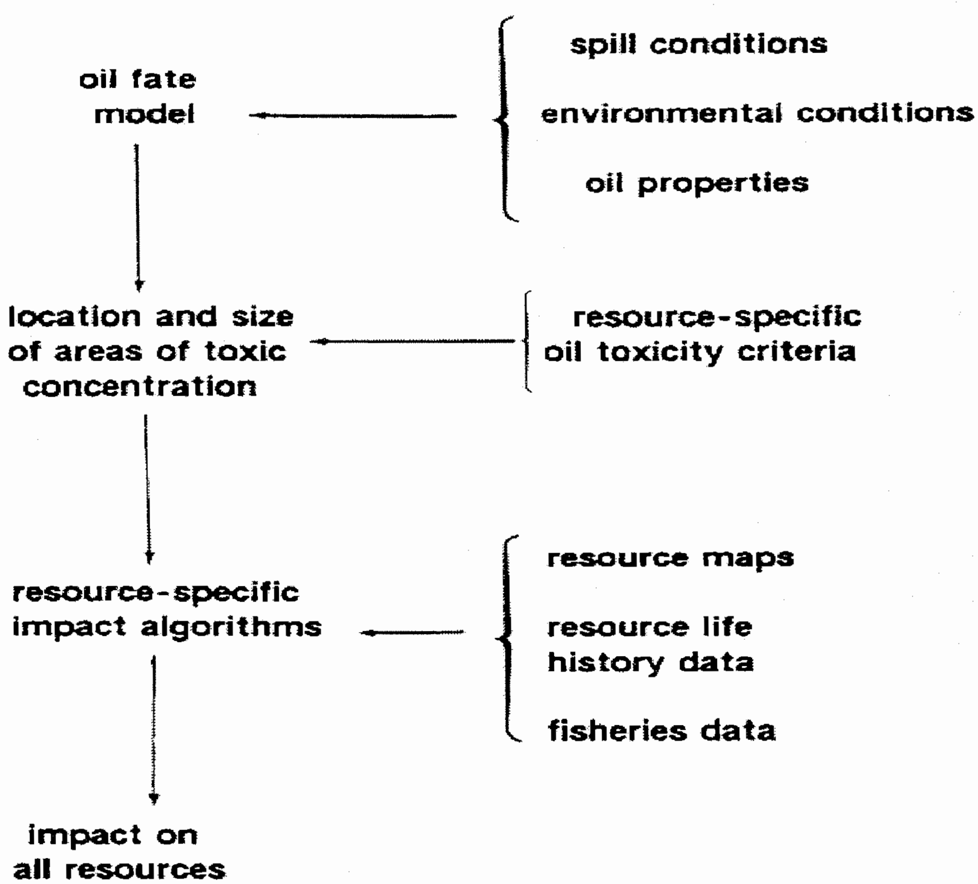

Figure 1. Impact assessment flow chart for untreated or dispersed spills.

Important environmental resources

There are thousands of species in the biological communities of the Gulf of Mexico, and it is not practical to compute spill impacts on all of these. Our approach was to compute the effects of spills on major resources, such as habitat types, dominant species, species of special concern, and economically important features, such as fisheries, property, and shorelines. To arrive at a list of resources, those that have been known historically to be sensitive to oil were identified, and with the cooperation of representatives of the five Gulf states, a representative list of 70 resources was compiled. This list containes representatives of all oil-sensitive groups and includes all major ecologically or economically important resources, major habitat types, model representatives of other oil-vulnerable groups, endangered species, and species of local concern. The list of these biological resources is given in Table 1. Also included in the study, but not shown in Table 1, were certain property resources (e.g., marinas, parks, and nature preserves) and all shorelines in the study area.

Table 1. Biological resources included in the Gulf of Mexico dispersant study.

Habitats	**Birds**	**Finfish**
Salt marsh	Lesser scaup	Bay anchovy
Mangroves	Mottled duck	Gulf menhaden
Seagrass	Redhead duck	Spotted seatrout
Coral reefs	Common loon	Black drum
Oyster reef	Laughing gull	Red drum
Reptiles	Royal tern	Southern kingfish
Green seaturtle	Least tern	Striped mullet
Loggerhead seaturtle	Sooty tern	Sheepshead
Kemp's ridley seaturtle	Black skimmer	Tarpon
Leatherback seaturtle	Reddish egret	Snook
American crocodile	Snowy egret	Southern flounder
G ulf saltmarsh snake	Great white heron	Spanish mackeral
Mammals	Sanderling	King mackeral
Manatee	Piping plover	Cobia
Right whale	Snowy plover	Crevalle jack
Invertebrates	Oystercatcher	Florida pompano
Brown shrimp	Northern gannet	Atlantic croaker
Pink shrimp	Magnificent frigate bird	Red snapper
White shrimp	Brown pelican	Mangrove snapper
Blue crab	Whooping crane	Scamp grouper
Stone crab	Roseate spoonbill	Sailfish
Spiny lobster	Bald eagle	Sturgeon
Eastern oyster	Osprey	Sand seatrout
Mercenaria clam		
Bay scallop		
Queen conch		

Oil fate

A key element of the impact analysis is the ability to predict oil fate and movement as a function of time after discharge. The characteristics of surface slick thickness, volume left on the surface, subsurface hydrocarbon concentrations, and physical properties of the oil must all be known to determine whether resources exposed to oil may be adversely affected. The movement of oil either on the surface or in the water column must be specified to identify resources at risk and to compute the proportion of each resource that might be affected.

For this application, we used an oil spill fate model that accounts for all major oil fate processes: advection, spreading, evaportion, natural dispersion, and emulsification. The model generates dimensions and thicknesses of oil slicks and slicklets, oil properties, and dispersed oil concentrations as a function of time after discharge. An early version of the oil fate model was described in S.L. Ross (1984).

Vulnerability of resources

Certain populations are widely distributed over large areas. Even though individual members of such populations may be at risk from spills, these individuals may represent only a very small proportion of their respective populations. Other resources, on the other hand, are highly aggregated in a limited number of specific locations. If oil enters these areas, the risk of significant effects to these populations is high. In the present system, the historical data on the distribution and aggregation patterns of resources (and hence their vulnerability to spills) are depicted using distribution maps (Figure 2). These maps represent the distribution of each resource, identify sub-populations or stocks, and the location, size, and density of any areas of aggregation. For resources in which certain life stages (eggs, larvae, or juveniles) differ dramatically from adults in their habitats or when habitats or distributions of any life stage change seasonally, each life stage and/or seasonal distribution is mapped separately. When the location and extent of the AOE resulting from a spill are mapped and compared with the distribution map of a population, the proportion of the population that may be at risk from the spill can be determined.

Toxicology and resource sensitivity

To determine the impact of a spill on a resource, it is necessary to compute the critical point at which oil concentrations (either oil on the surface or dispersed in the water column) fall below lethal or toxic levels. Impact is determined, in part, by the proportion of a population that falls within the area of toxic conditions, the AOE. The toxic threshold value is an important factor in estimating risk.

The literature on the toxic effects of oil is large and diverse, and some of this work is difficult to interpret in terms of ecological impacts. Different types of resources respond differently to oiling: some are affected by the chemical toxicity of hydrocarbons, others suffer as a result of the physical effects of oil, and others suffer both All resources display a range of severity of responses

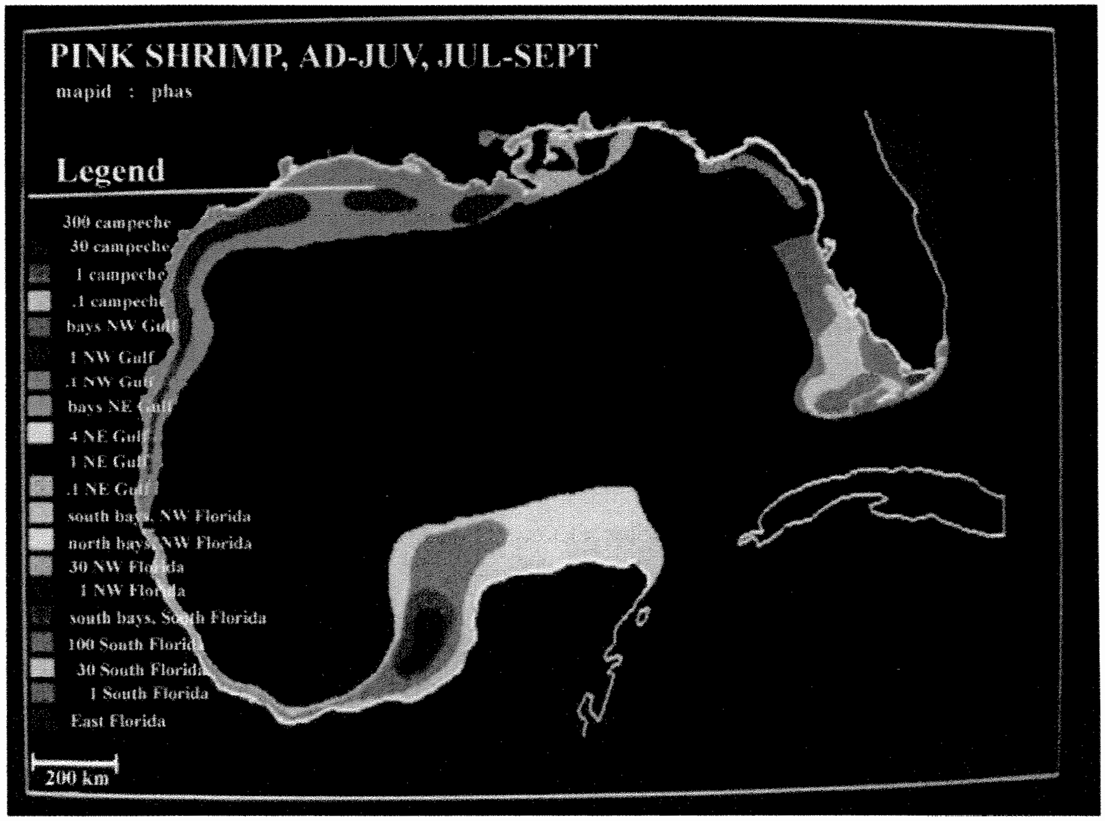

Figure 2. Geographic distributions of Gulf of Mexico pink shrimp populations.

from sub-lethality to lethality depending upon exposure conditions. Some sublethal effects are ecologically relevant while others are transitory and are far less ecologically significant. Hence, in this model some sublethal effects are considered to be significant while others are ignored. Unique toxicity criteria have been developed for each major subgroup of resources and in some cases additionally for different life stages. These criteria reflect as closely as possible the exposure conditions that members of each group are likely to experience under natural conditions. Lethality is evaluated based on concentrations or amounts of oil that have caused mortality (or ecologically relevant sublethal effects) under laboratory conditions that simulate exposure conditions in the field. In this study, emphasis was placed on results of toxicity tests using Gulf of Mexico species or closely related species from other areas.

Impact algorithms

Estimates of spill impacts on resources are computed by a series of resource-specific impact assessment algorithms that integrate information on oil fate and the sensitivity and vulnerability of resources. Because of the different kinds of effects oil has on resources, unique algorithms were developed for each resource. The algorithm for brown shrimp is shown in Figure 3 and is discussed as an example below.

Data from the oil fate model are combined with effect/toxicity criteria for brown shrimp and the brown shrimp fishery to yield unique mapped AOE's for each of four effects (Figure 3). Next,

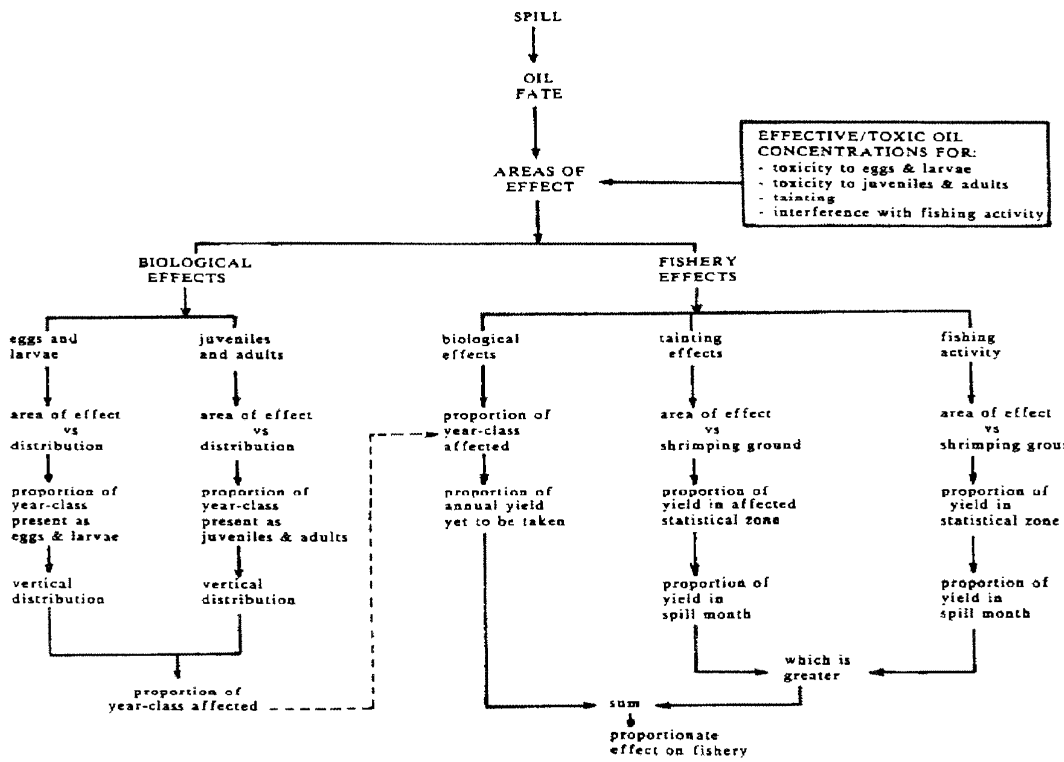

Figure 3. Algorithm for computing effects of dispersed or untreated oil on the brown shrimp stock and its associated fishery.

the algorithm proceeds to two main subroutines that compute effects on the shrimp population ("biological effects") and on the shrimp fishery ("fishery effects"). In the biological subroutine, the proportion of the northwest Gulf brown shrimp population that might be at risk from the spill is computed. This routine computes the effects on the various life stages that are present at the time of the spill, taking into account the proportion of the standing crop that lies within the AOE, the proportion of the year class that is in each life stage (larvae, juvenile, and adult), and the vertical distribution of the various life stages in the water column. The effects on all life stages are summed to yield the effect on the total population. The fisheries subroutine considers both the possible damage to the shrimp population itself (computed in the biological subroutine) and losses to the fishery through tainting and possible interference with fishery activity. The fishing activity and tainting algorithms compute the possible reduction in the annual yield to a fishery that might result if fishing were disrupted by an oil slick or by tainting or the risk of tainting. In both cases, impact is taken to be proportional to the area of the shrimping grounds that is affected, weighted according to the proportion of the annual yields landed historically in the month of the spill and in the affected fishery management grid zones.

The predicted effect of a spill on resources and associated fisheries are reported in a summary table, and details of calculations are reported if required.

Relative importance of resources

Any dispersant decision must take into account not only the impact of oil on resources, but also the relative importance of the resources to the local human population. In a system such as this, the "relative importance" question might be handled in a number of ways ranging from a rigid quantitative ranking scheme based on socioeconomic and ecological criteria, to a completely unstructured subjective system. In the Gulf of Mexico model system, the state representatives decided to assess the relative importance of resources subjectively at spill time, based in part on economic and other data that are documented as part of the system.

Summary of impact assessments

Once the effects of treated and untreated oil have been computed for all resources, these results are summarized so that the user can quickly determine whether dispersants can reduce the overall effect of the spill. As in earlier versions of the system (Trudel et al. 1983), this summary is achieved by listing together the predicted effects of the treated and untreated spill on key resources. On the basis of these estimates of impacts and assessments of importance, the user can then prepare arguments both in favor and against the use of dispersants, and can quickly formulate a logical and defensible decision on dispersant use.

Documentation

One of the most important concerns of decision-making on dispersant use is documentation. The decision-maker legitimately requires detailed documentation of the dispersant decision for justifying and defending the decision to superiors, the press, interested parties, and the public at large. In this regard the system has been designed to provide, on demand, details of impact calculations for each resource (effects on life stages and fisheries), along with the biological, toxicological , and oil fate data that went into the calculations.

System operation

The following is a brief description of system operation. To illustrate the operation of the system, a batch spill of 25,000 m^3 of light crude is considered, occurring off the west coast of Florida in June (Table 2).

To start up the system, the user enters data on spill conditions, environmental conditions, and protential target resources using a menu system that covers the following:

1) Spill conditions (I): oil type, spill volume, spill duration, and treatement options;
2) Spill condition (II): spill location; spill month;

3) Wind data: wind forcast by direction, speed, and interval duration;
4) Target resources: any or all of 70 resources can be specified.

Table 2. Summary of effects of dispersed and untreated oil on the total fishery of all five Gulf States[1]

Resources	Untreated	Dispersed (100 percent)
Fisheries Species (stock area)	Percent of Stock Area At Risk	
Pink shrimp (east Gulf)	0.1 (0.5)[2]	0.4 (1)
Blue crab (east Gulf)	0.2(0.2)	0.0 (0)
Spotted seatrout (Charlotte)	0.8 (3)	0.5 (3)
Red drum (east Gulf)	0.0 (2)	0.2 (1)
Wildlife Species (range)	Percent of Range Area At Risk	
Reddish egret (Florida)	2	0
Least tern (west Florida)	5	0
Brown pelican (east Gulf)	3	0
Habitat (area)	Percent of Habitat Area At Risk	
Mangrove (Charlotte)	10	0
Property	Number of Properties	
Marinas	8[3]	0
Shorelines	Shoreline Distances (km)	
Beach, nonamenity	8[4]	0
Mangrove	39	0

1. Spill conditions: 25,000 m^3 of light crude oil spilled at 26°30'N, 82°30'W, in June, with winds constant from the west at 12 km/h
2. Values in parentheses represent percent reduction in annual yield to fishery
3. Numbers of marinas at risk regardless of size
4. Length of shoreline oiled in km (resulting mean level of shoreline oiling 28 L/m)

After these data have been entered, the system operates to completion without further operator intervention, drawing data from files (on oil properties and oil toxicity to different resource groups, along with biological and fishery data) and maps (of ocean currents and seasonal distributions of resources, life stages, and fisheries) as required. A sample map showing the predicted fate of the untreated spill and the distribution of a limited number of resources is given in Figure 4.

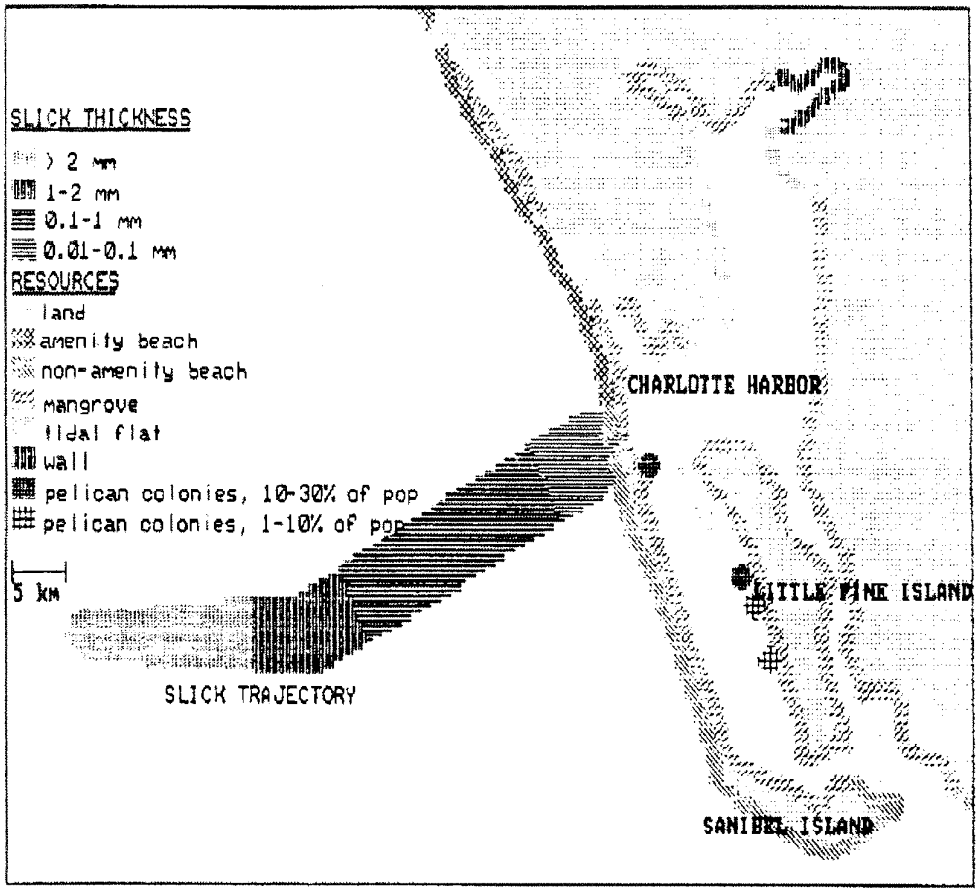

Figure 4. Map of oil fate and resource distribution.

An example of the type of output yielded by the system is given in Table 2. Impact on biological resources and fisheries are expressed in terms of the proportions of identifiable populations or stocks that may be affected by the spill. Impact on shorelines is expressed in terms of the length of shoreline oiled in kilometers, and volume of oil per linear meter of shoreline. Impacts on fisheries (values in parentheses) are expressed as the proportional reduction in annual yield for the specified fisheries. In the present example, fishery impact is expressed as a proportion of the total landings in the five Gulf States, but impact can be expressed by state if desired.

In addition to this summary, the system will also produce, on demand, details of impact calculations for individual resources, so that the users can better understand the basis of the predicted impact and can undertake real-time verification of the predicted impact.

Summary

A computerized spill impact system has been developed that yields quantitative estimates of impacts of spills on all major resources for a large ecosystem, in this case applied to the U.S. Gulf of Mexico. The system simulates impacts using models of oil fate, ecotoxicities of hydrocarbons, and vulnerabilities of individual resources. The system operates on a microcomputer and uses the spatial analytical capabilities of a Geographic Information System. The system has been developed to operate quickly and is user-friendly; it can therefore be used for real-time analysis of spills by decision-makers and resource experts with a minimum of training.

Acknowledgements

Major funding for the development of this computerized oil spill impact assessment system has been provided by the Marine Industry Group (MIRG). Funding has also been provided by S.L. Ross Environmental Research Limited. Strong technical input has been provided by the five Gulf of Mexico states and federal agencies. Technical information on resources has been provided by resource management agencies of the states of Alabama, Florida, Louisiana, Mississippi, and Texas, and by federal resource agencies, the U.S. Fish and Wildlife Service, National Marine Fisheries Service, Minerals Management Service, and National Oceanic and Atmospheric Administration. We would also like to thank Tydac Technologies, Inc., developers of the SPANS Geographic Information System, for their assistance throughout the project.

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A Fishery Management System Approach for Gulf of Mexico Living Resources

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Abstract

Requirements for fishery management have changed substantially. At issue is the variability of populations and the contemporaneous notion that coupled biological-physical mechanisms drive fundamental population frequencies. Fruitful areas of research now probably transcend the bounds of traditional theory and new approaches must be explored. Increased technological capabilities have emphasized the need to maintain a global perspective when problem solving. Important advances in computer technology have stimulated many generalizations of basic demographic, population dynamics, and assessment theory used in support of fishery management. New algorithms have also substantially extended analysis techniques. The technological base now exists to implement an operational fishery management system for Gulf of Mexico fishery resources. However, such an endeavor requires strategic advances in data acquisition, analysis and long-range planning. This paper develops a strategy which defines the structure and considers the requirements for implementing modern renewable natural resources theory in a computer-aided fishery management system. The fishery management system is effective for development of cost-effective methodologies of sampling fish stocks for assessments and short-term fishery forecasts.

Introduction

Management has grown more complex as a result of multifarious interests competing for highly valuable, but finite fishery resources. There are escalating management pressures in most fished areas of the United States. Principal management issues involve average stock size, spawning stock biomass, average recruitment, resource allocation and sustainability. Conflicts over the quantity of fish present, who will catch which fish, what gear may be used, and how much will be caught provoke great and long debate and are commonplace in State and Federal fishery management councils and newspapers. With escalating usage decision-makers are now pressured to make spontaneous decisions on the regulation and allocation of fishery resources that may have significant long-term biological, economic and socio-political consequences.

Fishery managers are typically faced with the situation where exploited stocks have declined, while attendant pressures for management have intensified. To ameliorate the situation and gain focus, the responsible decision-maker begins by seeking out an approach to serve as a model of strategic fishery management decision-making. However, such a search would likely reveal that *no* existent approach is sufficiently robust to serve as the paradigm. The reasons are manifold: a general lack of data for even routine stock assessments, incomplete coverage of commercial catch and effort, minimal recreational fishery data; those statistics available are typically of low accuracy, projects are poorly coordinated resulting in inordinate delays in data availability, social and economic data are severely deficient, and data collection programs generally lack or have suboptimal sampling survey designs. A key to developing a robust approach will be to address increased understanding of biological systems nested within and driven by physical systems (Rothschild and Ault 1992).

The global objective of management could be defined as the attainment of a process model sufficient to maximize fishery derived benefits. The objective function of a benefits maximization is formalized by inclusion of all constituency concerns and preferences, subject to statistically estimated economic, biological and physical constraints. These issues need to be evaluated from several points of view. Traditionally while solving problems, fishery management decision-makers considered only single objectives (e.g. maximum sustained yield or maximum net economic revenue). Increasingly managers are coming to believe that it is important to take into account the results of their decisions on all those who are directly affected by them. This novel approach is a classic operations research problem in multi-objective decision analysis (e.g., Ault and Fox 1989).

The operational paradigm for addressing the maximization problem has been to consider the process as linear from data collection to research, to advice, to decision, to management, with no apparent feedbacks in the system. The problem with this approach is that separating the system components into discrete units makes it difficult to determine sensitivity, or to integrate components which interact.

Existent fishery management approaches at the strategic level tend to concentrate on one or more of the three well-dated (c. 1950) stock assessment workhorses: surplus production, yield-per-recruit, and stock-recruitment. These traditional assessment models possess minimal data requirements, but have very restrictive assumptions. Clearly, a broader view is necessary. When evaluating the road forward, we need to consider what is known and whether fishery dynamics are adequately represented. There are clear indications that the environment and other stocks influence variability of fish stocks. Therefore, we need a mechanism or "process model" by which the biology of the exploited stock within the physical environment can be better understood. Both the stock and the physical environment are subject to time-based perturbations introduced by natural and anthropogenic sources.

Requirements for fishery management have changed substantially. Catch and effort data alone will not be sufficient to optimally manage the biology, economics, and socio-political issues relevant to fisheries in the next century. There are significant problems with applying traditional fishery management theory to Gulf of Mexico subtropical fishery resources (e.g. Ault and Fox 1990; Ehrhardt and Ault 1992, Bohnsack and Ault 1996). Increased technological capabilities have emphasized the need to maintain a global perspective when problem solving. The importance of considering linkages between the stock, environment, recruits, yield, and economic value is now thought to be paramount to successful fishery management.

However, important connections between data acquisition, analysis and strategic long-range planning are still lacking. It is apparent that any advances in knowledge and technology would result in improved management capabilities. Taking into account the costs and value of obtaining increases in knowledge arbitrarily sets an upper bound on investment appropriate for scientific technological development. However, contemporaneous economic valuation practices like "contingent valuation" or taking an "ecological" as opposed to a "commodity" view of the industrial and recreational fishery sectors would make this upper bound large indeed.

Adopting the systems view would lead us to conclude that we now have techniques which provide solutions for problems which have been insufficiently defined, and that these solutions might suggest policies which are not necessarily consonant with the higher level system goals. Thus, it is imperative to initiate creation of a program environment conducive to strategic decision-making. A pure *fishery management system* should be the most efficient program overall because it allows for complex phase trajectories between all system components while maintaining a cost-effective global view supported by principles from control-feedback theory and risk-sensitivity analysis.

The basic philosophy of the fishery management system (FMS) emphasizes strategy over tactics in dealing with resource management problems. To define the system we must at least consider: inputs and outputs; system resources modifiable by the system; system environment which behaves independently of the system; system management; and measures of performance. When our concept of the system is in place we must then think of alternative systems and determine whether these alternatives are better than existing systems.

Fruitful areas of research now probably transcend the bounds of traditional theory and new approaches must be explored. Important advances in computer technology have stimulated many generalizations of basic demographic, population dynamics, and assessment theory used in support of fishery management. New algorithms have also substantially extended analysis techniques.

By increasing the complexity of our management concept to address relevant problems of fishery management, we are concomitantly required to develop a sophisticated information and analysis system capable of having flexibility in making broad management decisions and formulating policy. In this respect the fishery system facilitates attainment of management's global objective. The actual computer-based FMS provides an interactive environment for exploratory analysis and decision formulation. The system exploits current and emerging computer technologies for high performance UNIX workstations. These technologies include: 1) client/server computing environment; 2) networked and distributed computing and data resources; 3) platform inter-operability; 4) graphical user interfaces; 5) scientific data visualization such as remote sensing, image processing and GIS; 6) data analysis and simulation environments using visual programming and data-flow paradigms; and 7) advanced multiple process methods with interprocess communication.

About 80 percent of the conceptual basis of the FMS is appropriate for all fishery management activities. Individual peculiarities relating to specific fishery situations comprises the remaining 20 percent. The general components which comprise the full fishery system and the information flow are shown in Figure 1.

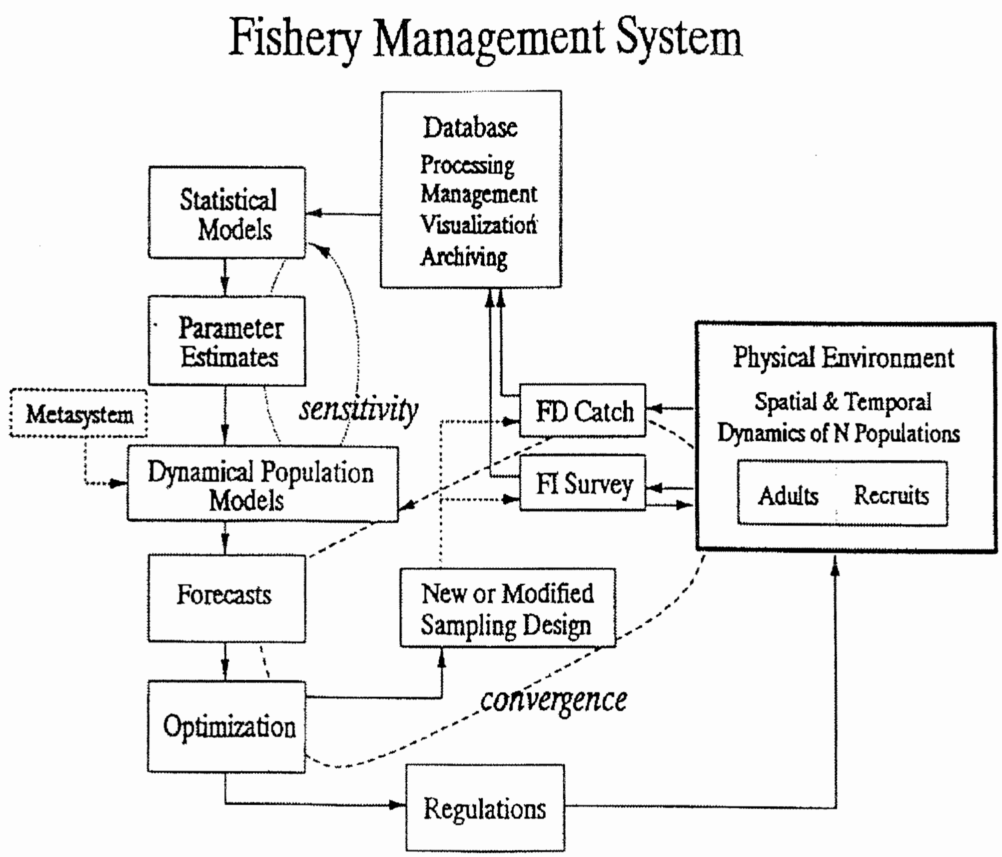

Figure 1. Diagram showing the modules involved in the sensitivity and convergence feedback loops of the fishery management system.

We have described fully the system flow elsewhere (Ault et al. 1996, Rothschild et al. 1996). These papers develop a strategy which defines the structure and considers the requirements for implementing modern renewable natural resources theory in a computer-aided fishery management system. We also discuss an application of a prototype version of the fishery management system applied to assessment of the Chesapeake Bay blue crab stock (Rothschild and Ault 1992, Zhang et al. 1993, Zhang and Ault 1995). Our primary objective was to develop, demonstrate and verify an efficient and cost-effective sampling design for overwintering blue crabs in Chesapeake Bay as a method to facilitate stock assessment and improve fishery management decision-making. Along with minimization of attendant costs, the method should be suitable for use in a long-term continuing sampling survey program. The statistics, abundance estimation, and analysis context of the survey design is directed at incorporating other sources of data, both fishery-independent and fishery-dependent, that correlate with blue crab population dynamics. Our goal was to assimilate all relevant sources of data into a common statistical and population dynamical framework within which the biases and variability of the various data sources can be described and explained. Net-net results suggest increased precision in our blue crab stock assessment and management estimation methodology using the systems approach. The fishery management system should also be effective for use with Gulf of Mexico fishery resources for developing cost-effective methodologies of sampling fish stocks for assessments and short-term fishery forecasts.

Of course there are several limitations with any quasi "perfect" approach. For example, the ability to determine model and data sensitivity relative to situation understanding and resolution. Second, complete detection of convergence of the population projections with the true underlying "real" population. Finally, full recognition that benefits are actually being maximized through a sufficient combination of policy and feedbacks. However, the advantages of the system lies in the fact that the approach concentrates upon formulating various problems in terms of their objectives, hypothesis, context, assumptions and criteria. The system is structured in such a way to recognize the need for understanding both the "sensitivity" of the system to parameter variability, and when "convergence" is reached or when adjustments are required for the system and reality to converge.

Finally, there needs to be greater concentration of effort and intellect on fishery data sources and the information base because they are at the heart of a good understanding about stock dynamics and productivity. Clearly, effective fishery management decision-making depends on data adequacy and the sufficiency of the analytic systems approach.

Conclusions

A *fishery management system* approach should be adopted for organizing statistics, analysis and management activities. Such a system, by connecting all relevant processes, allows efficient determination of how fiscal and manpower resources should be distributed among the various components to ensure the highest quality decision-making. Systems analysis supported by an expert Spatial Decision Support System (SDSS) provides a systematic approach to fisheries analysis and the elaboration of scientific advice. The system optimizes in the sense that it strives to minimize conflicts and complaints within the fisheries system. This view recognizes that the paradigm in fisheries is shifting from conflict-reduction to optimization.

I perceive four major practical benefits of a *fishery management system* for the Gulf of Mexico. First, it will provide the first complete working overview of the entire fishery management system. The systems approach is intended to reduce costs associated with gathering information necessary for fish stock management and harbors the additional benefit in that it allows identification of policies that enhance sustainable returns. Second, it shows how the sampling theoretic problem must be defined and analyzed. Third, the optimization component provides a simulated "link-trainer" resources system analogue for use by managers to improve their judgements and decision-making capabilities. This didactic tool provides "hands-on" experience to assist professionals and fishery management appointees in making fishery management decisions and fishery research program decisions. Finally, the systems approach allows for direct consideration, quantification and linkage of biological, economic, sociological and political factors into the decision-making process.

The system's **advantage** is that it maintains a global view where strategy is emphasized over tactics and strives to integrate all relevant processes into feedback loops and doesn't disconnect the biological from the physical or economic environments. Most importantly, the system emphasizes adaptive sampling. The method is **generic** in the sense that the systems idea presents a global approach which is applicable in *all* resource management situations. The framework assists determination of where the next sample comes from and thereby enhances management flexibility. The **future** of the systems approach is capsulized in what is seen as a control-room environment producing up-to-date forecasts and self-validating feedback control. The fact the *fishery management system* is modularized provides a framework that is conducive to expansion and modification as new techniques become available because modularized components are interchangeable.

While we consider research as part of the management process, there is a significant amount of management beyond research. As one of it's most important attributes, the systems approach allows this fact to be understood by scientists who have to date considered this the end rather than the means. The direct result will be more balanced and focused management, and significantly improved recommendations that maximize and optimize the return on the Gulf of Mexico's living natural resources.

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Ecosystem Management Relating Habitat to Marine Fisheries In Florida

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Abstract

Ecosystem management is being implemented throughout Florida by the Florida Department of Environmental Protection (FDEP). With respect to estuarine and marine ecosystems, fisheries managers realized they did not have adequate information to effectively manage Florida's marine fisheries. The Florida Marine Research Institute (FMRI) within FDEP is largely responsible for providing the technical information concerning the marine environment used by fisheries managers. It was recognized that managers lacked the means to link information pertaining to ecology, fishery species, and human dimensions. To fill this need, FMRI created the Marine Resources Geographic Information System, a comprehensive data base tied to visualization tools targeted for management of fisheries and coastal ecosystems. The results have been new approaches using remote sensing, image processing, geographic information systems (GIS), and modeling to link the seascape to marine resources in Florida. Monitoring and research on marine communities at all trophic levels is being implemented to support ecosystem management of marine recreational and commercial fisheries. Habitat-related mapping is being assessed and modeled in relation to fisheries independent monitoring data. Examples are presented concerning scientific studies relating fisheries species to habitat and environmental factors in the Big Bend, Tampa Bay, and Florida Bay areas. The reduction of freshwater inflow to Florida Bay, coupled with other environmental changes, have induced seagrass, mangrove, and sponge die-offs, persistent plankton blooms, and a shift to plankton feeding fishes. Modeling and GIS mapping are being conducted to demonstrate the importance of maintaining marine habitats to sustain fish and invertebrate fisheries.

Introduction

Historically, coastal resources management in Florida was inadequate, and often was not used in planning the economic development of the region (Haddad and McGarry 1989, Culliton et al. 1990). Human population growth, resulting from tourism and urban development, has led to increasing point and non-point nutrient, contaminant, and/or pathogen pollution, habitat losses, alterations in freshwater inflow, land cover changes, coastal erosion, dredging and filling, over-fishing, and shifts in marine communities. Many people failed to realize that degraded water quality, wetlands losses, and other forms of coastal habitat alteration would have long-term negative biological and economic impacts on marine communities, such as the production and harvest of recreational and commercial species of fish and shellfish.

Florida has traditionally managed fisheries at the species level. Fragmentary regulations and case by case permitting have been difficult for the public to understand and comply with (Haddad managers in making resource decisions (Haddad 1993, Friel and O'Hop 1996). Each map includes the coastline, depth contours, and aids to navigation digitized from NOAA charts. Benthic habitats such as seagrass, saltmarsh, mangrove, coral reefs, oyster reefs, hard bottom, and bare bottom are included along with managed area boundaries.

Environmental Sensivity Index Mapping

Habitat and fisheries data are being used by FDEP for oil spill response/mitigation. The Florida Marine Spill Analysis System (FMSAS), which is part of the MRGIS, contains text, maps, and other graphic information to support oil spill cleanup, and the assessment of economic damages to marine resources (Friel et al. 1993, FDEP 1996). Coastal Environmental Sensitivity Index (ESI) maps (Figure 2) and corresponding GIS data files have been created that classify shoreline types statewide, according to their sensitivity to oil spills (FDEP-RPI 1996). Biological and human-use resources at risk are part of the digital ESI coverages within the MRGIS. Some biological resource areas at high risk include seagrass beds, marshes, coral reefs, oyster beds, bird rookeries, sea turtle nesting beaches, and areas occupied by West Indian manatees. The FMSAS also contains information on roads, boater access sites, marinas, parks, water intakes, and other human-use features.

The FMSAS is being developed as a biological baseline that can be used for oil spill response/mitigation and fisheries management. It can be used to identify: a) the distributions of animal and plant populations at risk; b) shorelines with sensitive habitat; c) critical nursery areas; d) spawning or reproductive areas; e) the distributions of endangered and/or threatened species; and f) economically important areas for tourism and/or recreational fisheries. These GIS coverages were originally developed to be viewed using the ARC/INFO GIS on UNIX workstations. It was recently transferred to ARCVIEW 2 using Microsoft Windows on microcomputers. The information is now more easily accessible to a wider user community.

Fisheries Independent Monitoring

Biologists from FMRI conduct fisheries independent monitoring (FIM) in various Florida estuaries and the Florida Territorial Sea (McMichael 1991, FDEP-FMRI 1994, Covocoresses and McMichael 1995). FIM monitoring is presently conducted in Choctawahatchee Bay, Tampa Bay, Charlotte Harbor, Florida Bay, and the Indian River Lagoon. The FIM Program monitors the entire fish community including forage species, as well as sport and commercial species of fish and invertebrates. A variety of gear types (drop nets, throw-traps, seines, gill nets, and trawls) are used to capture fish and invertebrates associated with different habitats using fixed and random-stratified sampling. Hydrological and meteorological data are also collected at each station. A network of satellites allow biologists on the ground to accurately determine their sampling locations using Global Positioning System (GPS) receivers. The fisheries and environmental data from the FIM Program are being merged with the MRGIS to facilitate ecosystem management of marine fisheries.

Information For Anglers

CAMRA is using the information in the MRGIS to create boaters guides that inform anglers about the locations of marinas, parks, boat ramps, manatee zones, and aquatic preserves as well as potential fishing sites such as seagrass beds, marshes, mangroves, coral reefs, oyster beds, and

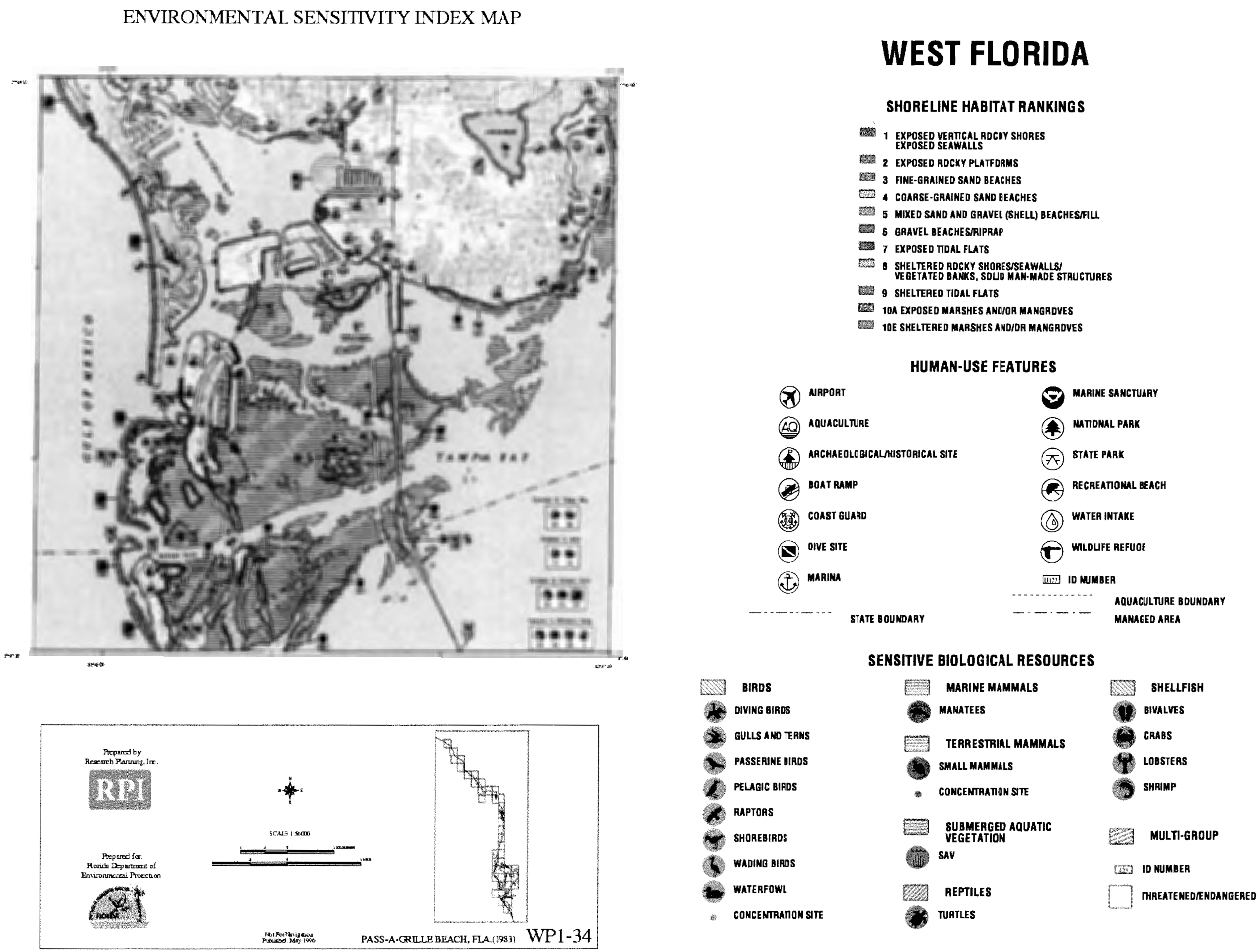

Figure 2. Environmental sensitivity index map depicting shoreline habitats, biological and human-use resources at risk from oilspills in Tampa Bay (FDEP-RPI 1996)

artificial reefs. Boaters guides have been published for Tampa Bay, Charlotte Harbor, and the Indian River Lagoon (FDNR-TBNEP 1993, FDEP-Charlotte County 1994, FDEP-IRLNEP 1995, Norris and Poehlman 1996). New boaters guides are in preparation for Apalachicola Bay, Pensacola Bay, Biscayne Bay, and the St. John River estuary in Duval County. The habitat requirements and life history information for fish species of interest to anglers have been integrated with the rules and regulations of the department, tips on boater safety, navigation rules, and waste disposal sites for boaters. These waterproof materials including maps, photos, drawings and text are intended to inform sport fishermen and the general public. More than 100,000 are in circulation.

Florida's Big Bend Region

Shrimp Management Plan

The Florida Marine Fisheries Commission (FMFC) has used RIM maps to assist with the implementation of a shrimp management plan for five regions statewide (Haddad et al. 1993). The first phase of the plan addressed allowable gear specifications, mesh size of nets, and the shrimp count for harvesting activity. Numerous local laws were repealed, which simplified inshore and near shore shrimp regulations and standardized the shrimp fishery on regional and statewide levels. The second phase of rule-making addressed the issues of finfish bycatch associated with shrimp trawling, and the adoption of a zone management plan to determine allowable shrimp-harvesting areas.

The Big Bend Region was one of the first areas where the FMFC examined the need to establish harvesting areas for pink shrimp (*Penaeus duorarum*) in state waters. Extensive consultations with live-bait, food shrimp, and recreational fishermen were conducted to determine the areas utilized in their fisheries. The areas utilized by the pink shrimp fisheries were visually compared with the geographic distributions of benthic habitats in the MRGIS using the RIM maps (Steele and Norris 1995, Poehlman and Westlake 1995). Maps were prepared and periodically updated by CAMRA, during the consultation process, showing proposed closure zones for pink shrimp (Figure 3). Existing closure zones for stone crab (*Menippe mercenaria*) were also added to the maps. The comparisons assisted fisheries managers in making decisions to protect critical nursery habitats, while reducing user conflicts between various factions within the commercial and recreational fisheries.

Seagrass beds represent one of the most productive and important habitats in the nearshore marine systems of Florida, used by a wide range of species as feeding grounds, nurseries, and for refuges from predation (Livingston 1990). In the Big Bend Region, shallow-water seagrass beds were closed to pink shrimp fishing (Steele and Norris 1995). The seagrass areas set aside provide nursery habitat needed by juvenile fish, shrimp, and crab species. The protection of nursery habitats enhances the carrying capacity of the estuary by promoting the recruitment, growth, and production of shrimp and other fishery species. These species are being harvested at a larger size, after migrating from the nursery areas to deeper water further offshore. RIM maps produced using GIS allowed the FMFC to explain complex issues to all concerned parties, and successfully moved the plan for the Big Bend Region into law during January 1994. Similar consultations were conducted to define closure areas, in order to implement the shrimp management plan in the Northeastern and Northwestern Regions of Florida.

Coastal habitats and shrimping areas on Florida's west coast.

Figure 3. RIM map indicating closure zones established to exclude shrimping over shallow seagrass beds (<2m) in the Big Bend Region (Poehlman and Norris 1995).

Greater Tampa Bay EMA

Fisheries Habitats

The tributary rivers and estuary associated with the Greater Tampa Bay EMA have been detrimentally influenced by the growing human population (Haddad 1989). The Little Manatee River is the last major tributary river remaining in a relatively natural condition (Haddad and McGarry 1989). Headwaters of the system contain bottom land hardwoods, cypress swamps, freshwater marshes, and other wetland habitats. The estuarine portions of the watershed consist of mangrove swamp, tidal marshes, seagrass beds, oyster bars, and other marine habitats. The watershed lies directly in the path of urban development.

CAMRA created the Little Manatee River Watershed Atlas within the MRGIS as a means to document and relate human demographics to the natural resources of the watershed (Haddad and McGarry 1989, MacAulay 1993). GIS and remote sensing have been used to assess land-use changes in the area (Figure 4). Analyses of the estuarine portion of the watershed show tremendous increases in agriculture and urban coverage with concurrent losses of undeveloped lands. Between 1950 and 1982, there was a 66% loss in undeveloped upland, 35% loss in seagrasses, 7% loss in mangrove/marsh, 16% increase in open water, 1% increase in freshwater wetlands, 420% increase in agricultural land, and 341% increase in urban areas. The land-use information derived from the MRGIS were used to make recommendations concerning the expansion of the Cockroach Bay Aquatic Preserve at the mouth of the river. This preserve area contains important mangrove, salt marsh, and seagrass habitats that provide shelter from predators, and food for larval, juvenile, and adult fishes.

Within the Little Manatee and Manatee Rivers, the oligohaline tidal zone (0.0-0.05 $^o/_{oo}$) was found to support productive nursery areas for early-juvenile fishes (Peebles et al. 1991, Edwards 1991). The tidal zone in the Little Manatee River was heavily utilized by young estuarine-dependent fishes, including menhaden (*Brevoortia* spp.), bay anchovy (*Anchoa mitchilli*), snook (*Centropomus undecimalis*), red drum (*Sciaenops ocellatus*), sand seatrout (*Cynoscion arenarius*), spot (*Leiostomus xanthurus*), and striped mullet (*Mugil cephalus*) (Peebles et al. 1991). Most fish species migrated to, and concentrated within, the lower part of the river during the postlarval or early juvenile stage. The spatial peaks in mean fish concentrations coincided with peaks in abundance of benthic and planktonic crustaceans. Planktonic copepods appeared to be more susceptible to downstream dis-placement during times of higher river discharge than the benthic crustaceans. Various nutrients and dissolved organic carbon were associated with higher inflows. Detritus deposition and the production of benthic diatoms formed the base of the food web being exploited by juvenile fishes.

Studies have been conducted to locate and determine the micro habitats important for larval, and early juvenile snook in Tampa Bay (Peters 1993, Peters and McWillians 1995). Larval snook recruitment to coastal habitats was studied in the Little Manatee and Alafia Rivers. They are also known to colonize similar habitats in Cockroach Bay, Terra Ceia Bay, Boca Ceiga Bay, and the Manatee River. Postlarval (5-7 mm) snook move from open water to shallow-water habitats and remain in the water column until they attain lengths ranging from 15-45 mm, before adopting

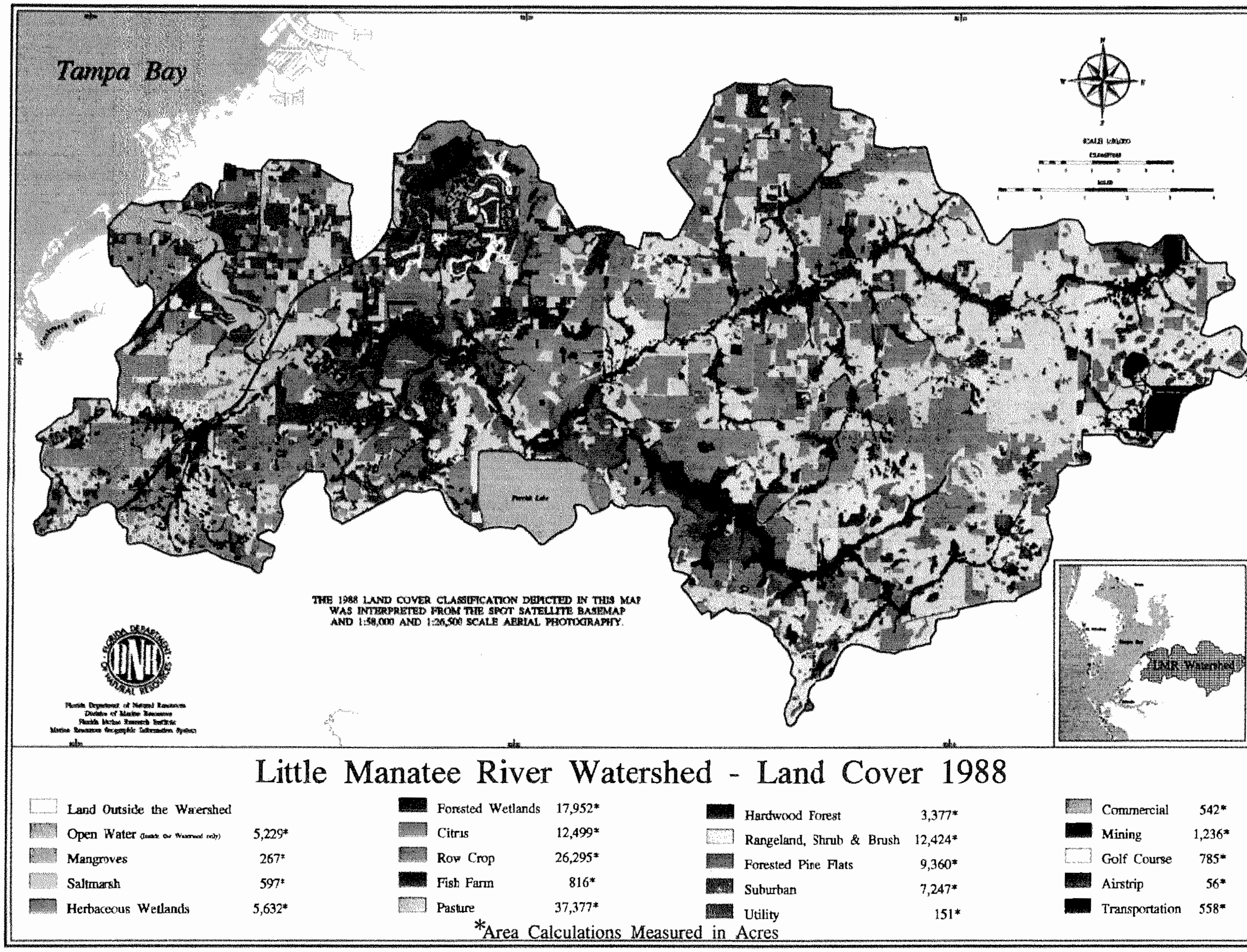

Figure 4. Land-use changes in the Little Manatee River watershed estimated using GIS (MacAulay 1993).

benthic-oriented behavior. Early juvenile snook were found in oligohaline habitats ranging from red mangrove swamps to black rush marshes. Common characteristics of juvenile snook habitat include: 1) protected shorelines within shallow lagoons, creeks, and canals having limited current and wave motion; 2) shorelines with relatively steep slopes, dropping quickly to 0.5-1.0 m depths; 3) underwater structure for orientation and cover such as mangrove prop roots; and 4) overhead shade provided by a canopy of trees near the water.

Because snook are at the northern edge of their range in Tampa Bay (Taylor et al. 1993), a rapid drop in water temperature during the winter may periodically result in kills of adult snook. The last major cold kill occurred in December 1989. Additional management regulations (increase in minimum size from 18" to 24", and reduction in the daily bag limit from 4 to 2), coupled with mild winters and habitat protection/restoration, have contributed to increases in snook population abundance in Tampa Bay during the past six years (Taylor et al. 1996, Taylor pers. comm. 1996)

The historical seagrass cover in Tampa Bay was inferred to be 76,496 acres prior to 1879 (Lewis et al. 1985). Interpretation of aerial photography indicated that the areas occupied by seagrasses declined from 40,627 acres in 1950, to 21,647 acres in 1982, then rose to 23,917 acres in 1988 (Haddad 1989). Seagrasses were estimated by the Southwest Florida Water Management District (SWFWMD) to occupy 25,654 acres in 1992, and 26,607 acres in 1994 (TBNEP 1996). Efforts by municipal and state government agencies were successful in reducing nutrient inputs from point and non-point sources. The reduction in levels of nutrients and increased water transparency are believed to be contributing to the recovery of seagrass beds and salt marsh.

Spotted seatrout (*Cynoscion nebulosus*) is one of the most important marine sport fish species in Florida. Juveniles and adults are commonly found associated with seagrass meadows (Carr and Adams 1973, McMichael and Peters 1989). The decline in landings of spotted seatrout from 1950 to 1980 is believed to be related to the reduction in the total area of seagrass habitat in Tampa Bay (Haddad 1989). Further studies are needed to determine whether recent increases in the areal extent of seagrass meadows in Tampa Bay are associated with increases in the population of spotted seatrout.

FMRI has administered a number of projects to restore salt marsh and seagrass beds (Pierce and Culter 1991, Fonseca et al. 1991). Gill-net license fees were used for salt marsh restoration programs in Pinellas, Pasco, Manatee, Hillsborough, and Sarasota counties. One example is the planting of smooth cordgrass (*Spartina alterniflora*) on the Hendry Delta, a clay spoil area that buried the former mouth of Redfish Creek (Pierce and Culter 1991). Seagrass restoration projects have been conducted using funding from the Florida Legislature and the SWFWMD (Fonseca et al. 1994, 1996). Research for improving mangrove establishment is also being conducted by FMRI scientists. Benthic macro invertebrates have colonized these habitats, that now support fish populations (Culter et al. 1991).

South Florida Watershed

The headwaters of the South Florida watershed start at Shingle Creek in suburban Orlando

(Levin 1996). Water flows down the Kissimmee River to Lake Okeechobee; then passes through the Florida Everglades, Florida Bay, and the Florida Keys into the Atlantic Ocean. This watershed has been drastically altered over the past century. It has been lacerated and divided by 1,400 miles of canals, dikes, and levees. The Kissimmee Valley drains about 3,000 square miles of wet prairie and pinelands. Between 1958 and 1972 over half of this area was drained and planted with Bahia grass to support central Florida's cattle and citrus industries. The channelization of the Kissimmee River resulted in the loss of 45,000 acres of swamplands. The south shore of Lake Okeechobee, that originally seasonally flooded an area of approximately 850 square miles, has become the 700,000 acre Everglades Agricultural Area (EAA) supporting agriculture including the sugar industry. Four canals presently divert 3 to 4 million acre feet of water toward the Atlantic for irrigation and urban uses. Over 4.5 million people from West Palm Beach to Key West utilize the water. Half of the original Florida Everglades is gone, replaced by farms, suburban lots, and a dense tangle of exotic trees. In Everglades National Park, 1.5 million acres of wetlands are impacted by altered flow regimes. Some of the critical ecological relationships affected are the composition of plant communities, the seasonal flooding of wetlands, and freshwater fish communities. Associated with wetlands losses in the Everglades, there was a 90% decline in the abundance of wading birds.

Florida Bay EMA

Fishing guides were the first people to sound the alarm about seagrass die-offs during 1987 in Florida Bay. Nestled between the Florida Everglades and the Florida Keys, its waters support important sport and commercial fisheries. Starting in the fall of 1991, the waters of the bay became clouded with algal blooms. With the blooms came shifts in the geographic distributions and abundance of spiny lobster (*Panulirus argus*), pink shrimp, and sport fishes sought by anglers. Public concern about what is ailing Florida Bay has stimulated research to find a cure.

It is still not clear how the alterations of the South Florida watershed have influenced Florida Bay. Nutrient inputs and changes in freshwater inflow are suspected of causing algal blooms and changes to the Florida Bay marine community. An interagency group of state, federal, and university scientists was formed to determine cause and effect relationships. FMRI has a team conducting monitoring and research within the Florida Bay Science Program.

The interagency Florida Bay Science Program seeks to develop an understanding of the structure and function of Florida Bay to facilitate its restoration, in the context of the overall South Florida ecosystem. Restoration of the bay implies establishing and sustaining the natural diversity, abundance, and behavior of the flora and fauna. The challenge to the bay research community is to deliver timely information to South Florida ecosystem restoration managers.

Some of the key issues pertaining to Florida Bay include the need to answer the following questions from a spatial perspective: 1) how have changes in freshwater inflow and other factors altered the hydrography within the bay and between adjoining areas?; 2) what are the sources and relative importance of nutrient inputs to the bay, versus nutrient cycling within the system, in explaining the bay's nutrient budget?; 3) what environmental changes led to die-offs of seagrasses, mangroves, sponges and other benthic communities?; 4) what are the mechanisms that initiated and control the persistence of plankton blooms within the bay?; 5) how have the changes influenced the production of commercially and recreationally important fisheries resources? It is necessary to determine if the observed changes represent a response to anthropogenic alterations and/or result from natural variability in climate and/or geophysical factors.

Seagrass Die-Offs

Seagrass die-offs were first observed in North-Central Florida Bay during 1987 (Zieman et al. 1988, Robblee et. al. 1991). Robblee et al. (1991) estimated that 4,000 ha of highly productive *Thalassia*-dominated seagrass beds had been almost completely denuded, and an additional 23,000 ha had been affected to a lesser degree. Seagrass distributions in Florida Bay have been compared by FMRI between pre- (1983/84) and post- (1994) die-off periods (Durako 1994, Durako 1995, Durako et al. 1995). They found that seagrass distributions and abundance have changed little in the Eastern zone of the bay. Seagrass die-offs are currently occurring along the bay's western margin and in the Johnson Key Basin (Figure 5). The North-Central zone, which experienced the greatest seagrass decline, corresponds to the area of most persistent and severe algal blooms.

Among the possible causes of *Thalassia* die-off are increases in the area, density, and biomass of seagrass communities due to high salinities in Florida Bay resulting from water management activities and a decade-long drought in south Florida (Zieman et al. 1989). There was an increasing salinity trend in different regions of the bay from 1984 to 1986 (Sogard et al. 1989). The lack of a major hurricane during the past 27 years resulted in the accumulation of high levels of inorganic and organic sedimentation that, in turn, restricted water circulation in the bay and increased summertime salinity and temperature stress (Zieman et al. 1989). Porewater sulfide concentrations of Florida Bay seagrass beds were found to be higher than those measured in other Florida estuaries (Carlson et al. 1994). Sulfide concentrations in sediments were highest in the fall and might have caused hypoxic stress of *Thalassia* roots and rhizomes. A pathogenic strain of slime mold, *Labyrinthula*, has been found in lesions on *Thalassia* leaves (Durako and Kuss 1994). Mean air temperatures during 1987 over North America were the highest recorded in this century (Easterling 1989). Air temperature data from the National Weather Service (Figure 6) indicates that the maximum air temperature recorded at Key West was markedly higher during September 1987 than during the same month of 1986 or 1988. Higher air temperatures would result in higher water temperatures, which in combination with high salinities, may have contributed to seagrass die-offs. Figure 7 depicts a conceptual seagrass die-off model developed by a panel of seagrass experts.

FMRI is working with NOAA/NMFS to inventory benthic habitat change in seagrass beds in Florida Bay using metric quality contemporary (1991-1995) and historical (1950-1990) aerial photographs (Sargent et al. 1995). The protocol for interpretation, surface level verification and classification system being followed was developed by the NOAA Coastal Change Analysis Program (C-CAP) and is similar to that used for the Florida Keys National Marine Sanctuary. Products will include photographs of central and eastern Florida Bay (1992 and 1995), digital geospatial data, and hard copy maps of seagrass bed occurrence and change.

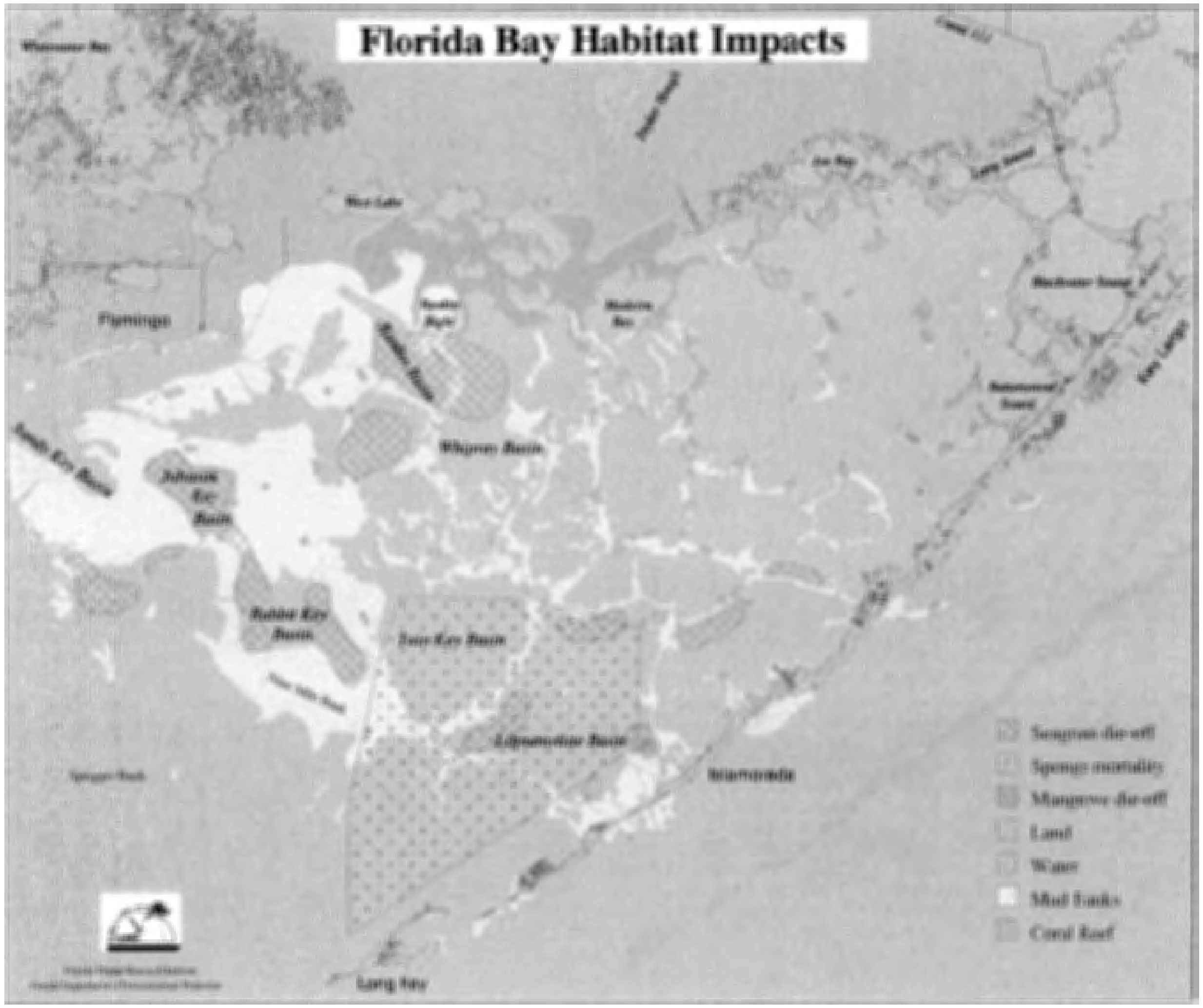

Figure 5. Respective die-off areas for seagrass, sponges, and mangrove in Florida Bay. J. Bexley, FMRI.

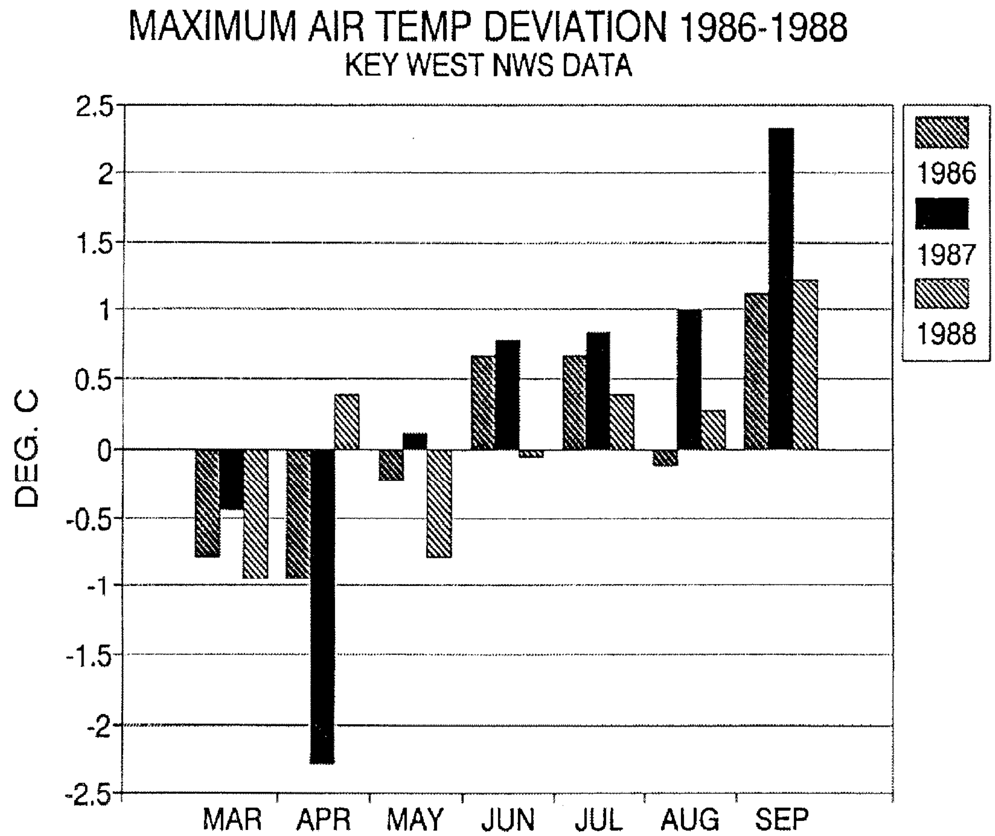

Figure 6. Maximum air temperature deviation at Key West from 1986-1988. P. Carlson, FMRI.

Mangrove Die-Offs

Widespread mortality of mangroves occurred in Florida Bay (Figure 5) during spring and early summer 1991 and again in spring 1992 (Carlson et al. 1995). Black mangroves (*Avicennia germinans)* growing on keys with central shallow basins were the most adversely affected. Air temperature, rainfall, and evapotransporation data indicate that spring 1991 was similar to preceding and following years. To hindcast porewater salinities during the 1991 die-off episode, porewater was sampled at two islands every 4 to 8 weeks between May 1992 and August 1993. Dump Key in the North-Central zone was severely impacted by die-off, Clive Key was not. Porewater salinity at Clive Key varied from 40 $^{o}/_{oo}$ in winter to 49 $^{o}/_{oo}$ in summer. At Dump Key, salinity varied from 40 $^{o}/_{oo}$ in late winter to 67 $^{o}/_{oo}$ in summer. Regression of porewater salinity against tidal inundation frequency resulted in estimates of salinities greater than 90 $^{o}/_{oo}$ during periods of infrequent tidal flooding. Frequent tidal inundations during the winter of 1990-91 was the single most striking climatic event coinciding with the mangrove mortality in North-Central Florida Bay.

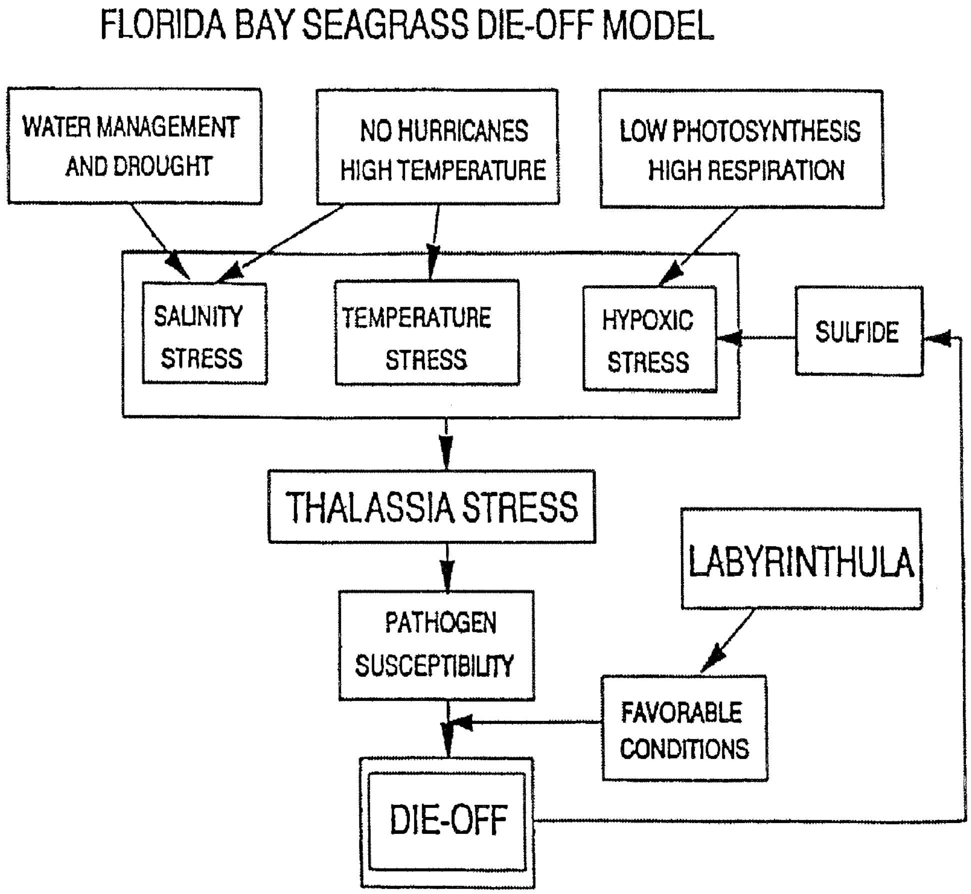

Figure 7. Conceptual Florida Bay model depicting various factors contributing to seagrass die-offs. P. Carlson, FMRI

Plankton Blooms

Surface water color patterns in Florida Bay are being monitored monthly from an airplane (Friel et al. 1995). The outlines of colored water patches are being determined using GPS and mapped in the MRGIS. The colored patches are related to changes in algal blooms, turbidity, and water quality which are being studied at the bay surface by other members of FMRI's Florida Bay team. Analysis using GIS indicates (Westlake et al. 1995 a, b) that the North-Central zone has the most persistent colored water resulting from cyanobacterial blooms (Figure 8). This zone was also characterized by high salinities during August 1994 (Westlake et al. 1995a). The Western zone has colored water that is known to be caused by suspended sediments and micro algae (Westlake et al. 1995b). During the fall of 1994 and 1995, the blooms mapped using GIS were noted to expand out from the North-Central zone. They encompassed the Florida Keys during mid-winter of 1994-95 and 1995-96.

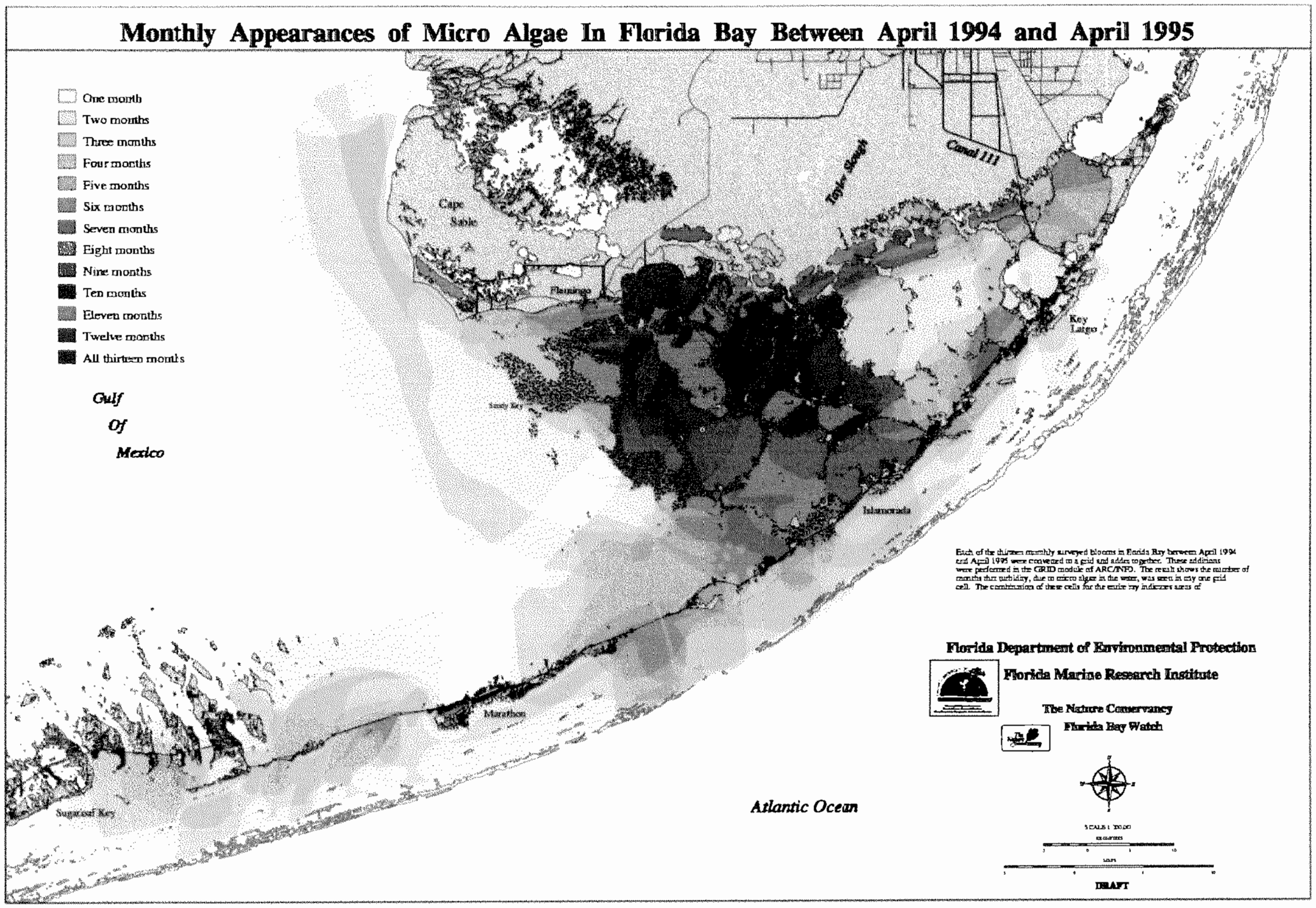

Figure 8. Composite GIS map of monthly monitoring from April 1994 to April 1995, depicting areas with persistent algal blooms in Florida Bay (Westlake et al. 1995a).

Phytoplankton species composition and fluctuations are being monitored (Steidinger et al. 1995). The blooms consist of cyanobacteria, diatoms, and flagellates, all of which contribute to the water discoloration. Resuspended carbonate sediments and bottom organic material can also add to the discoloration and the turbidity. Over 120 diatom, 70 dinoflagellate, and 30 other algal taxa have been identified. One of the most dominant species in the North-Central zone is the cyanobacterium, *Synechococcus elongatus* The colored water in the Western zone is dominated by resuspended sediments and diatoms (predominantly *Rhizosolenia* sp.)

Tomas and Bendis (1995) found that the primary production of phytoplankton in the water column, in different basins of the bay, is limited by the availability of different nutrients. Rankin Basin in the North-Central zone, dominated by *Synechococcus,* was found to have the highest primary production and biomass of phytoplankton. Zimba (1995) has measured primary productivity and obtained standing stock estimates of benthic, epiphytic and planktonic algal and seagrass communities in Florida Bay for FMRI. Sampling was conducted bimonthly for 15 months during 1994-95. Primary productivity was compared between Captain Key in the South-Central zone, and Rankin Bight in the North-Central zone. Increased sediment productivity (32 fold increase over initial conditions) at Rankin Bight has coincided with periods of increased light transmittance in the water column. Zimba found that the biomass of epiphytic algae in Rankin Bight (75 μg/seagrass shoot) exceeded levels found in the Indian River Lagoon (50 μg/shoot). The primary productivity and standing stocks of communities of seagrasses, and benthic and epiphytic algae at both sites have been declining due to reduced light penetration, resulting from the resuspension of sediments and benthic micro algae.

Kleppel et. al. (1995) have been studying zooplankton dynamics as part of FMRI's team. Results from the initial (June-July 1995) experiments indicate a close coupling between phytoplankton biomass and the feeding and production of the copepod (*Acartia tonsa*). Highest production of copepods appears to occur when copepod diets are composed of a combination of phytoplankton and ciliates. Rankin Basin, in the North-Central zone, most clearly typifies the transformation from benthic to water column dominated trophic dynamics, leading to increases in the abundance and biomass of phytoplankton and zooplankton.

Sponge Die-Offs

From November 1991-January 1992, a massive sponge die-off occurred in South-Central Florida Bay (Figure 5) following an episodic phytoplankton bloom (Butler et al. 1994). Butler et al. (1995) observed that during mid-November 1991, the cyanobacteria dominated bloom swept southward into the Lower Arsnicker Keys area of the central Florida Keys. Nearly every species of sponge in the area was impacted, and over 90% were observed to die or become damaged during the time interval of the bloom. Sponges transplanted from areas without blooms died in the phytoplankton bloom area near Marathon (Sharp 1993). The mechanism by which cyanobacterial blooms kill sponges is presently unknown (Butler et al. 1995).

Stevely and Sweat (1995) have surveyed sponge species composition, abundances, and distributions in various areas of Florida Bay for FMRI from 1991 to 1995. During 1991 and 1992, a total of 15 areas were sampled (5 areas north of Long Key, 2 areas west of Everglades National

Park, and 4 areas north of Marathon). The loggerhead sponge, *Spheciospongia vesparia*, and the vase sponge, *Ircinia campana*, represented 68% of the total sponge community biomass during 1991 and 1992. The sponge die-offs became apparent during late 1992, with a reduction of up to 90% of the sponge community biomass during 1993. It is believed that many years will be necessary for the sponge populations to recover.

Spiny Lobster

Florida Bay is the primary nursery area for south Florida's spiny lobster populations (Herrnkind et al. 1994). Postlarval lobsters are carried into the bay on tidal currents through interisland channels from the Atlantic Ocean. Peaks in recruitment occur during the spring and fall. The postlarvae settle within 3-4 days in shallow waters of 1-3 m depth on benthic macro algae (especially red algae *Laurencia* spp.). Several months later, juvenile lobsters leave the algae to reside by day beneath sponges, octocorals, seagrass undercuts, and rock crevices. A misconception has been that the interior of Florida Bay is an essential nursery area for Florida spiny lobster, but there is evidence that postlarval settlement is limited in the North-Central zone (Field and Butler 1994). Most of the area colonized lies within the South-Central zone of the bay.

Hard bottom habitat containing sponges was thought to be prime nursery habitat for juvenile lobsters (Herrnkind et al. 1994, Forcucci et al. 1994). The sponge die-offs in the Lower Arsnicker Keys area precipitated dramatic shifts in lobster abundance and shelter use (Butler et al. 1995). The loss of sponges in a hard bottom area resulted in the movement of juvenile lobsters to 27 artificial shelters, and a decline in lobster abundance at other sites lacking artificial shelters. It has been proposed that juvenile lobster abundance will decline over the region where sponge loss was extreme. However, recent data suggests that juvenile lobsters are adaptable, since they have been observed colonizing seagrass beds in the South-Central zone where sponges have disappeared (Herrnkind et al. 1995, Hunt et al. 1995). Large scale surveys for juvenile lobster have been coupled to a spatially explicit individual-based model. Initial predictions from the model are that lobster recruitment will decline 2-19%, depending on the availability of alternative shelters, which corresponds with a field survey based estimate of 10% loss in new recruits.

Pink Shrimp

A multi-investigator study of pink shrimp involving scientists from NOAA, the University of Miami, and the National Biological Service was initiated in 1994 to investigate the fishery, and to examine it in relation to conditions on known nursery grounds, particularly Florida Bay (Browder et al. 1995). The decline in pink shrimp recruitment to the fishery in the Dry Tortugas was one of the recent signs of deterioration in the health of Florida Bay. Shrimp landings are positively correlated with indices of freshwater runoff, and loss of freshwater inflow to Florida Bay is a major hypothesis for the bay's decline. Pink shrimp also act as an indicator of the health of seagrass beds. The National Marine Fisheries Service in Galveston had previously found a positive correlative relationship between Tortugas shrimp landings, adjusted for effort, and freshwater inflow to the coast (Sheridan 1996). One objective of new research in 1994 was to develop a computer model to simulate shrimp growth as a function of temperature and to determine the timing of maximum shrimp catches in the Tortugas, by size, resulting from the month and day of maximum abundance of juveniles on the nursery grounds (Browder et al. 1995). A second objective has been to explore the environmental variables that might be influencing recruitment. Sea surface temperature and salinity data have been analyzed and related to laboratory studies, which have examined the growth and survival of young pink shrimp under different temperature and salinity combinations. A strong relationship was found between Tortugas landings and salinities in Florida Bay. Laboratory experiments indicated reduced survival at temperatures exceeding 30°C, and salinities exceeding 45 $^{o}/_{oo}$. The research also indicated an effect of freshwater inflow on early survival, as reflected in juvenile densities on the nursery grounds. These results suggest that parts of Florida Bay are unsuitable as nursery grounds in most years.

Pink shrimp landings from the Tortugas were extremely low from July 1986-June 1987 through July 1992-June 1993 (Browder et al. 1995). Landings increased greatly associated with higher rainfall from July 1993 to June 1995, tending to confirm the relationship between pink shrimp catch rates and freshwater inputs. Genetic studies are also being conducted to determine whether different physiological phenotypes exist that contribute to seasonal pulses in recruitment of shrimp. Analysis confirmed that the decline in pink shrimp landings and catch rates from the mid 1980s to the early 1990s was due almost entirely to the decline in the fall cohort. Within-year cohorts may come from different nursery grounds, and may survive and grow best under different environmental conditions.

Ecosystem Health of Communities

Assessing the "health" of the ecosystem necessitates determining the status of marine communities (Norse 1993, NRC 1995). Research is being conducted to map the geographic distributions of species, and to determine the well-being of marine fish and invertebrate communities. Data collected by FMRI in Florida Bay are being used to calculate indices, that can be used to spatially assess ecosystem health.

Mollusk Community

Lyons (1995) began studying the assemblages of live benthic mollusks in Florida Bay during 1994, for comparison to the distributions of dead mollusk shells in bay sediments deposited several decades ago. The results are intended to provide a baseline for measuring changes due to environmental perturbation or for efforts to mitigate such disturbance. Mollusk species distributions have been mapped with GIS by the CAMRA group. High rainfall during late 1994 and 1995 reduced salinities, leading to reductions in the abundance and even the disappearance of many species of mollusks (Lyons, pers. comm. 1996). Paleolimnological methods involving the identification of mollusks offers a means of assessing past communities associated with either estuarine or marine environments in Florida Bay. This will be important for decision-makers interested in restoring historical conditions in the bay.

Marine Fish Community

Studies by FMRI are being conducted to determine how variations in environmental factors and the levels of freshwater input affect juvenile fish recruitment, and lead to changes in the composition of juvenile assemblages. Acosta (1995) has examined the relationships of juvenile fish species abundance, number of species, and diversity with dissolved oxygen, temperature, and salinity at 30 fixed stations sampled by FIM monthly with seines and bottom trawls from January 1994 to May 1995 (Colvocoresses and McMichael 1995). There is a strong heterogeneity in species composition and abundance across the different sections of the bay. The North-Central zone presents the lowest abundance and diversity. Both abundance and diversity decreased with low levels of bottom dissolved oxygen.

Matheson et al. (1995) have been evaluating the faunal community of healthy and degraded seagrass beds on banks representing five different vegetational environments. The areas sampled were near Cross Bank, and Eagle Key in the Eastern zone, between Roscoe and Dump Keys and at Coon Keys in the North-Central zone, at Oyster Key in the Western zone, and at Buchanan Keys in the South-Central zone. Throw-trap samples collected during 1994-95 were compared with those taken during an earlier study in 1984-86 (Powell et al. 1987). Most sites were numerically dominated, in both studies, by two species of surface-oriented fishes commonly found associated with seagrasses, the rainwater killifish (*Luciana parva*) and the goldspotted killifish (*Floridichthys carpio*). The area between Roscoe and Dump Key in the North-Central zone, which experienced the most severe decline in seagrass densities, was found to have significant declines in the numerical abundance of these killifish species, and the total fish sampled. Benthic fish and alpheid shrimp densities increased significantly in the same area. Significant increases occurred with two benthic residents, the code goby (*Gobiosoma robustum*) and gulf toadfish (*Opsanus beta*). Robblee (1995) has used a somewhat different throw trap methodology to compare changes in the fish and invertebrate communities in Johnson Key Basin within the Western zone of Florida Bay. The abundance of seagrass associated caridean shrimps, fishes, and pink shrimp was lower in 1995 compared to either 1985 or 1990. During 1995, the rainwater killifish, goldspotted killifish, and gulf toadfish were less abundant than previously found, while bay anchovy occurred in greater numbers.

In deeper water of the North-Central zone, Hoss and Thayer (1995) of the NOAA/NMFS Beaufort Laboratory, using a midwater trawl, have found a shift in dominance of resident fishes. There was a shift in the impacted seagrass areas from mojarra (*Eucinostomus spp.*) and rainwater killifish to bay anchovy from July to May 1994-95 compared to 1984-85 (Thayer and Chester 1989). Mojarra are benthic feeders, and rainwater killifish feed on crustaceans associated with the seagrass canopy, while anchovy feed on zooplankton in the water column. This suggests a shift in dominance of the resident fish community from predatory fishes to planktonic filter feeders, in the zones where phytoplankton and zooplankton densities have increased.

Modeling

Florida Bay Ecosystem

An Interagency Task Force developed an ecosystems-based South Florida Comprehensive Science Plan that identified research needs including ecosystems monitoring and modeling (Brown et al. 1994). The task force concluded that models currently existing or under development were not broad enough in geographic scope to meet region-wide ecosystem management needs. Restoration management using the adaptive management approach will be heavily dependent upon simulations from models, particularly hydrological models.

FMRI is presently developing and adapting both single species and community-oriented models, which are coupled with GIS. The data from the various Florida Bay studies previously described are being added to a common data base and habitat coverages created using GIS. It is envisioned that FMRI's modeling effort will help to explain how freshwater inflows, water circulation, and nutrient dynamics within the bay influence productivity at different trophic levels.

Modeling Fisheries With Habitat

Scientists at FMRI are collaborating with NOAA's Strategic Environmental Assessment (SEA) Division to model and map the geographic distributions of fishery species at different life stages. FIM data are being analyzed to relate the abundance of fisheries and forage species to physical/chemical and habitat-related factors. Biological and hydrological data are being subjected to multivariate analyses to classify the community of fishes associated with various portions of environmental gradients (Bulger et al. 1993). Biologically-relevant ranges of salinity, temperature, depth, sediments, and benthic habitats can then be contoured and stored in the MRGIS. Suitability Index modeling is being undertaken to define which portions of environmental gradients are most important in explaining species abundance. The environmental maps being created summarize seasonal changes in factors such as salinity zones resulting from high and low freshwater inflow, and water temperature changes. Pensacola Bay data from FMRI and other sources were recently analyzed and mapped in this manner using GIS by SEA Division.

Habitat Suitability Index (HSI) models access suitability indices associated with the environmental zones stored in the data base (Brown et al. 1994). The HSI models can be used in conjunction with GIS to produce predicted maps (Figure 9) of the geographic distributions of estuarine species by life stage. The HSI modeling approach provides a means to produce predicted fish and invertebrate distribution maps in Florida estuaries not being surveyed by FIM.

The goal is to map the geographic distributions of juvenile and adult life stages of approximately 50 species of marine fish and invertebrates in twelve west Florida estuaries over the next few years. The fish and invertebrate species distribution maps will complete the ESI mapping of biological resources needed for oil spill response/mitigation and fisheries management.

Oil Spill Response Modeling

Oil spill models have been developed that can calculate the trajectory and toxicity of oil spills (Spaulding 1995, Trudel et al. 1996). By linking the models to GIS containing coverages pertaining to habitat types and biological resources, it is possible to determine the areas occupied by an oil spill in relation to the areas occupied by marine species and human-use resources at risk. Biological and economic impacts on the marine community can be calculated from the proportions of the species' ranges impacted by an oil spill. The Tampa Bay oil spill, which occurred in August 1993, caused injury to marine resources in Boca Ceiga Bay. The NRDAM/CME model (French et al. 1996) developed by Applied Science Associates (ASA) for the Department of the Interior was used as part of the process of natural resource damage assessment of marine communities by FDEP.

Harwell et al. (1995) at the University of Miami used FMRI's fisheries and habitat data for Tampa Bay in conjunction with the Princeton 3-D ocean circulation model, ASA's SIMAP oil spill

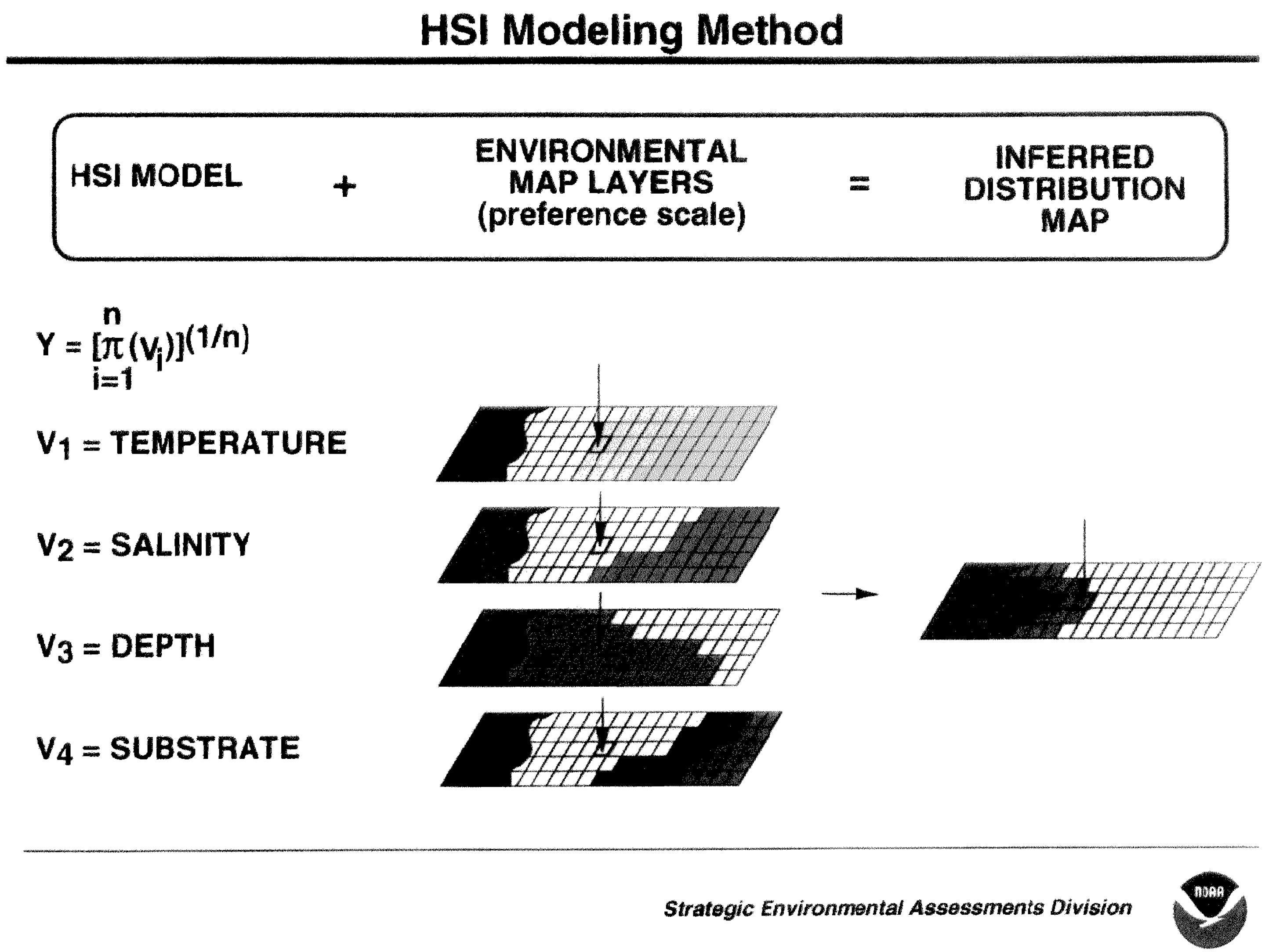

Figure 9. Predicting fish distributions from a grid using GIS in conjunction with HSI modeling.
M. Monaco, NOAA SEA Division.

models (French and Mendelson 1994), plus new fisheries models to evaluate various oil spill scenarios. Spotted seatrout were one of 18 key species chosen for modeling to evaluate the potential ecological impacts of various kinds and sizes of oil spills on fish and invertebrate species and associated coastal habitats in Tampa Bay. The oil spill scenarios were modeled and visualized in three dimensions using GIS (Figure 10).

Advances in computer and GIS technology now make it possible to tightly link various physical and biological models to GIS. Modeling can be used to analyze the impacts of anthropogenic and natural perturbations on marine ecosystems. Submodels developed for assessing the impacts of oil spills are being adapted to assess other perturbations as well. One recent example is ASA's Water Quality Mapping and Analysis Package (WQMAP). This is a set of hydrodynamic and water quality models integrated with a GIS through an intuitive Microsoft Windows graphical user interface (ASA 1996). Similar approaches have been developed by the University of Miami for ecological risk assessment at a landscape level that can support ecosystem management (Harwell et al. 1995).

The Benefits of Ecosystem Management

The Florida Department of Natural Resources (FDNR) was merged with the Florida Department of Environmental Regulation (FDER) to form FDEP during 1993. The functions of pollution monitoring and regulation, habitat protection, oil spill response/mitigation, ecosystem assessment and restoration, and fisheries management have been integrated within the new department. The integration of these functions facilitates the implementation of ecosystem management by FDEP.

Fisheries resource managers are faced with numerous environmental problems that traditional single-species fisheries stock assessment models, based on fisheries dependent monitoring of the recreational and/or commercial fisheries, were not designed to address (Rubec 1996). Fisheries independent monitoring allows the assessment of fish and/or invertebrate species abundance and environmental/habitat variables collected at the same geographic locations. These data are now being analyzed to obtain information explaining fluctuations in marine species abundance, changes in marine communities, and the factors limiting fisheries production. The monitoring programs and data collected by different sections within FMRI are being integrated to facilitate ecosystem modeling and management (Ehler and Basta 1993). A seascape-level approach to management and research is being developed by FMRI involving GIS mapping and modeling, based on more comprehensive monitoring of ecosystems at different trophic levels.

By protecting marine habitats, FDEP hopes to conserve the aquatic community including fishery species. Ecosystem management that protects and restores marine habitats and water quality, should allow the persistence of recreational and commercial fishery species. This holistic approach benefits the biological community, the fisheries, and the tourism-dependent Florida economy. Sport Fish Restoration Program funding from the U.S. Fish and Wildlife Service is being matched with funding from the State of Florida to support FIM and CAMRA fisheries-habitat related studies (FDEP 1993). FMRI's integrated efforts support better management decisions, increased fishing

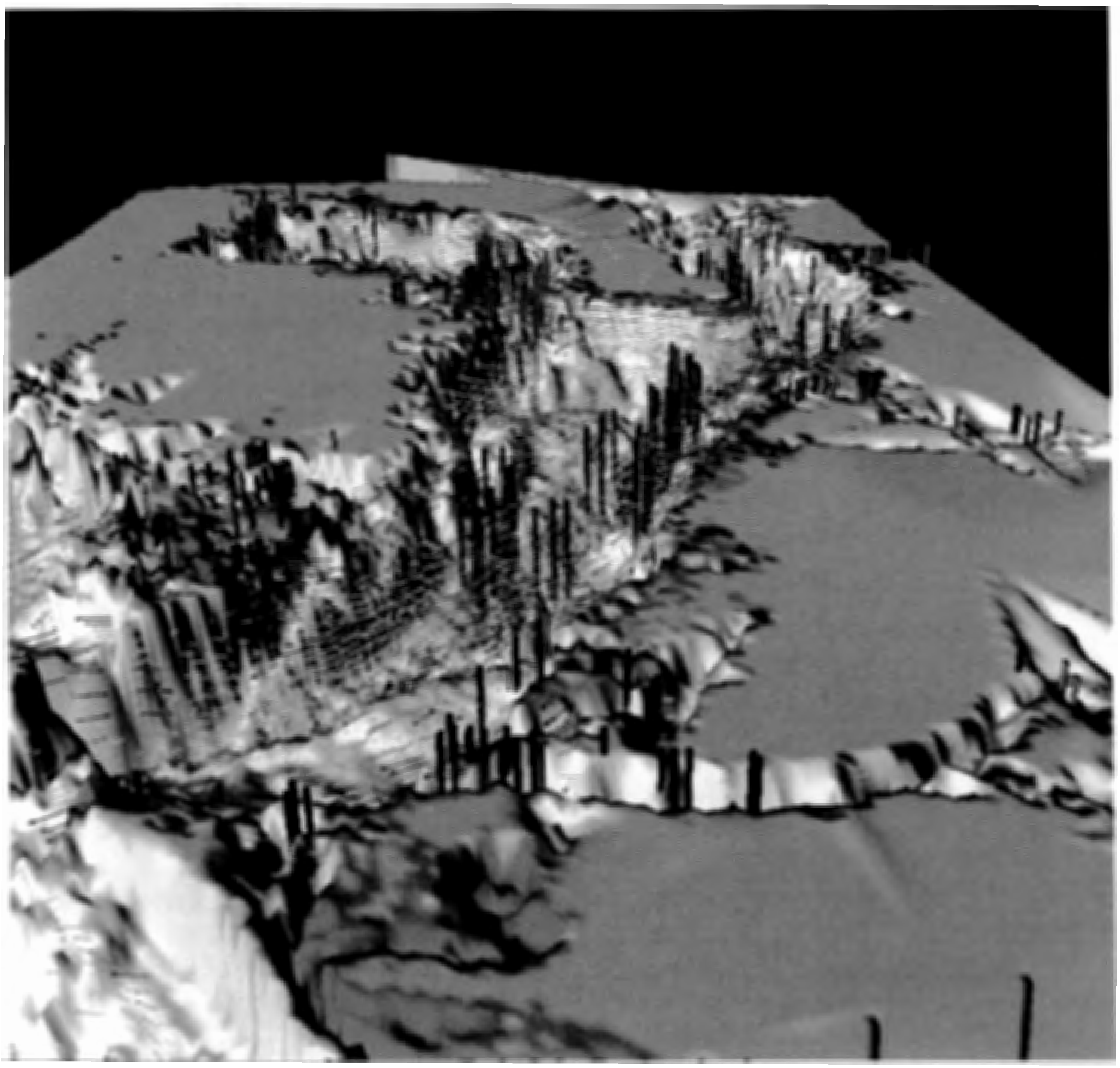

Figure 10. Tampa Bay depicted in 3-D showing ocean currents (arrows), shoreline habitats (colored areas), fish abundances from FIM monitoring (vertical bars). J. Ault, University of Miami.

opportunities, a more informed public, and a more stable fisheries in balance with natural and anthropogenic forces. By making the link demonstrating the importance of habitat for fisheries, FMRI hopes to influence decision-making that results in sustainable fisheries.

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Developing Electronic Information Services to Help Protect the Nation's Environment

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The Strategic Environmental Assessments (SEA) Division is one of four Divisions within the NOAA's Office of Ocean Resources Conservation and Assessment (ORCA). Through its five branches, the Division develops and implements a wide variety of information technologies to collect, organize, present, and distribute data on the United States' coastal and ocean resources. The goal is to obtain this data in as complete a manner as possible, organize and present it in a way that is comprehensive and easy to use, and develop ways to make it accessible to a wide range of users--from Federal and State agencies to universities and other academic institutions, as well as users in the private sector, including environmental organizations and interested individuals.

While this used to mean simply producing hard-copy products such as reports, maps, and data atlases, new technologies have become available that now enable the information collected to be more accurate, comprehensive, and user-friendly than ever. In addition, the electronic nature of these technologies allows information to be updated and manipulated with ease, and distributed to a wider audience than ever before.

Recognizing the value of these new technologies, in the mid-1980s the Division redefined its commitment to providing environmental information in electronic formats. The GeoCOAST Facility was formed, allowing Geographic Information Systems (GIS) analyses to be conducted in-house. The Division also began the development of a suite of desktop information systems, also termed Spatial Decision Support Systems (SDSS), such as COMPAS, the Coastal Ocean Management, Planning, and Assessment System and *Cmas*, the Computer Mapping and Analysis System. These capabilities have now reached maturity, and the Division has turned its attention to a new generation of information services, such as interactive multimedia CD-ROMs, to help present data in a way that is not only functional, but user-friendly and visually interesting as well. Finally, SEA is connecting to the Internet to enable as many users as possible to have access to these new products and services.

This document presents the Division's work in three areas (Figure 1) from September 1993 to May 1994: 1) Desktop Information Systems; 2) Geographic Information Systems; and 3) Internet and Multimedia, a new Division focus. To find out more about the projects or products described, contact the Division at (301) 713-3000, or by fax (301) 713-4384.

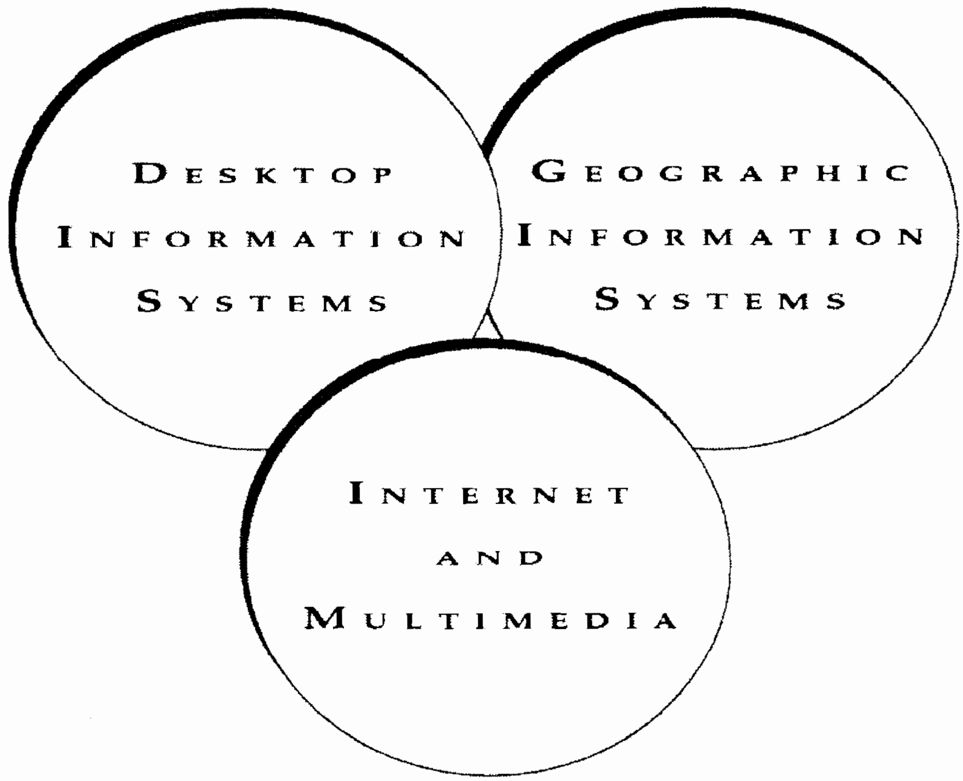

Figure 1. Three areas of focus for SEA Division's electronic information services, September 1993- May 1994.

Desktop Information Systems

Over the past five years, SEA has been involved in designing, building, and distributing microcomputer-based desktop information systems to enable a wide range of resource information to be presented in one user-friendly and easily updatable format. Systems have been completed on topics ranging from seabird population distributions to nutrient enrichment potential to shellfish growing areas and water quality. COMPAS (the Coastal Ocean Management, Planning, and Assessment System) has been at the forefront of the Division's products designed to help State managers make decisions about protecting coastal resources. The desktop activities described below are among those completed in the last nine months.

COMPAS Florida Product Completed and Transmitted to Florida Marine Research Institute and the State of Florida

COMPAS Florida was completed and transferred to the State in April 1994 (Strategic Environmental Assessments Division 1993a; 1994a,b,c,d). Building on work done to produce a similar product for the State of Texas, this Oracle-based desktop information system was developed with the help of the Florida Department of Environmental Protection to enable resource-use decision-making focused on the Florida Keys. Accordingly, it contains Keys-specific data sets on enforcement actions, benthic resources, and marine facilities within the Florida Keys National Marine Sanctuary. At the conclusion of the two-year COMPAS Florida development effort, however, the project was expanded and additional information was included on Florida in general, such as data sets on shellfish-growing areas, fisheries, pollutant sources, and water quality.

COMPAS Oregon Prototype System Completed in Cooperation with Oregon Department of Land Conservation and Development

Completed in May 1994, the Oregon prototype system represents the first trial implementation of a generic COMPAS product that can be released to all coastal states (Strategic Environmental Assessment Division 1993a, 1994b,c). It primarily includes information on shoreline management and land use, aggregated by watershed and county. The system was developed in close coordination with the Oregon staff, which will assume primary responsibility for managing the product as the SEA Division moves toward more of a consulting and support role in the near future.

Mid-Atlantic Desktop Mapping and Information System Completed

Working with the U.S. EPA, the Division developed a desktop information system that will be used to help distribute data collected in the near-coastal component of the EMAP Virginian Province Demonstration Project. The final product, which is currently being distributed, contains over 30 data sets on the area between Virginia and Massachusetts. Among other data sets, information is included on ORCA's National Status and Trends Monitoring Program, SEA's program to estimate coastal pesticide use, and EPA's Toxic Release Inventory. The goal is to use the system to make available the resource information, generic software, and mapping utilities necessary to help State agency, university, and EPA National Estuary Program members develop custom-designed information systems for their areas of the country.

SEA to Help Develop and Test a Desktop Information System Focusing on Central California Region

In a project designed to benefit coastal ecosystem health, improve short-term warning and forecast services, and increase the quality and availability of environmental information, SEA will help develop a desktop system for the Central California region as part of the Ocean search/California Partnership Program. Working with NOAA's Office of Ocean and Earth Sciences, a primary activity will be the input of its GIS-based atlas information into the system. Additional contributions will include general consulting collaboration and assistance in beta-testing for the product being developed.

Cooperative Effort Completed to Modify the SURFACE III Contouring Application

Working with the Kansas Geological Survey, the SEA Division completed work in September 1993 to modify SURFACE III, a custom computer mapping application that facilitates interpolation and contouring activities. The SURFACE III interface was improved and additional functionality was incorporated, including a query tool. The modified version is currently being used by the Division to analyze and map salinity regimes in the United States' South Atlantic and Gulf of Mexico estuaries.

Phase II of Cooperative Effort Completed with University of Dublin to Enhance REGARD Spatial Analysis Application

Completed in December 1993, Phase II concerned increasing the functionality of this analytical mapping application that is used to examine multiple spatial relationships among several parameters at the same time. The program now includes zooming and geo-referencing capabilities not previously available. REGARD is currently being beta-tested by the Division's Shellfish Program and is also being used by the team assembled to propose a strategic assessment capability plan for EPA's Gulf of Mexico Program. Phase III of the effort will include the direct input of SEA information from geographical databases.

COMPAS to be applied to State of Delaware Resource Management Needs

As part of the continuing application of COMPAS technology to coastal states, the SEA Division will meet with representatives of Delaware's Department of Natural Resources and Environmental Control in early June to discuss the development of software specific to managing the state's coastal resources (Strategic Environmental Assessments Division 1993a). The focus of the joint project, which will also include input from county planning agencies, will be maintaining swimmable and fishable waters and preserving coastal habitat statewide. State and local data will likely be included on land use, habitats, and water quality parameters.

Geographic Information Systems

The development of Geographic Information Systems (GISs) has revolutionized the way environmental data is collected, organized, and presented. Within the SEA Division, the GeoCOAST Facility is used to conduct digital geo-referencing, image processing, data base management, and information exchange and analysis. Spatially and temporally examining coastal and ocean information, the Facility combines commercial and NOAA-developed software to support a wide range of assessment activities. Among other projects, it has been recently been used to define a digital set of spatial areas comprising a framework for U.S. estuarine and coastal regions, and was also used in assisting with restoration efforts following Hurricane Andrew in 1992.

Capture and Assembly of 1:70,000 Digital Shoreline Data Set Completed

In October 1993, the Division supplemented its suite of digital geographic products by completing a 1:70,000 U.S. shoreline that was vectorized from NOAA nautical charts. Designed in a generic format, the shoreline is being put on CD-ROM for distribution, and will be publicly available.

Project to Reclassify Florida Keys Benthic Habitats Enters Second Stage

Working with NOAA's Coast and Geodetic Survey (C&GS) and the State of Florida, SEA is processing photogrammetry of the Florida Keys through GeoCOAST to reclassify and map the area's benthic habitats. As of February 1994, 47,000 square hectares had been mapped. In the second stage of the project, the next block of 60 photographs are being classified by the State of Florida and compiled by the C&GS. The SEA Division will then build topographies using the GeoCOAST Facility. In all, over 977,000 square hectares within the Florida Keys National Marine Sanctuary will be mapped and classified, based on 31 benthic habitat types. The Division presented a paper on the project at the Second Thematic Conference for Remote Sensing for Marine and Coastal Environments on January 31-February 2, 1994 in New Orleans.

Cooperative Effort Initiated to Develop a Very High-Resolution Shoreline from NOAA Topographic Sheets

In another project being conducted with the C&GS, SEA is using the GeoCOAST Facility to convert data obtained from existing topographic sheets (T-sheets) to develop a 1:20,000 very high-resolution U.S. shoreline (Strategic Environmental Assessments Division 1993b). The shoreline will be especially useful to State agencies, which typically require very detailed shoreline geographies. The work is part of an ongoing NOAA effort, and is being compiled in the Spatial Data Transfer Standard (SDTS) format for distribution.

Enhancements to SPANS MAP Application Progressing

The Division is currently enhancing SPANS MAP, a viewer and low-end mapping program, by improving the capabilities necessary to geo-reference and add annotations to raster-type images. In addition, the program, which is currently being used for manipulating scanned photos and other images, will be made easier to use with its associated data base. A paper on the program and its application within the GeoCOAST Facility was given at the U.S. Hydrographic Conference for Marine Information Partnerships in Norfolk VA on April 18-23, 1994.

GeoCOAST Used to Process Data for SEA's East Coast of North America Strategic Assessment Project

As part of an international effort with Canadian environmental agencies, a digital shoreline of the East Coast from Cuba to northern Labrador has been created using a 1:1 million scale chart of the world (Brown et al. 1991). A habitat suitability assessment was also conducted for Atlantic Cod to determine where the species was most likely to be found within the study area of the East Coast Strategic Assessment Project. Data were also processed to map mean East Coast temperatures over a 50-year time span. In the future, data will be mapped on topics including surficial sediments and point sources of pollution.

SEA to Provide GIS Support for the Tijuana Bay Estuary Partnership

As part of the Division's continuing goal to provide technical support to other NOAA offices as well as other Federal and State agencies, SEA met in May 1994 with representatives of the Tijuana Bay Estuary Partnership as a first step in applying GIS and other desktop mapping capabilities to the activities being conducted in this area.

Ability to Overplot Vector Lines on Raster NOS Nautical Charts Achieved

SEA has begun using a raster graphics plotter to produce E-size overplots of vector data on NOS raster nautical charts. The work, being conducted for EPA's National Estuary Program, allows precise geo-referencing and registration alignment for the first time on images of this size.

Prototype Study of U.S. Dam Attributes Initiated

The GeoCOAST Facility is currently being used to analyze data on U.S. dams that are located within the Division's Coastal Assessment Framework. The work is designed to assess the effectiveness of fish ladders being used by anadromous species to help expand their existing range.

Two Presentations Made at Coastal Zone Management Workshop for Small Island States (Barbados)

The presentations made at this conference focused on applying GIS technology to enable improved resource management and decision-making for small island states. Specific examples were given from the GeoCOAST Facility, and their application to the needs of these areas was discussed.

Use of SEA's Coastal Assessment Framework Widens

Initially distributed to 50 users in July 1993, the CAF, a digital spatial framework developed in GeoCOAST, is currently being used by more than 100 individuals and organizations including the U.S. EPA, FEMA, various State agencies, and The Nature Conservancy (Strategic Environmental Assessments Division 1993a,b).

Internet and Multimedia

With the advent of new interactive technologies such as CD-ROMs and computer video imaging, SEA has implemented an effort to design and produce a variety of new information products. Through the use of the Internet and other routes of the Information Super highway, the Division will make its products available to a wider audience of potential users than ever before. The activities described below are helping to build the framework of these new technologies.

SEA Spearheads Development of NOS CD-ROM Product

In what will be the first major interactive product produced by the National Ocean Service (NOS), SEA will be integrally involved in developing a CD-ROM product designed to provide general information on NOS programs and activities. The 30-minute interactive piece will be produced in collaboration with InterNetwork, Inc. of Delmar CA, and has been designed for general nontechnical audiences to present information on four thematic areas: 1) marine navigation; 2) national marine sanctuaries; 3) coastal development; and 4) pollution of coastal waters. It is intended for use in schools, libraries, museums, etc. to help explain some of the environmental strains being faced by the nation's coasts and to foster both an understanding and desire to help protect vital natural resources such as wetlands, estuaries, and beaches.

SEA Establishes Multimedia Center in Division Offices

In February 1994, SEA began building a multimedia center designed to support a range of product development activities including video and audio editing and production, computer animation and rendering, and advanced design and illustration capabilities. The center will include a complete audio and video library, and is being designed to eventually allow in-house development of interactive CD-ROM products. It contains a Macintosh 950 Power PC, 4.8 gigabyte hard drive, direct audio and video input, two VCRs, and a video camera to facilitate video editing, a 25-inch video monitor, a color scanner, and a 486/66 IBM-compatible PC. The products designed by the center will be distributed both in-house, through conventional release, and via the Internet. Finally, the Division will use its knowledge of the new technology to act in a consultative capacity for other offices within NOAA and other Federal, State, and local agencies.

ORCA to Establish World-Wide Web (WWW) Mosaic Server

To keep up with the needs of NOAA users, the SEA Division will assist ORCA in establishing an Internet Mosaic server to enable the transfer of information on topics including long-term sampling and monitoring, coastal environmental quality, the physical and hydrologic characteristics of coastal areas, and coastal marine resources. It will be the first step in allowing ORCA's data to be easily transferred to the widest potential user community.

SEA Division Network Operating System and Server Capabilities Upgraded

The network operating system connecting the Division's 70 Macintosh and 30 IBM-compatible computers was upgraded in February 1994 to include a UNIX component to enable greater speed and efficiency of database activities and to allow enhanced access to Division Servers and the Internet. In the future, UNIX will also be used to create a "firewall" server that allows Internet connectivity. The system also features a new Novell Netware configuration that allows all platforms (e.g., Mac, PC, etc.) to share information more efficiently.

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The ORCA Information Service On The Internet: Bringing Information For Coastal Decision-Making On-Line.

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NOAA's Office of Ocean Resources Conservation and Assessment (ORCA) has initiated an effort to distribute various types of program-related information and services to the public via the Internet. Planned offerings include publications, graphics, environmental data sets, geographic boundary files, and multimedia products. Clients can select offerings based on a particular geographic location, product type, and topic of concern, and have the capability to download directly or e-mail a request for hard-copy products. This paper answers commonly asked questions about the service.

What is the ORCA Information Service ?

The ORCA Internet Information Service utilizes a World-Wide Web (WWW) server to offer information to the public. The service can be accessed through emerging *point-and-click* graphic interfaces such as Cello, Lynx, Mosaic© or Netscape. The ORCA server allows users to search through ORCA's corporate database of products and services; explore related project information; order publications; download data sets; and access products directly on-line. The corporate data base organizes most of the system and manages ORCA's information products. The service also provides the public with direct communication via e-mail to experts involved in various projects, and tracks orders and usage by issue. ORCA's Information Service has been designed to follow current and identified standards on metadata, and will provide complete data descriptions according to Federal Information Processing Standards (FIPS) 173 Spatial Data Transfer Standard, and the Content Standards for Digital Geospatial Metadata as soon as these modules are completed.

Why do it ?

The ORCA Internet Information Service meets two major goals. First, it provides a mechanism for ORCA to develop a centralized *corporate data base* for its ever-increasing data product holdings (e.g., publications, data sets, geographic boundaries, graphics, and multimedia offerings). Second, it allows ORCA's nationally based coastal resources and assessment data products to be provided to a wider audience, including other government agencies, academic and research institutions, and the private sector. While accomplishing both these goals effectively, it also provides centralized management and the capability for expansion to additional data, capabilities, and services. A functional overview of the ORCA Information Service is depicted in Figure 1.

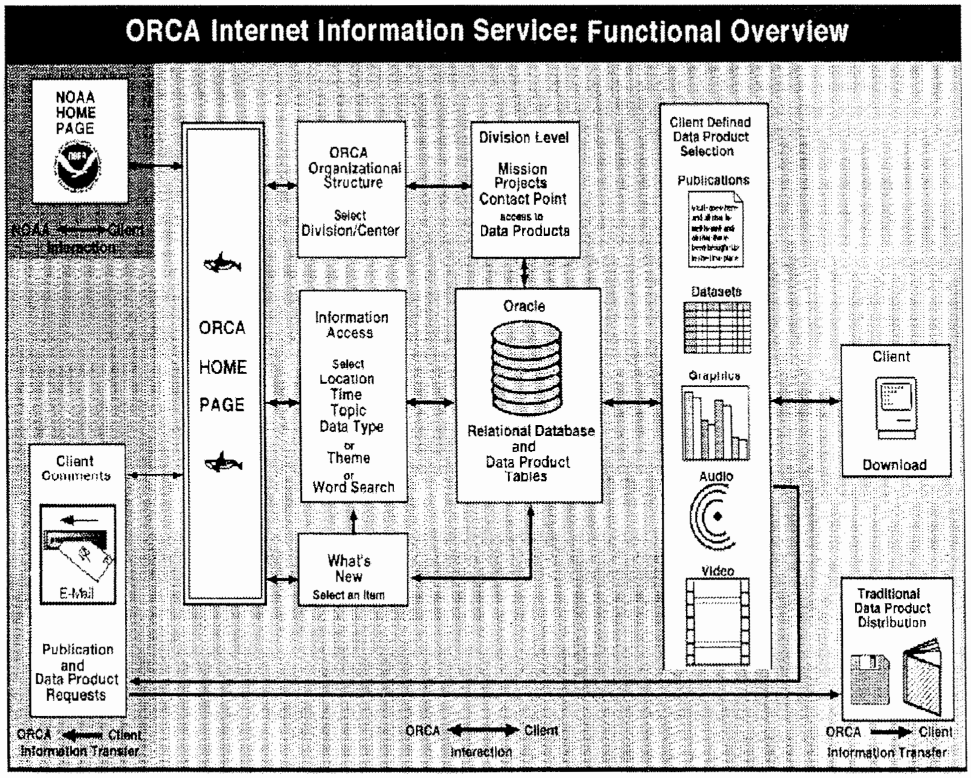

Figure 1. Orca Internet Information Service: functional overview.

As the Information Super highway grows, so too does the potential customer base for ORCA's data products. Making these data products available on demand to customers via the Internet, through a widely accepted and available interface, allows these important data to be put to wider and better use. Automated data product selection and distribution lessens this burden for ORCA staff and frees critical time that can be used to further develop and analyze data important in coastal resource decision-making. The service also allows ORCA to automatically track customers' connections, downloads, comments, and requests and to enhance the system to enable better customer-service.

This centralized and standardized corporate data base also facilitates collaborative data development and synthesis efforts and technology transfer between ORCA units, which will increase overall productivity and efficiency.

What information is available ?

ORCA provides coastal and ocean decision-makers with comprehensive scientific information on the resources of the nation's coasts, oceans, and estuaries.

The Information Service will contain a wide spectrum of data products including publications; relational data sets; graphics such as maps, tables, and graphs; the GeoCOAST geographic boundary file library; sound bites describing programs or projects; and short multimedia presentations.

Three basic access paths are available. Clients may access data based on the organizational structure of ORCA, choosing to learn more about data sets, products and/or services developed by particular units. Access utilities for selecting data type, geographic location, topic, and time frame are also included. For example, a regional manager may choose to select relational databases for the Gulf of Mexico that have been developed since 1990 which include the word "pollution" in their description, while a local planner might select data sets, graphics, and geographic boundary files dealing with the shellfish resources of Buzzards Bay.

A chronological "What's New" section allows users to directly access the most recent ORCA offerings. Step-by-step instructions are included to assist clients with information access routes.

The Service currently includes a description of the ORCA organizational structure, as well as a complete publications listing and select data sets with request forms and limited download ability. Geographic boundary files describing ORCA's *Coastal Assessment Framework* are also available, as is a detailed description of the National Status and Trends (NS&T) Program. Direct connections to related servers are also provided.

Future offerings will include a complete NS&T raw data offering, data from the National Coastal Pollutant Discharge Inventory, the Estuarine Living Marine Resources database, National Estuarine Inventory, National Shellfish Register, select population census data and more, as well as software, maps, and other geographic files.

How is it accessed ?

ORCA's Internet Information Service is currently on-line and available to Internet users who can connect directly to ORCA's WWW server with a client such as Cello, Lynx, or Mosaic©. Modem access is being planned for the future.

To access the ORCA Internet Information Service, enter the Universal Resource Locator (URL): **http://seaserver.nos.noaa.gov**

GIS Applications For Fisheries: For Data Base Management, Data Sharing, Sampling, Analysis, and Visualization in Support of Ecosystem Management

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Problems In Fisheries Management

Fisheries managers are faced with numerous environmental problems that traditional single species fisheries models were not designed to address. In addition to overfishing, some of the problems facing managers include the effects of the following: point and non-point source pollution, periodic freezes, the loss of wetlands, red and/or brown tides, freshwater inflows, the introduction of exotic organisms, and stocking programs. These problems often involve hearings where commissioners, politicians, other government agencies, the press, representatives of the sport or commercial fishery, and/or the public demand to know impacts on the fish community, on marine habitats, negative and/or positive interspecific interactions, economic impacts of changes in management etc. The managers in many cases may not have the data from state or federal monitoring programs to address these issues.

Sampling programs of coastal marine fish communities are much more comprehensive and quantitative than most terrestrial monitoring (NRC 1994a). Hence, it is possible to analyze fisheries data bases to conduct stock assessments etc. Fisheries dependent and independent sampling programs have only been in place within the past 20 years for states monitoring marine fisheries in the northern Gulf of Mexico. Hence, they can not answer questions about the fish community composition or habitat changes which occurred before the initiation of consistent monitoring programs.

The Data Management Subcommittee of the Gulf States Marine Fisheries Commission has been advocating more comprehensive monitoring and data sharing through joint Federal-State programs such as the Recreational Fisheries Information Network (RecFIN) and the Commercial Fisheries Information Network (ComFIN) to support better marine fisheries management. These programs are patterned after the SEAMAP program in which trawl survey data is collected and shared between the Gulf States and the National Marine Fisheries Service. While there are problems in funding such programs; it is generally agreed that more monitoring data is needed to support fisheries management.

Marine fisheries management as practiced in North America and Europe usually involves single species stock assessments utilizing population estimation models. Some of the most common include virtual population analysis (VPA), cohort analysis, and production models (Hilborn and

Walters 1992). These models were developed for management of commercial fisheries. The states bordering the Gulf of Mexico are interested in adopting quantitative stock assessment methods to support management of both commercial and sport fisheries.

Environmental and habitat related data are not usually collected by commercial or sport fishermen. Hence, models to predict population numbers or biomass using data from fisheries dependent monitoring programs do not contain information on hydrography, pollutants, wetlands, or other habitat related variables. The models rely on information concerning the fisheries and/or the fishers and their gear. The commercial fisheries data may be biased due to changes in vessel types, gear, and/or targeting of fish aggregations by fishermen. Likewise, size limits and other factors can create problems in analyzing sport fisheries data sets.

Fisheries independent sampling programs allow the collection of environmental and habitat related information. Biologists working for state and federal agencies can collect meteorological and hydrological data in conjunction with such survey methods as bag seine, gill net, trammel net, and/or trawl sampling. Interest is growing in developing better methods to analyze fish distributions, estimate population abundance, assess critical habitats needed by fish communities, map biodiversity and/or indices of biotic integrity (IBI), and model temporal changes in abundance of fisheries in relation to environmental or habitat changes. Fish abundance variables such as the catch-per-unit-effort (CPUE) need to be related to environmental or habitat related information. This type of information may have been collected by the agency conducting fisheries independent monitoring. However, it is often not effectively analyzed.

Other kinds of information may exist with another government agency or university. It is often difficult to obtain data collected by another agency for a variety of reasons. Remote sensing data may be too costly. The need to integrate information from a variety of sources for environmental management is often not recognized until a crisis arises. For example, it may take a serious oil spill before a government agency sees the need for a data base containing information on critical habitats such as nursery areas, spawning beds, the location of endangered species, endemic species etc. Oceanographic data such as current directions, tidal exchanges and tide heights become important to predict the direction, dispersion, toxicity, and fate of the oil spill (Trudel et al. 1996). The data is needed in a data base before the spill has occurred; if it is to be used for oil spill prevention or remediation. An integrated data base is necessary for analysts to assess whether catastrophes such as oil spills, freezes, red tides, or habitat changes are impacting fisheries.

The Need For Ecosystem Management

Darnell (1992) reviewed the ecological history, catastrophism, and human impact on the Mississippi/Alabama continental shelf and associated coastal waters. These areas together form a complex ecological system of integrated parts. The biological system became established during the period of sea level rise during the last continental glacial maximum about 18,000 years ago. Contemporary biological populations of the inshore waters are subject to episodic catastrophic events caused by exceptional cold fronts, flooding, major storms, hypoxia, red tide outbreaks, and major droughts. Most of these events are not known to affect the continental shelf populations directly, but indirect effects through food chain disruptions are likely. Loop Current intrusions and entrainment of deep Gulf waters could directly impact the shelf species. Imposed upon these events are various human intrusions which have severely reduced the quality and quantity of inshore habitats over the past two decades. During the same period, the increase in commercial and recreational fishing pressure in the near shore waters and on the continental shelf was accompanied by dramatic declines in abundance of populations of demersal and pelagic fish species. Human activities have had major effects upon the near shore and possibly offshore environments and populations. The contributing factors are many and complex, and the biological data are too recent and unrefined to permit association of each cause and its specific effects or to understand synergistic effects of several factors acting in combination. It is against this background that efforts must be made to interpret the current ecological systems of the Mississippi/Alabama shelf and related coastal waters. Considering the rate of coastal habitat deterioration and declines in fishery populations, there was an urgent need to understand the natural functioning of the entire complex ecological system, in order to manage resources of the area successfully.

Ray (1991) pointed out the urgent need to use the principles of landscape ecology to help explain coastal-zone biodiversity patterns. It is obviously a formidable task to develop fully a time-species-function ecology for the combined land and seascape. A complex of physiographic and biotic analyses are required. For many problems, the coastal-zone must be addressed across its entire breadth. For other problems, lesser segments need to be examined. But the important ingredient is the willingness of scientists and managers to merge their disciplinary and institutional constraints for cooperative endeavors. Also important is the evolution of inter-institutional cooperation for coastal-zone conservation.

Ray (1991) noted that the coastal-zone includes the coastal plains, continental shelves, and the interceding estuaries, lagoons, coastal barriers, and deltas. These areas are poorly understood ecologically, largely because the land and sea portions have been considered separately. He defined five reference units of a coastal-zone, the uplands, coastal plains, tidelands, shore face entrainment, and the offshore entrainment. The ecotone concept was discussed in terms of physiographic, biogenic, climatic, and physicochemical processes that create boundaries between the different zones.

Spatial and temporal relationships among coastal morphological systems and biogeographical distributions of different taxa set the stage for a coastal-zone counterpart to landscape ecology termed seascape ecology (Ray 1991). The coastal-zone and its diversity depend on interactions that can be hierarchically scaled. These include: 1) coastal configuration and habitat diversity; 2) species assemblages as boundary indicators; and 3) species responses and feedbacks.

The application of time-space relationships to reveal and predict coastal ecosystem function will require a virtual revolution in the ways that coastal-zone science is conducted (Ray 1991). Physical oceanography has dominated attempts to explain patterns on the high seas. Biological science dominates in intertidal and terrestrial environments. Biological oceanography is largely concerned with primary producers and zooplankton, based on the assumption that these organisms drive oceanic biological systems. Fisheries ecology is almost exclusively focused on larger, edible creatures. Coastal-zone science must now attempt to combine all of these approaches (NRC 1992, NRC 1993 a,b,c; NRC 1994 a,b). The examination of biogeographical patterns (using remote sensing and GIS), as related to coastal-zone structure, could provide unifying principles.

Inherent in the above discussion is the need to sample coastal areas in a comprehensive manner for physical, chemical and habitat related parameters, as well as at different trophic levels taking into account adequate spatial coverage (Rubec and McMichael 1996). Provided one has these data, one can conduct spatial and statistical analyses of the ecosystem (NRC 1993c, 1994 a). Models can then be created to test hypotheses that may explain fish abundance in relation to environmental variables, habitat variables, or man's influence. The analyst would like to quantify the relative importance of these factors. In particular, the fisheries biologist would like to quantify separately the relative importance of environmental or habitat related change versus the effects of man's influence on the fishery.

Policy effectiveness could be improved by shifting focus from populations and species to landscapes (Angermeier and Karr 1994). The organizational processes and ecological contexts that maintain populations typically operate at larger spatio-temporal scales than the populations themselves. Because human impacts are applied at landscape scales, management prescriptions should be focused at the same scales. Landscape-scale approaches are especially important in managing aquatic ecosystems, which can rarely rely on high profile species to garner public support for protection. Application of integrity goals and landscape approaches are perhaps nowhere more important than in estuaries or with anadromous fisheries, which depend on interactions between terrestrial, freshwater, marine, and even atmospheric systems.

The Need For Integrated Data Management

Agencies often maintain data on various resources in a number of separate data bases maintained by different groups. For example, the Texas Parks and Wildlife Department (TPWD) has about 70 separate data bases on an IBM mainframe. There are problems and time delays involved in bringing these sources of data together for management purposes. This makes it difficult to obtain an integrated overview of the ecosystem.

For improving environmental decisions, the Geographic Initiatives Subcommittee of the U.S. Environmental Protection Agency (EPA) proposed a framework for data integration to meet the needs and expectations of multi-program users accessing and using data from all necessary sources (EPA 1992). To carry out their mission, EPA recognized that the whole is greater than the sum of its parts. Integrated data becomes *information* with many potential users. The vision of data integration from the perspective of an environmental manager implies the ability to use data and information to assess, diagnose, and implement appropriate corrective actions for improving the overall health of a particular ecosystem. The capabilities needed to achieve the vision were: 1) the ability to create data in a standardized way; 2) the ability to identify and access data efficiently, and; 3) the ability to analyze data spatially. GIS can play a central role in data integration and ecosystem management.

Definition of GIS

A Geographic Information System (GIS) is often perceived to be its products, such as maps produced on a computer. Not all GIS have the same functionality. It is important to recognize that a GIS is a computer system that stores and links non-graphic attributes or geographically referenced data with graphic map features to allow a wide range of information processing and display operations, as well as map production, analysis, and modeling (Antenucci et al. 1989). Dangermond (1991) stressed that GIS is not simply technology, not simply hardware and software; it represents data and the well-thought-out, well-conceived organization of data.

The two main components of a GIS are a data base management system (DBMS) and the software for spatial data management (Figure 1). Dangermond (1991) stressed that GIS is a data base language. It has a data base that adheres to a formal model of how to organize data and a series of software tools that surround that formal model. It is a single data model that is multi-used.

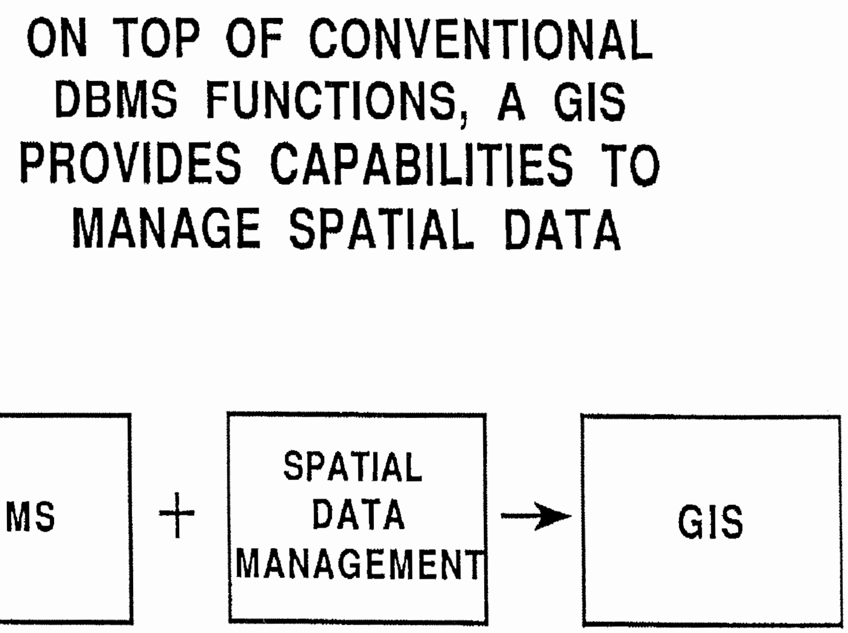

Figure 1. The data base management system (DBMS) and spatial data management software are the main components of a geographic information system (GIS).

An agency planning to establish a GIS should consider that more than 80% of the cost is for the creation of integrated data. This would include the acquisition or construction of digital base-maps of the areas being managed, as well as for data acquisition and data conversion to an integrated data base. Multiple users can look at and analyze the same commonly managed data so that data is not stored redundantly. The data in the common agency data base becomes accessible to a wider group of users.

The main strength of a GIS is its ability to integrate information from a wide variety of sources in a DBMS. Some GIS systems have data bases that can store and retrieve alpha-numeric data from field monitoring, remote sensing data from satellites and/or from airplanes, scanned images from paper maps, photographs, and/or video images (Figure 2). These data can exist in the data base in a variety of formats such as vector and raster. Provided the same map scales are used, the data can be overlaid on the computer screen to produce composite map images.

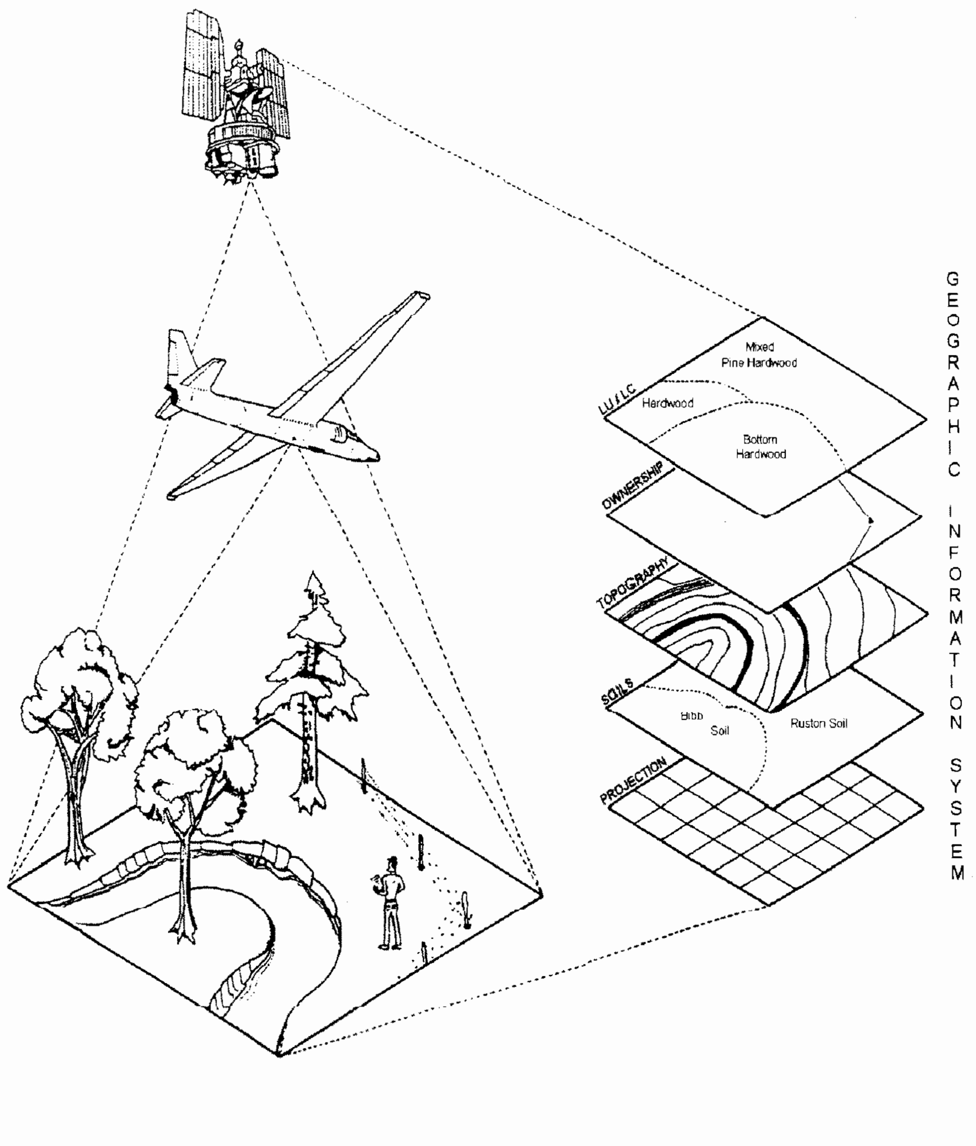

Figure 2. The ability to integrate data from a variety of sources for spatial comparison as overlays on a computer is one of the main advantages of GIS.

Data bases have to be crafted so that they survive changes in technology (Dangermond 1991). That requires the development of generic data bases in a very open architecture. Dangermond envisioned that such a data base should be a relational data base management system (RDBMS) to facilitate data transfer from one technology generation to the next. Since then, a number of RDBMSs such as Oracle, Sybase, Informix, and Ingres have become more widely available running on a variety of computer platforms.

Bibliographic Data

A serious problem exists pertaining to the in-house "gray" literature produced by most government agencies. It was estimated that the majority of the gray literature of most government agencies pertaining to Galveston Bay prior to 1980 had been irrevocably lost (Ward and Armstrong 1991). Similar situations exist elsewhere. There was a low priority assigned to archiving and preservation of older data. The general perception was that archiving of information was an unwarranted expense, in conjunction with the dubious value of "obsolete information". Other factors cited were personnel turnover, natural calamities, and agency instability due to reorganization, displacement and relocations. These and other factors can result in an agency discarding its in-house literature; which is often the source of much of the information on species, water quality, pollutant sources, leasing information, environmental impact assessments, wetland distributions etc. Once discarded, the information that government agencies have paid millions of dollars to gather often cannot be replaced. There is an urgent need for all agencies to store this information in digital form.

Scientists conducting fisheries analyses prefer to work with consistently collected quantitative data sets, such as those collected by their agency from fisheries dependent or independent monitoring programs. While fisheries agencies have traditionally made use of information from a variety of sources; there has been a tendency to rely on computerized data in recent years. The scientific literature, environmental impact statements, the agency's gray literature, reports from universities or other agencies are often regarded as being inconsistently collected, and hence not useful for analysis purposes. However, these publications may be all that was known about an ecosystem, prior to the implementation of more quantitative monitoring programs. Considering the cost of the latter, there is still a need to make use of bibliographic information, that often describes qualitative samples of fish communities taken sporadically at various localities.

The library holdings of government agencies and universities are a gold mine of data on species occurrences and distributions. The Texas System of Natural Laboratories Inc. (TSNL) has developed a computerized system for entering and retrieving information on species distributions in Texas from unpublished gray and published scientific literature. TSNL is using Novell's Quattro Pro 6.0 spreadsheet for data entry and Borland's Paradox 5.0 data base to store information on microcomputer, about species occurrences and distributions extracted from the literature by graduate students. Paradox comes with Structured Query Language (SQL) links which can facilitate transfer of the data to larger RDBMSs such as Oracle, Sybase, and Interbase. TSNL is in the process of converting its library and the data in its volumes of the TSNL Ecological Atlas to the computerized system.

TSNL has coded information back to the mid-1800's, which summarizes the literature pertaining to the distributions of 1,046 Texas fish species. Geographic codes are linked to the taxonomic name and to bibliographic reference sources. A watershed approach has been taken in coding fish distributions to sections of headwaters, river basin systems, estuarine bay systems, the continental shelf, and the abyssal plain of the Gulf of Mexico. The Paradox data base has been used to create a book titled "Freshwater and Marine Fishes of Texas and the Northwestern Gulf of Mexico" (Travis et al. 1994). More recently, the data has been distributed to the public on diskette using Paradox Run-Time. TSNL plans to link the geographic codes pertaining to various areas (polygons) to a GIS. The computerized TSNL Ecological Atlas can be queried to list the species composition of the fish community by area, to list any specie's geographic distribution by areas (counties or watershed segments), to list the occurrences of particular species in the literature etc. Hence, the system can be used to summarize the literature on species, and to relate it to ecological information such as habitat etc. It can be queried within species, across species, and across geographical and habitat boundaries, to interrelate whatever ecological parameters are under consideration.

In 1985, NOAA began a program to develop a comprehensive data base on the distribution and abundance of selected fish and invertebrate species in the Nation's estuaries. The Estuarine Living Marine Resources (ELMR) Program is conducted by NOAA SEA Division, in cooperation with the National Marine Fisheries Service (NMFS) and other agencies and institutions. The objective was to develop a consistent data base on the spatial and temporal distribution, relative abundance, and life history characteristics of fishes and invertebrates to enable comparisons among species and estuaries. These data have been obtained from quantitative as well as more qualitative (bibliographic, expert opinion) sources. The information has been published in a series of reports, including those pertaining to the southeast Atlantic and Gulf of Mexico (Nelson et al. 1991, 1992). The Florida Marine Research Institute, which is part of the Florida Department of Environmental Protection (FDEP), has collaborated with SEA Division to enhance the ELMR system for Tampa Bay, Sarasota Bay, Florida Bay, and the Indian River Lagoon. The NOAA and Florida ELMR data bases are being used with other data sets to better define and understand the biological coupling of estuarine and marine habitats.

Scientific literature or field data sheets can be scanned and the information stored on optical disks. Erasable and/or non-erasable optical disks can be used to store text from publications, large amounts of alpha-numeric data, and digital maps. The cost of these technologies has dropped to where it becomes feasible for an agency to use optical disks for the storage, retrieval, duplication, and distribution of large amounts of these kinds of information. Katz (1996) has described how CD-ROMs are being used by NOAA for the storage and distribution of spatial data products.

With some CD-ROM systems it is possible to retrieve all or part of a document, and convert it into a text format using software for optical character recognition (OCR). The text can then be edited using word processing software. Some high-end OCR systems, available from companies such as OptoWand and Scan-Optics, can rapidly convert the text of documents with a low error rate (<5%). The written text or numeric tabular data can be stored on the hard disk or diskette of the microcomputer being used for editing. The information may be lists of species or numeric tabular data on fish abundances or distributions, that were extracted from the original document stored on CD-ROM. For example, the TSNL computerized Ecological Atlas could be updated with species names extracted from documents on CD-ROM.

Sharing Data Over Networks

Benefits of Networks

Geographic Information Systems are moving into the realm of office automation and, are becoming standard tools for the management and administration of land (or marine) information (Menes and Sondheim 1991). Baseline mapping data including topographic, boundary, and geographic variables, is relatively static information from which to reference other, more specialized information. The specialized information is often most important to one agency, usually the agency of collection, but is often required by other agencies or programs. Providing both types of data is difficult to manage. A single agency manages many data sets, which are usually shared via electronic communications, paper forms and reports, or by communication between individuals using the data. The full utility of GIS, can only be realized if the data can be shared via electronic communications networks.

The concept of distributed computing using GIS related RDBMSs can provide a mechanism for integration of spatial information within an agency or between agencies. Marine ecosystems and their associated fisheries can be more effectively managed using ecosystem analyses (Ray 1991, Darnell 1992, Rubec and McMichael 1996).

Productivity From Networks

The paper which described the SEA Division network stressed the use of desktops tied to a network in order to enhance the creation of spatial products (Rubec and LaPointe 1996). Various workers carry out different phases in the spatial analysis and assembly of the product. To some degree, this is analogous to the assembly line concept for manufacturing automobiles pioneered by Henry Ford.

Most organizations invest in personal computer systems expecting to increase productivity. Once they have acquired microcomputers, they need a network to share computer resources such as printers and files. A study by Nolan and Norton found business productivity increased by office automation (Netserve 1994). In the first phase, by replacing typewriters with desktop computers individual productivity increased by 15% as measured in terms of return on investment (ROI). The second phase involves automating the flow of information through a work group. The typical ROI for work group automation ranges from 200 to 500%. The final phase involves automating information flow among all work groups as well as among vendors and the company's customers. Organizations involved in this level of enterprise automation have attained around 1000% ROI. Government agencies using GIS linked to distributed RDBMSs should be able to increase their productivity in a similar manner.

Local Area Networks

Various types of networks exist (Menes and Sondheim 1991). With the growth in the availability of desktop microcomputers and workstations many agencies have implemented networks that utilize their mainframe more as a server and less as the main computational unit. The reduced costs of purchasing and maintaining desktop computers has prompted the creation of networks tied to servers. Within a building, it is possible to have a number of desktop computers tied into a local area network (LAN).

In the shift to distributed computing, the data may reside on a number of servers at separate locations on the network. Distributed networks can come in a variety of configurations, some of which may still contain a central processing unit (Menes and Sondheim 1991, Bell and Grimson 1992). In a GIS network there are multiple GIS executing independently at each node (server) or on desktops tied to the servers. The data can be distributed at different localities with servers acting as nodes; which may have the same or different kinds of RDBMS. With the distributed network, the data base is the totality of all workstations acting as servers (Figure 3). This expands the concept of the GIS to include all of the data base localities containing data.

The Texas Parks and Wildlife Department presently has an IBM mainframe in its Austin headquarters tied to a GIS laboratory and GIS users in different branches connected over Ethernet and Token Ring LANs (TPWD 1993). The staff use the Statistical Analysis System (SAS) and the M204 System to pull data from the mainframe. In this type of GIS network, the desktops and workstations function independently while sharing common digital base maps and summary data residing on the server in the GIS laboratory.

Client/Server

There is a trend called "client/server" which can involve the movement of data from a central data base, by replacing it with a number of minicomputers or workstations acting as servers to desktop machines on a network. The TPWD plans to move to client/server using Sybase as its RDBMS over the next 5-7 years. This is similar to the client/server approach adopted by the SEA Division of NOAA (Rubec and LaPointe 1996).

Open Architecture

Sharing data over a distributed network is easier if all the servers use the same RDBMS. With an open architecture, it is theoretically possible for an agency to have more than one GIS system using data from the same RDBMS. This can allow different spatial analytical tools to be used on the desktops and workstations. For example, building designs and parks planning might be done with AUTOCAD. Base mapping could be done by another group in ARC/INFO. Endangered species information might be analyzed in the GRASS system used by the U.S. Army Corps of Engineers. Fisheries or oil spill spatial modeling could be done with CARIS or SPANS (Trudel et al. 1996). Further analyses, such as image analysis, contouring, and over plotting point source data

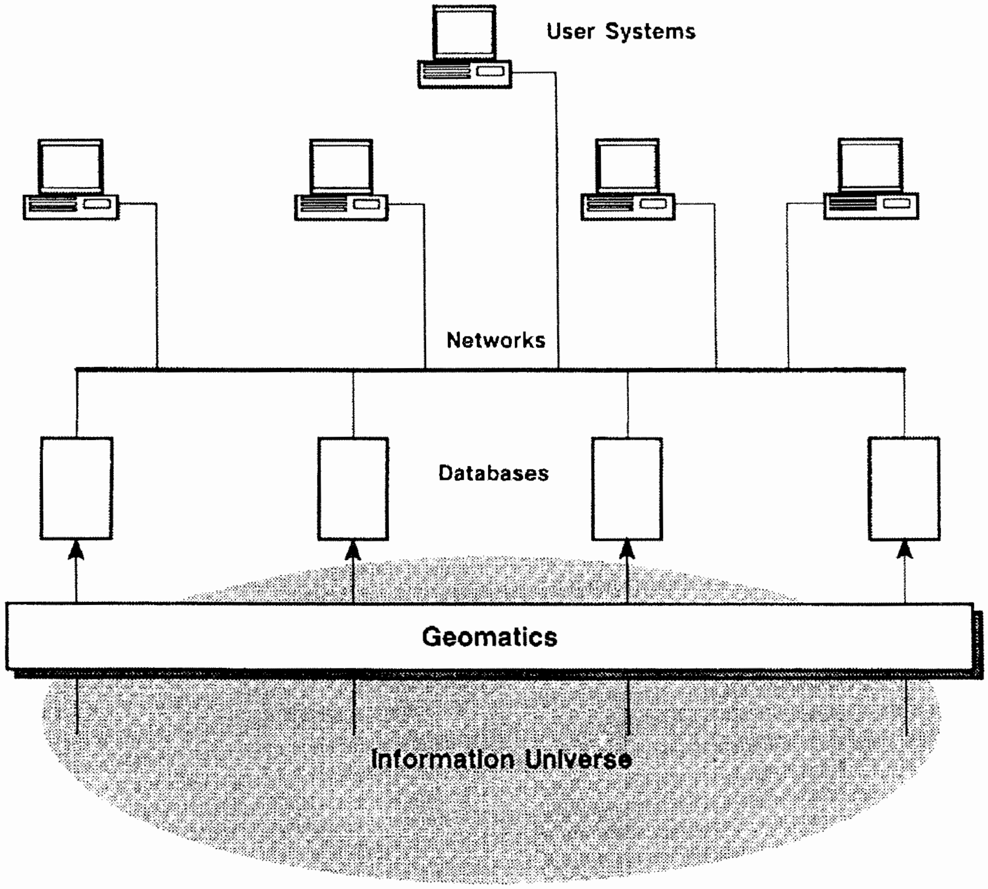

Figure 3. A distributed network in which many users access a number of relational data bases (RDBMS) housed on servers situated at different locations.

can be done using software with a Spatial Data Analysis System (SDAS) such as SURFER, ATLAS, and MAPINFO on a PC-compatible (Rubec 1996), or MAPFACTORY, SURFACE III, and REGARD on a Macintosh desktop (LaPointe et al. 1996, Rubec and LaPointe 1996). Most of the systems mentioned have their own GIS tool box and data base. Many are not presently designed to work off of a common RDBMS. While the Spatial Data Transfer Standard (SDTS) has been adopted, there may still be problems converting coverages and attribute data between the GIS systems of different vendors, which may reside on various computer platforms using different operating systems.

Many organizations have adopted one GIS system agencywide. Two of the larger GIS vendors in the United States are Environmental Systems Research Institute (ESRI) and Intergraph. These vendors have developed GIS products that can operate on computer platforms using different operating systems such as UNIX and MS-Windows. Compatability problems have been overcome allowing the sharing of coverages between operating systems. For example, ESRI supports versions of its ARC/INFO GIS that operate with UNIX on workstations and with MS-Windows on PCs.

ARCVIEW 2 or ARCVIEW 3 can be used on PCs operating in MS-Windows over networks to share GIS coverages with servers and/or workstations using a UNIX version of ARC/INFO. Hence, rather than adopting a variety of GIS from different vendors, some organizations have adopted one company's systems across the agency. This approach can save the organization time and money by minimizing the need for data conversions etc.

Wide Area Networks

Part of the problem in traditional environmental management of estuaries and the continental shelf is that many levels of government have narrowly defined mandates over different parts of the ecosystem (Darnell and Simons 1993, Newell et al. 1994, Imperial and Hennessey 1996). The traditional approach involves a collection of narrowly defined initiatives, by agencies operating in semi-isolation from one another. Traditionally, individual problems have prompted separate legislation and the creation of a system of diverse regulatory mandates by different agencies. Authority derived from a top-down, command and control approach, requires continuous bureaucratic energy, and often results in a semi-adversarial approach with stakeholders. Regulatory initiatives which begin with a mandate from government, often end with litigation or compliance by the users of the estuary. The agencies responsible for enforcing the various mandates pursue agendas specific to their missions in a system that provides checks and balances of their power; but which discourages integrated planning and results in sub-optimal use and management of the resources.

Agencies can manage coastal ecosystems more effectively by cooperating and sharing GIS data over a wide area network (WAN). GIS systems require data from many sources and broad access to these systems implies the utilization of data from disparate DBMSs (Menes and Sondheim 1991). In the most general case, large-scale access to GIS functionality means the interaction of many different GIS systems operating on a variety of hardware platforms. This necessitates communication and data sharing by different groups at separate localities within an agency or between agencies over a WAN. There are numerous problems in getting the systems to talk to each other. However, the sharing of GIS data is necessary for cost-effective government (Sharp 1991) and particularly for coastal resources management.

A comprehensive proposal for the creation of the Inland waters, Coastal and Ocean Information Network (ICOIN) was submitted to the Canadian Department of Fisheries and Oceans (MRMS 1988). This document outlined a national strategy for Canada to interface digital and geo-referenced data bases primarily resident in federal and provincial departments. The strategy would use GIS and digital base maps at various scales for data capture, input, storage, analysis, manipulation, display and output functions. The proposal recognized the need to link government information to the private sector to support economic development and management of marine resources. The network (Figure 4) would facilitate the coordination, access and flow of inland, coastal and ocean data among all user groups including all levels of government, industry and academia. While this proposal costing $160 million Canadian was not funded; it was viewed favorably by the Canadian government. Parts of the strategy are presently being implemented.

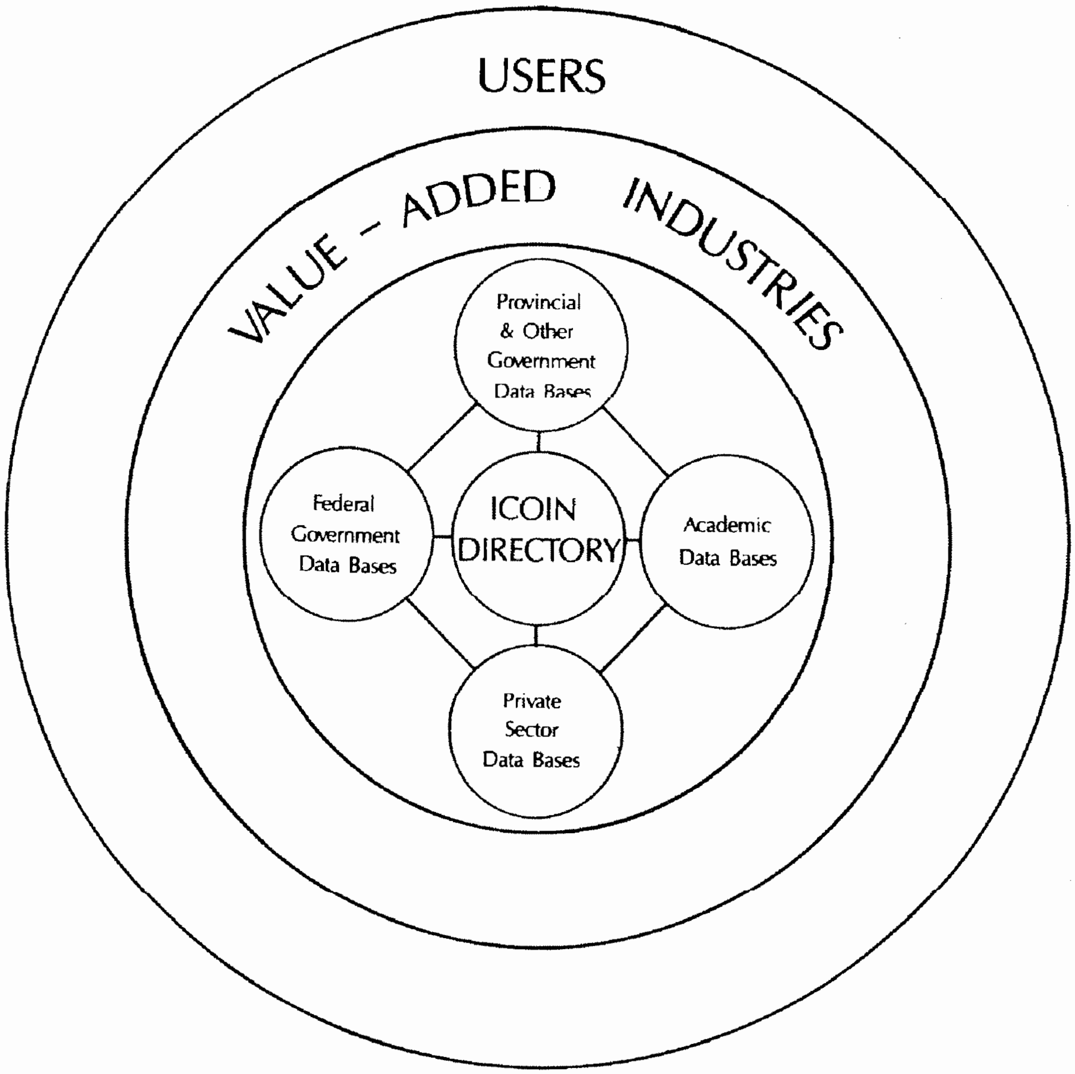

Figure 4. The ICOIN conceptual distributed model by which data from regional, federal, private and academic data bases are shared to support research, management, development, and value added uses of freshwater and marine environments (MRMS 1988).

A number of interagency GIS networks exist, are planned, or are being created involving WANs in the United States of America. Louisiana has the Louisiana Coastal Geographic Information System Network (LCGISN) which shares spatial data (Highland et al. 1991, McBride et al. 1991). Louisiana State University's Coastal Marine Institute (CMI) recently received funding from the Minerals Management Service to create an oil spill contingency planning GIS network from Florida to Texas. A Steering Committee has been set up to work with state and federal agencies, industry and other sources to obtain information on natural resources at risk from oil spills.

Texas is in the process of creating a coastal GIS network through the Natural Resources

Inventory (NRI) to support oil spill response and coastal zone management. The Texas General Land Office (GLO), TPWD, and the Texas Natural Resources Conservation Commission (TNRCC) are cooperating with other agencies in the creation of data sets and GIS map layers with funding from the Texas Legislature. Texas has a GIS Planning Council, which with the cooperation of the Department of Information Resources (DIR), has set GIS standards, and has created a GIS Business Plan, a GIS Implementation Plan, and other documents (GISPC 1994). The long term goal in Texas is the creation of a GIS network to tie together state, federal, regional and municipal agencies, universities, and the private sector. The state agencies maintain data bases for their programs; which will be used to update and maintain different map layers shared with other groups over the network.

The Internet and Information Super Highway

Vice-President Albert Gore (U.S.A.) has been the principal author and advocate of a proposal to build a national network termed the Information Super highway that would link super computers, workstations, and digital libraries to create co-laboratories, making it possible for people to work together despite being at different locations (Gore 1992). This could be managed either by government, by the private sector, or by some combination of both.

The most comprehensive information network presently in existence is the Internet. It was originally created in this country by the U.S. military (Rittner 1992, Krol 1994). Academic institutions became linked together to form a network, through the efforts of the National Science Foundation, which adopted the Internet Protocol for communication. The Internet has grown to become a world-wide network linking more than 1.7 million computers in over 125 countries (Stix 1993). It makes use of a variety of communication systems including copper and fiber-optic telephone wiring, microwave and satellite linkages. The Internet is a loose conglomeration of a variety of sub-networks and user groups. The migration to the Internet by government agencies, universities, community organizations and even business electronic mail users has recently resulted in an large expansion of this network; which threatens to overload the system.

The Distributed Environmental Information System (DEIS) is a GIS network being developed in Canada (AXSES-MacLaren Data Systems 1994). It is a relatively low-cost system designed around sharing information over the Internet among users of microcomputers. It is a group of tools for organizing and viewing collections of environmental information and maps. The premise behind the DEIS is to allow multi-disciplinary groups of policy-makers, etc., who work with environmental and marine data to communicate and share information from their databases. These groups may be organized to collaborate in regional monitoring, research or policy-making.

The main area of focus for the DEIS is the Bay of Fundy, Gulf of Maine, and Georges Bank for which an interagency GIS database (FMG) was created by Environment Canada (Ricketts et al. 1989). The AXSES FMG InfoATLAS™ is an environmental information and mapping system which combines the GeoAXSES™spatial analysis software with Environment Canada's FMG Resource and Environmental Database. Users of the DEIS system obtain the AXSES FMG InfoATLAS™ which resides on the hard disk of the microcomputer. This can be used as a Spatial

Decision Support System (SDSS).

Users of the DEIS will also be able to download data over the network from various sources. The data can then be overlaid onto base maps using GeoAXSES™ spatial analysis software resident on the user's microcomputer. The user will be able to add their own base maps and data to the system for analysis on the desktop. The DEIS allows users to visually combine maps that can be overplotted with pertinent data records permitting users to explore, test and develop their hypotheses. Hence, it is more than simply a means to view data originating from another computer.

The Texas GLO is in the process of developing a GIS structure that will enable state and federal agencies to efficiently manipulate and exchange wetlands resources data (Friedman 1995). The Wetlands Resource Database (WRD) pilot project is a multi-agency, cooperative data and information sharing program focused on the wetland resources of Corpus Christi and Galveston Bays funded by the EPA. The project also involves the Texas Natural Resources Information Service, TNRCC, TPWD, DIR, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, NMFS, and EPA. The project is using ARC/INFO, and ARCVIEW 2 to pull down and display GIS maps, text, and data over the test network.

The WRD pilot project is using the Internet Wide Area Information Server (WAIS) as a means to locate and distribute data. The shared data includes text, graphic, or export files. The rapidly expanding World-Wide Web (WWW) browser technologies such as Mosaic, Netscape, or MS-Explorer provide gateways to WAIS servers. Web browsers allow the use of word queries to find and access DBMSs over the network (Schatz and Hardin 1994). Mosaic's ease of use has opened the Internet to millions of new users.

NOAA's Office of Ocean Resources Conservation and Assessment (ORCA) has initiated an effort to distribute various types of program-related information and services to the public via the Internet (Jacobsen 1996). This includes publications, graphics, environmental data sets, geographic boundary files, and multimedia products. Clients can select digital offerings based on a geographic location, product type, and topic of concern, and are able to download them directly or e-mail a request for a hard copy. It is currently on-line and available to Internet users who connect to ORCA's WWW server with a browser such as Mosaic, Netscape, or Microsoft Explorer.

With recent regulatory changes, a number of alliances have been made between telephone, cable, and entertainment companies seeking to create separate super highways, or networks linked to the Internet, primarily for commercial purposes (Stix 1993). Different technologies exist, but must be integrated, before these networks are implemented. The use of fiber-optic cable and other technologies can increase bandwidth, which will facilitate moving large digital image files such as raster-based GIS maps, and video images over the network. Deregulation is creating competition and stimulating the private sector's participation in the creation of a more sophisticated super highway. This can benefit GIS users of the network seeking to share GIS map files, data sets, and other documentation.

The National Geospatial Data Clearinghouse is a distributed electronically connected Internet network of geospatial data producers, managers and users (NRC 1993a, NRC 1994c). The clearinghouse will allow its users to determine what geospatial data exist, find the data they need, evaluate the usefulness of the data for their applications, and obtain or order the data as economically as possible. As part of their participation in the National Spatial Data Infrastructure (NSDI), federal agencies are beginning to provide data and use the clearinghouse. On April 11, 1994, President Clinton signed Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure." The order instructs federal agencies to adhere to standards and share geospatial metadata (descriptions of data) with other agencies and the public through the clearinghouse. Clearinghouses are being created that will document metadata and facilitate the sharing of spatial data.

A Vocabulary For Networking

The Need For A Common Data Dictionary

Distributed RDBMSs can only share data if they speak the same language and by sharing a common data dictionary. Hence, a user querying the network must use the same vocabulary at each terminal on the system. Words can be used to access various parameters in the data base. To merge data in an agency, or to access data on a server in another agency, there must be agreement on the definition of the terms used to describe the structure of data files. Part of the problem is finding a vocabulary that is interdisciplinary.

Once the vocabulary is agreed upon and the various servers have adopted compatible file formats; it becomes easier to create a network to link separate data bases. Structured Query Language software has been developed for use in communicating with one or more RDBMS over LANs and WANs. To access a RDBMS, the user enters a string of words in a SQL program. This simplifies the retrieval process making the data more accessible to a wider group of users.

A comprehensive profile of a data dictionary was developed by the Texas System of Natural Laboratories over a nine year period from 1972 to 1981. The TSNL International Base Line Data Coding System (IBLDCS) is a system to accomplish the storage and retrieval, on a global scale, of the information we need about the biosphere that is essential to the future of our species (Travis and Shepherd 1982). The IBLDCS was developed by querying almost 5,000 scientists from most disciplines in government and academia across the nation. The master hierarchical outline includes the terminology describing the physical and biological aspects: meteorological, hydrological and hydrogeomorphic, geological, pedological, chemical, as well as taxonomic and ecological classifications. Man is included within the overall taxonomic classification scheme, linking the human species with other species. This ties economic and industrial aspects with the biological factors, which can influence, impact, or alter ecosystems.

The IBDLCS is simple but sophisticated. It was originally developed as the ecological base-line for a series of atlases being created to inventory terrestrial and aquatic environments in Texas. Its strength is that it can be used as the framework needed to support ecosystem management. This was done manually, when the State of Texas used data from the TSNL atlases in 1979 to win a court judgment concerning the ecological impact of the Ixtoc Oil Spill on estuarine biota. Now that computer systems can accommodate the verbal framework; it can be used to access vast amounts of environmental information buried in the data bases of various agencies. The IBDLCS has the potential to be used on a distributed network within an agency or between agencies for environmental research and management.

Protecting the environment requires suitable geographic information (NRC 1993a). It involves the understanding of spatial relationships of human population centers, natural resources, and sources of pollution. The EPA has become the largest government consumer of spatial data in support of GIS applications. It is currently investing more than $500 million per year in assembling spatial data and disseminating the data.

EPA is modernizing its water information management systems. The data base systems, STORET (Storage and Retrieval of National Water Quality Data), BIOS (Biological Information System), ODES (Ocean Data Evaluation System) and the Water Quality Analysis System (WQAS) have supported a user community that includes Federal, State, and local governments, as well as the private sector, and academia. STORET alone contains data that is worth an estimated $1.7 billion. A Modernized STORET System is being created by merging the STORET, BIOS and ODES data bases (EPA 1995). The technical architecture being proposed is a client/server-based, relational, off-the-shelf system incorporating GIS.

The Florida Marine Research Institute (FMRI) within the Florida Department of Environmental Protection (FDEP) has been evaluating a prototype of the Modernized STORET System for managing data from the Florida Keys National Marine Sanctuary. Chris Friel was the state keynote speaker at the Third Storet Modernization Workshop (EPA 1995). He described how the Coastal and Marine Resource Assessment (CAMRA) subsection at FMRI was using the Modernized STORET data model for data base management to integrate data from the Florida Keys.

The FDEP is creating an integrated distributed statewide data base (Figure 5) tied to GIS (FDEP 1994). The Oracle RDBMS and WAN will tie together the computing facilities serving over 4,000 full time employees in 16 divisions in support of ecosystem management.

Recent developments such as the Spatial Database Engine, MapObjects, and the MapObjects Internet Map Server developed by Environmental Systems Research Intitute should facilitate linking GIS such as ARC/INFO and ARCVIEW (ESRI 1996) to the Oracle RDBMS distribute network being created by FDEP. Hyper Text Markup Language (HTML) and Java will probably be utilized.

GIS Applications

GIS For Ecosystem Analyses

Information in a data base on species composition at various localities can be used to calculate species diversity indices or indices of biotic integrity (Miller et al. 1988, Angermeier and Karr 1994). These indices could then be mapped in a GIS (Norse 1993, NRC 1995, Conroy and Noon 1996) to determine areas of high and low diversity, or to assess the distribution of degraded more than $500 million for marine fisheries monitoring and management, while the budget of the NMFS is $269 million (Graham and Martello 1994). One could argue that U.S. commercial marine fisheries sampling programs are inadequately funded. The Gulf States Marine Fisheries Commission sees the need for more funding for RecFIN and ComFIN to support state monitoring and management of species that are estuarine dependent. However, it is unlikely that there will be any substantial increase in funding for more federal and state fisheries monitoring.

Managers would like to know how many samples are needed to attain certain levels of precision for estimating trends in catch rates over time and for estimating population numbers and biomass for various fisheries. The answers depend to a large degree on how the samples were collected and on how one intends to analyze the data. Mean CPUEs and variances differ depending on the sampling scheme (Rubec 1996). Sampling may be adequate if the goal is an annual average for an entire estuary. Sampling is probably inadequate to estimate trends by sub-areas or by habitat types within the estuary. One should recognize that the CPUEs generally don't fit a normal distribution. Most fisheries CPUEs tend to approximate a negative binomial distribution (Osborn et al. 1992). Hence, power calculations should take into account the sampling scheme (fixed, random, stratified-random) and the statistical distributions of the CPUEs. Assuming that some sampling has already been done, the spatial distributions of species can be examined with the use of GIS. The GIS can be used in evaluating past sampling; and may prove useful in designing more cost-effective sampling programs capable of yielding population parameters with greater precision.

A good example of the use of GIS to improve sampling is the monitoring and stock assessment done on blue crab (*Callinectes sapidus*) in Chesapeake Bay (Rothschild et al. 1992, Ault 1996). The study focused on the quasi-hibernation behavior of blue crabs in winter. A pilot winter survey was initiated in 1989 with 328 stations and 656 tows using a Virginia crab dredge. The number of stations increased each year to 1992, when 1629 stations were sampled. Each station was sampled twice. Data taken in the earlier years was analyzed to refine the sampling scheme in subsequent years. The LORAN position, water depth, temperature, salinity and dissolved oxygen values were recorded at each station. The carapace width, sex, and maturity condition were recorded for each crab captured. Habitat variables were also added to the data base. Sediment-types, salinity, temperature, depth, and the distributions of different size-sex groups were mapped in a GIS. Modeling was conducted to relate CPUEs of different crab size-sex groups to environmental and habitat variables. CPUEs were correlated with sediment-type, depth, and salinity. The models were then used to define areas of varying crab density, on which an efficient sampling stratification scheme was built.

Environmental suitability by different size-age groups of blue crab were determined using univariate polynomial regressions (Rothschild et al. 1992). Group 0 abundance peaked at medium levels of salinity; while groups 1 and 2 male crabs preferred lower salinities. Hence, adult males were most abundant in the upper part of the estuary. Adult females exhibited the greatest abundance in zones with high salinities and were found in the lower part of the estuary. Age 0 and 1, and adult male crabs were less abundant at greater depths. Adult females were found at medium depths typical of their southern bay habitat. Group 0 crabs were most abundant in muddier habitats, while juvenile and adult males preferred mid-range sediment halfway between sand and silt. Adult females were more abundant over sandier sediments. The polynomial regression results were used to improve the stratification scheme and increase the intensity of sampling in preferred habitats during 1992. A piecewise constant model was used to divide the habitat up into small homogeneous sections.

By defining the habitat and environmental suitability of different crab size-sex groups, it was possible to reduce the number of strata from 22 geographic strata in 1990, to 6 strata based on sediment-types in 1992 (Rothschild et al. 1992). The sediment maps were created from 7,500 stations sampled by EPA and 4,000 stations sampled by the University of Maryland. Using GIS and modeling allowed the extrapolation of crab densities to areas which did not need to be sampled. The 1992 survey, using the 6 sediment strata and 3 geographic strata, allowed better allocation of sampling effort in proportion to previous crab densities. Areas which modeling indicated were the most suitable habitats received more sampling effort. This improved the precision of the sampling; which in turn reduced the variances associated with population estimates.

Double tows at each station allowed the analysis of measurement error (Rothschild et al. 1992, Zhang and Ault 1995). The population estimates and standard errors were not significantly different for most sex-size crab groups. Since the second tow did not improve the estimates of crab abundance; it was recommended that future surveys use single tows at most stations. This would reduce the cost of future surveys.

Sampling locations can be more precisely determined using Global Positioning Systems (GPS). A number of rugged data logging devices that incorporate GPS receivers have become available in the last several years, made by such companies as Motorola and Corvallis Microtechnology. The precision of the location can be improved by having a radio receiver attached to the device. This allows for differential fixes (DGPS) of positions from satellites. The U.S. Coast Guard has been setting up ground stations along the U.S. coast broadcasting corrections which can allow DGPS locations to be determined in real-time, with an accuracy of less than 1 meter. The latitude and longitude, and associated sampling attributes, can be added to a data base to improve the positional accuracy of data being used with GIS.

A variety of navigation systems that incorporate charts are available to the commercial and sport fisheries (Landreth 1991). Systems from companies such as Trimble and Laser Plot use DGPS linked to NOAA charts that are read off of CD-ROM to facilitate navigation to fishing or sampling localities.

Toshiba, NEC, and some other companies have laptop computers with color displays which can be used with a GIS in the field. The Tusk and Walkabout Computer's Hammerhead are exceptionally rugged pen-based computers that can be used with DGPS. GIS maps on the computer can be used with software such as GeoResearch's GeoLink to navigate a vessel and to record sampling data. The use of GIS software on laptops in the field can allow the addition of information to digital maps, to facilitate sampling specific habitats, such as sediment-types, submerged aquatic vegetation, and coral reefs (McAllister et al. 1994).

Modeling and Spatial Decision Support Systems

The emphasis is shifting in natural resources management from inventory and exploitation to an integrated broad-scale approach with the goals of maintaining diversity, balance, and long-term productivity of the environment (Peuquet et al. 1993). Accomplishing this requires an understanding of spatial-temporal processes on a detailed, integrated and formalized level. The coastal marine ecosystem is very dynamic. Spatial visualization tools such as remote sensing (RS), image processing, and GIS can facilitate data interpretation. GIS technology allows the user to link with simulation models to create "what-if" scenarios and compare observational data with these model-generated situations. GIS now represents a powerful and flexible tool for managing resources and understanding and predicting complex and changing systems - from climate to habitats.

Modeling

Hunsacker et al. (1993) provided an overview of methods and techniques to integrate spatial ecological models with the technology of GIS. Various modeling approaches in freshwater, marine, and terrestrial environments were reviewed. Ecological modeling developed for marine systems includes models for ecosystems, migration, spatial stochastic, multispecies, and those that relate regression-based abundance to variable environmental factors. Marine ecosystems models have had limited acceptance in fisheries research, possibly because traditional fishery biologists distrust complex models with large numbers of state variables, coefficients, and assumptions. Only a few dynamic spatial marine ecosystems models exist. There are many needs for spatial information in fisheries apart from those required for ecosystem modeling. Spatial models have recently been developed to test the validity of common procedures for estimating stock abundance indices in a spatially heterogeneous marine environment.

Current spatial modeling capabilities in GIS generally have been limited to such operations as map overlaying and adjacency analysis (Peuquet et al. 1993). Map overlaying is the automated version of the cartographic process of detecting spatial correlations between two variables by overlaying maps showing their distributions. Adjacency analysis, or buffering, consists of drawing boundaries at a specified distance around a point, linear or areal feature on a map. Only the simplest of environmental processes can be analyzed with overlay and buffering operations.

Typically in current management applications, environmental models are used with GIS at a single scale and at one point in time with little integration between models (Peuquet et al. 1993). The modeling of environmental change, however, needs tools that can evaluate interactions between, and cumulative impacts on, many resources at a time. One of the most difficult issues facing GIS researchers is how to design a data base structure that can adequately represent the complex dynamics of geographic phenomena through time. The GIS needs to incorporate a modeling component in order to predict potential outcomes and evaluate alternatives. Otherwise they are restricted to displaying existing data; and their value to environmental managers is limited.

Operations that mathematically combine and relate attributes from many objects on many maps, some in a very applications specific context, are needed to provide any real or descriptive power in a GIS (Peuquet et al. 1993). The usual solution to modeling with GIS is to provide the GIS with links to external models where the operations can be performed in languages that are much better suited to complex mathematical calculations. Thus one can invoke an external model to calculate a parameter value and store that value in a data base where it is accessible to a GIS. However, this solution makes neither the spatial data handling and display capabilities of the GIS accessible to the model, nor the predictions generated by the model easily available to the data base.

Trawl survey data of redfish (*Sebastes spp.*) taken from 1983 to 1988 in the Gulf of St. Lawrence was subjected to spatial analysis and modeling (Rubec 1996). Categorical log-linear models were developed that explained catch rates in relation to temperature, depth, and years for juveniles, recruits, adults, and the total of all three size groups. Maps were created with a low-end Spatial Data Analysis System (SDAS) to show the distributions of the various size groups for each year. Kriging was used to map changes in water temperature zones between years. Redfish were most abundant in zones with a temperature range of 5.8-7.9 °C. The analyses explained how redfish distributions and CPUEs were being influenced by water temperature changes over time induced by climatic change. Mean catch rates for the stratum areas swept by the trawl were expanded to estimate total population numbers and biomass respectively for three stratification schemes: 41 depth strata; 4 depth strata; and 4 temperature strata. Stratification on temperature yielded population estimates that most accurately estimated inter-annual trends in total population abundance.

The estimation of blue crab abundance in Chesapeake Bay (Rothschild et al. 1992) involved five steps: 1) characterize the overwintering distributions by size and sex; 2) define the extent of the overwintering "potential habitat"; 3) determine the fraction of the stock within a given area per unit of effort; 4) measure the relationship between physical environmental parameters of potential habitat and abundance; and 5) calculate the absolute population abundance. Habitat and environmental variables evaluated with the GIS were used for sampling and stock assessment of blue crab. The spatial evaluation of these variables resulted in a sampling scheme that was more precise and more cost-efficient than earlier sampling schemes based only on geographic area. Population estimates derived by the area swept method, from the winter crab dredge survey in 1992, were compared with estimates made by projecting forward the 1991 winter population numbers, taking into account growth and mortality from the commercial and recreational fisheries. A drop in the overall population estimate in 1992, compared to earlier years, may have resulted both from reduced growth and from changes in crab distributions due to higher salinities in Chesapeake Bay.

Acoustic sensing and ecological modeling of striped bass (*Morone saxatilis*) in Chesapeake Bay allowed the spatial separation of the effects of fish density and habitat on fish production (Brandt et al. 1992, Brandt and Kirsch 1993). The growth rate potential of a 4-year-old striped bass was assessed by integrating spatially explicit field data on prey sizes, prey densities, and water temperatures with a foraging model and a species-specific bioenergetics model of fish growth rate. Prey sizes and densities were measured bimonthly at a high spatial resolution along a west-east transect of the bay with a 120-kHz dual-beam acoustic system. Along the transect, the water column was divided by columns and rows into a grid of cells 30 m long and 0.5 m deep. Growth and foraging models were implemented in each cell to calculate expected striped bass growth rate. Twodimensional (horizontal, vertical) spatial maps of striped bass growth potential showed strong seasonal differences, even though overall prey biomass was similar from month to month. Striped bass growth rates were highest during October and nil during August. Mean growth potentials across the bay derived from the spatially explicit model were lower in all months than estimates generated with cross-bay, spatial averages of prey density. The authors stated that such spatially explicit modeling was necessary for directly linking biological functions to physical and biological structure and for predicting how spatial patterning and absolute scaling of the habitat affect fish growth rates and production.

Decision-Making

Managers would like to have a system that is easy to use, from which they can rapidly derive spatial displays of information to assist with making decisions. Spatial Decision Support Systems (SDSS) are systems designed to provide answers to decision-makers (Densham 1991, Cooke 1992). They can come in a variety of forms from the low-end to the high-end. Some make use of models that are linked to the system. A SDSS is not the same as a traditional GIS, although both rely on GIS technology. SDSS is based on spatially referenced data; GIS on spatial data. Pure spatial data contain information about the relationships of entities in space. It is the information one stores on maps, either as lines on paper or bits in a computer. Spatially referenced data are *thematic* or applied data. The operator of the SDSS can quickly call up this information for immediate use.

At the low-end, are microcomputer-based SDSS that come with a set of base maps, which are tied to a data base of synthesized information. The base maps may have been created by the GIS laboratory in an agency. Alternatively, the maps may come as part of a package purchased from a private company. Data can be entered from a spread sheet or imported to the system as a data file. Some commercial packages include MAPINFO, MAPVIEWER, ARCVIEW, and ATLAS GIS. They only become a SDSS after summary information has been added to the data base. The user of the system can then query the data base and overlay point information, vectors and/or polygons on base maps. Different types of information can be retrieved and overlaid on maps for examination and comparison.

COMPAS is an example of a low-end SDSS in which data has been aggregated from a variety of sources within NOAA and from other agencies (LaPointe et el. 1996). Two concepts guided its development: 1) microcomputers could be used to enhance access to information pertinent to coastal resources decisions; and 2) information must be simple and easily understood to be effective in resource management. Creating such information directed at various possible uses required a considerable investment in data analysis, data synthesis, and data base design. From its inception, COMPAS was designed as an extension of NOAA's Federal/State Partnership program. COMPAS products in Texas, Florida, and Oregon have been designed to meet uses considered important to NOAA's cooperating state partners. The multi-dimensional design of COMPAS was consistent with SEA's program of strategic assessments of the Nation's coasts and oceans. As such, SDSS complements rather than competes with GIS (Rubec and LaPointe 1996). An integrated GIS data base such as the MRGIS can support the creation of base maps and summary information used in a SDSS like COMPAS (Friel and O'Hop 1996).

The developing research area of spatial decision support systems (SDSS) seeks to better integrate GIS, environmental models, and spatial data bases so that these types of software are coupled generically and flexibly (Peuquet et al. 1993). Generic means that different models can be integrated with GIS without the need for specialized programming. Flexible implies that the GIS and models can communicate quickly, frequently, preferably directly, and not through external data files.

Ji and Johnston (1996) described a SDSS for coastal management being developed at the Southern Science Center of the National Biological Service. The system is designed as a multi-functional decision-making mechanism with three subsystems: 1) resource management subsystem (RMS); 2) environmental impact assessment subsystem (EIAS); and 3) environmental data base management subsystem (EDBMS). The RMS focuses on coastal wetland restoration planning, permitting, rule-based modeling and spatial analysis. The EIAS deals with such issues as oil spill risk assessment, sensitivity modeling, contingency planning, damage assessment, and ecological risk assessment. The EDBMS is composed of both vector and raster-based map files and associated environmental data in the data bases that support the RMS and EIAS. The models being used to assist with decision-making operate within ARC/INFO and are written in ARC Macro Language.

The SPANS GIS comes with a programming language that allows the development of models operating within the GIS. The Oil Spill Impact Assessment SDSS developed using SPANS by S.L. Ross Environmental Research Limited for the Marine Industry Group (MIRG) allowed the incorporation of oceanographic models that were used to predict the direction, dilution, and ecological impact of oil spills (Trudel et al. 1996). The models used were also capable of evaluating alternative scenarios; such as what natural resources would be impacted if dispersants were used. Another model predicted the impacts on fisheries. The SPANS system was capable of doing this on microcomputer, because of the organization of the raster data base, and specialized software such as Quadtree that allowed rapid access to portions of the data base.

Simpson (1994) developed a framework for the interactions among the diverse groups involved in operational fisheries oceanography: fishing industry, basic and operational researchers, and tactical and strategic stock assessment managers. The basis of these interactions is the need for accurate and timely information, information so complex and diverse that no single sector of the community can efficiently, and economically satisfy its own information requirements. Some presently available remotely-sensed data and analysis methods that have potential for providing part of the required information were presented. Projections of future capabilities in this area were also made. The increased use of RS and GIS and near-real-time communication networks among the various sectors of the community were discussed. The CORAL GIS was described. A more sophisticated fisheries-oriented SDSS was envisioned which incorporates: 1) the graphical user interface; 2) RS/GIS analysis and display methods, and; 3) computer-aided decision-making. The SDSS would support the fishing industry, as well as researchers in fisheries oceanography and fisheries management. Simpson recommended that operational centers be created that incorporated these capabilities.

Ecosystem process models should be coupled with population dynamics models, with special attention given to scale coherence (NRC 1994a). Traditionally, ecosystem process models have been used to address questions of how nutrient or other anthropogenic inputs to coastal systems affect water and habitat quality, and overall ecosystem function. Conventional population models of fish and other living resources have been used to analyze relations between fishery harvests and fish abundance. A growing recognition of key interactions between water and habitat quality and fish abundance however, suggests that these two separate modeling approaches need to converge into an integrated framework. Moreover, the effect of physical transport processes on both recruitment into adult fish stocks and nutrient/trophic interactions reveals that these integrated process-population models should be driven by physical circulation models. Ecological feedback effects and material exchanges could be coupled between process and population models with simple seamless algorithms.

Ault (1996) discussed the need to create an integrated fisheries management system (FMS) comprised of a comprehensive data base containing fisheries dependent and independent monitoring data; habitat and environmental data; economic, and social human-demographic information pertaining to fisheries; linked to models using a systems management framework. Ault noted that traditional stock assessment models were inadequate, and that a broader series of process models were needed that would better explain the biology of the fish stocks. Modelers were also being asked to develop models to assist managers, that would explain man's impact on the ecosystem. This necessitates a sophisticated information and analysis system capable of supporting broad management decisions and supporting policy. The FMS would be an SDSS capable of exploratory analyses and decision formulation. Workstations operating in UNIX would be needed for the visualization of information derived from high powered modeling and GIS. The systems approach would allow for direct consideration, quantification and linkage of the biological, economic, sociological, and political factors in the decision-making process. The FMS was recently tied to the Princeton 3-D circulation model and the SIMAP oil spill model in order to assess ecological risks from oil spills on fisheries species in Tampa Bay (Harwell et al. 1995).

One should recognize that the use of high-end SDSS for modeling and decision-making is at the cutting edge of research and development. Tightly coupled GIS-models are still being explored and it will be some years before they are widely available (Peuquet et al. 1993).

Stewardship and Ecosystem Management

Ecological problems are interrelated, involving the estuary, its tributaries to some distance upstream, and the watersheds where humans carry out their daily activities (Newell et al. 1994, Colt 1994). Habitat losses, diffuse pollution from land runoff, human health, and shoreline management issues all point to the need for non-traditional management measures. The interconnectedness of the various parts of the ecosystem, shape the management planning process. The traditional top-down management approach being practiced by separate agencies (Figure 6A) is inadequate (Darnell and Simons 1993, Newell et al. 1994, Sherman 1994, Imperial and Hennessey 1996). Solutions to the problems impacting the marine environment can only be effective if they, like the problems, operate at a systems level. To be effective, both the scientific and resource conservation activities must be integrated and interdisciplinary (Colt 1994, Jacobson 1995, Brown and Marshall 1996, Griffis and Kimball 1996, Knecht et al. 1996).

Stewardship incorporates a philosophy diverging from traditional resource management (Newell et al. 1994, Griffis and Kimball 1996). It is central to the planning process, leading to coordination of governance at the ecosystem level. Stewardship begins with stakeholders and resource managers agreeing upon the problems-in the context of the entire ecosystem (Figure 6B). This bottom-up approach is heavily dependent on consensus building. It involves frequent meetings, education and communication, that leads to agreement concerning what are the environmental problems. From this consensus, recommendations are derived concerning cooperation at the ecosystems level. Solutions recommended find easier implementation because of wider acceptance by government agencies, stakeholders, and the general public. The stewardship process takes longer and is more difficult than the traditional process, but helps stimulate a self perpetuating sense of personal responsibility for public resources.

A number of government agencies and regional associations of local governments in Florida and other states have experienced problems similar to those of Tampa and Sarasota Bays arising from a lack of coordinated management of estuarine resources (Perry 1989). These groups need to communicate and interact with each other to promote a proactive rather than a reactive approach. Associated with stewardship is the inherent need for cooperation and sharing information between different agencies and stakeholders (Newell et al. 1994). Sampling, information management, and analyses should be coordinated between various agencies to facilitate informed ecosystem management (Sherman 1990, Rubec and McMichael 1996).

Spatial Products

This paper has described procedures and methods by which fisheries sampling and other spatial environmental data can be turned into information. Analysts can create graphics information derived from data sources within or outside the agency. The information may include maps from GIS and/or SDAS, histograms, fitted population trends from models, and/or data summaries derived from high-end SDSS.

It is now possible with office suite or desktop publishing software to produce a document on a microcomputer by merging maps, graphics and text. The images and other information can be distributed on diskette, on CD-ROM, over over a network (Katz 1996, Jacobsen 1996). A manager can have a report from agency staff transferred over a LAN or WAN to his or her desktop. The advantage of using networks is that the information becomes available in a timely manner, to support making environmental management decisions.

Data that has been integrated from a variety of sources can be visually displayed to communicate pertinent information. A low-end SDSS such as COMPAS (LaPointe et al. 1996), or the DEIS (AXSES-MacLaren Data Systems 1994), or the Florida Marine Spill Analysis System (FMSAS) running in ARCView 3 (Friel and O'Hop 1996, Friel et al. 1996) may reside on the desktop microcomputer of a manager wishing to examine spatial information. It should soon be possible to access SDSS such as COMPAS, FMSAS, or the DEIS over the Internet. Low-end SDSS

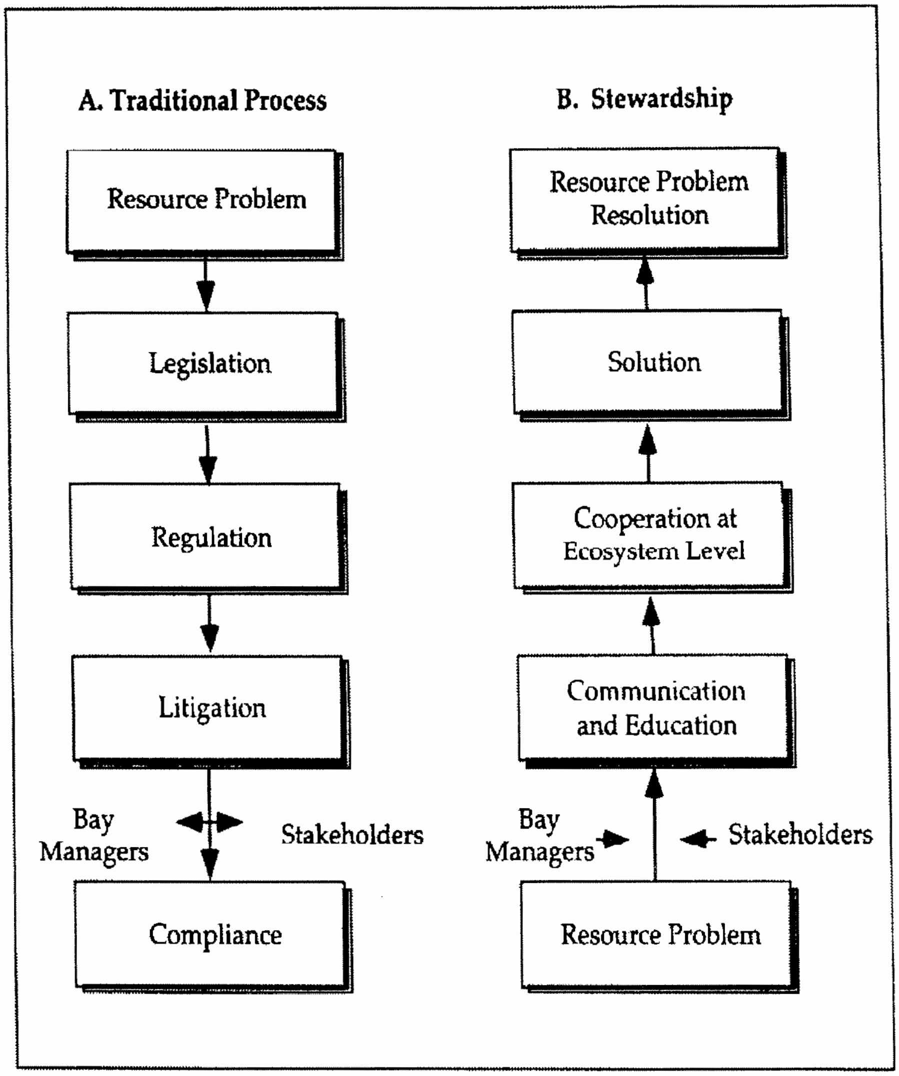

Figure 6. Traditional natural resource management (A) contrasted with stewardship (B). The traditional top-down approach by a number of agencies lacks coordination and may be difficult to enforce. Stewardship (B) is a bottom-up approach involving building consensus between resource managers and stakeholders concerning the best management solutions to deal with problems impacting coastal ecosystems (Newell et al. 1994).

may be used by managers, commissioners, politicians, news media, and the public in a manner similar to published products such as reports, books, and newspapers. The spatial information would be viewed as a series of overlays, without being changed. This would facilitate the rapid distribution of summarized spatial information to a wider audience.

Most fisheries monitoring programs occur at known locations (latitude and longitude, boat ramps, zip codes etc.) which can allow the data to be linked to a GIS. However, it is surprising how little use of GIS is being made in the field of fisheries. This paper has examined the use of GIS to facilitate data base management, data sharing, sampling, data analyses, and visualization of information to support marine fisheries management. It summarizes the concepts presented at a symposium titled "GIS Applications For Fisheries And Coastal Resources Management", held 18 March 1993, sponsored by the Data Management Subcommittee of the Gulf States Marine Fisheries Commission.

Disclaimer

Reference to commercial products and companies in this paper does not constitute an endorsement on the part of Texas Parks and Wildlife Department or the Florida Department of Environmental Protection.

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Acronyms and Definitions for GIS Symposium

AML	Arc Macro Language- programming used with the ARC/INFO GIS.
ANOVA	Analysis of Variance - statistical analytical procedure.
AOE	Areas of Effect-areas with toxic conditions created by an oil spill
ARC/INFO	The GIS developed by Environmental Systems Research Institute, Inc. in Redlands CA.
ASCII	Text file transfer protocol.
ATLAS	A desktop GIS developed by Strategic Mapping, Inc. in San Jose CA.
ATLAS*Pro	An SDAS developed by Strategic Mapping, Inc. in San Jose CA.
AUTOCAD	A computerized drafting system used by architects and engineers.
CAMRA	Coastal And Marine Assessment- the section within FMRI which conducts RS and GIS.
CARIS	Computer Aided Resource Information System - a GIS developed by the Canadian Hydrographic Service and Universal Systems Ltd., in Fredericton NB, Canada.
CD-ROM	Compact Disk-Read Only Memory - an optical disk for storing images, text or sound in digital form.
C&GS	Coastal and Geodetic Survey - a division within the NOS of NOAA.
CI	Confidence Interval- a statistical measure of probability.
CMAS	Computer Mapping and Analysis System - an SDSS developed by Sea Division of NOAA in conjunction with NMFS to geographically present shrimp statistics in the Gulf of Mexico.
CMI	Coastal Marine Insitute - administering the creation of an oil spill GIS network at Louisiana State University with funding from Minerals Management Service.
COLREGS	International Regulations for Preventing Collisions at Sea.

ComFIN	Commercial Fisheries Information Network- a proposed commercial fisheries monitoring/ statistical data base program with collaboration between NMFS and the states adjoining the Gulf of Mexico through GSMFC.
COMPAS	Coastal and Ocean, Management Planning, and Assessment System- a marine resources SDSS developed by SEA Division of NOAA in collaboration with state agencies.
CPUE	Catch Per Unit of Effort - the catch rate determined by dividing the number or biomass of fish or invertebrates caught by the number of units of effort of the fishing gear.
CZM	Coastal Zone Management
DBMS	Data Base Management System.
DEIS	Distributed Environmental Information System - a distributed PC-based GIS network using the Internet.
DFO	Canadian Department of Fisheries and Oceans.
DGPS	Differential Global Positioning System- a GPS system incorporating real-time corrections from land based stations, usually by means of radio communications, to determine coordinate positions with less than 5 m accuracy.
DIR	Texas Department of Information Resources in Austin.
DMSC	Data Management Subcommittee- associated with the GSMFC.
DOS	Disk Operating System- an operating system used with microcomputers.
EDBMS	Environmental Data Base Management System - a subsystem of the coupled SDSS-GIS being developed by the Southern Science Center of the National Biological Service.
EIAS	Environmental Impact Assessment System - a subsystem of the coupled SDSS-GIS being developed by the Southern Science Center of the NBS.
ELAS	A computerized image processing system.
EMAP	Environmental Monitoring and Assessment Program - a landscape level appoach to ecosystems management being used by EPA.

ELMR	Environmental Living Marine Resources - a program to characterize fish and invertebrate distributions in the nation's estuaries conducted by the Biogeograpic Characterization Branch of NOAA SEA Division in conjunction with NMFS, State, and other agencies.
EPA	United States Environmental Protection Agency.
ERDAS	A computerized image processing system.
ESRI	Environmental Systems Research Institute in Redlands CA.
FDEP	Florida Department of Environmental Protection.
FDNR	Florida Department of Natural Resources - now part of FDEP.
FEMA	Federal Emergency Management Agency.
FIPS	Federal Interchange Processing Standard.
FKNMS	Florida Keys National Marine Sanctuary.
FMFC	Florida Marine Fisheries Commission in FDEP.
FMRI	Florida Marine Research Institute - part of the Marine Resources Division of FDEP.
FMS	Fisheries Management System - An SDSS for fisheries management linked to GIS and modeling being developed by Dr. J. S. Ault at the University of Miami.
FMSAS	Florida Marine Spill Analysis System - part of the MRGIS at FMRI.
GeoAXSES	A GIS marketed by AXSES-MacLaren Data Systems in Halifax, NS.
GeoCOAST	The GIS facility within SEA Division of NOAA.
GIS	Geographic Information Systems - data management and information systems that are able to capture, synthesize, generate, retrieve, analyze, and output spatial information.
GISPC	Geographic Information Systems Planning Council - an interagency council in Texas setting standards and planning a statewide GIS network.
GLO	Texas General Land Office situated in Austin.

GPS	Global Positioning System- a system that obtains coordinate positions from an array of geostationary satellites.
GRASS	Geographical Resources Analysis Support System - a GIS in the public domain developed by the U.S. Army Corps of Engineers.
GSL	Gulf of St. Lawrence.
GSMFC	Gulf States Marine Fisheries Commission.
GUI	Graphical User Interface - an icon based screen system used to access programs and software on a computer.
IBI	Index of Biotic Integrity - a means of assessing the ecosystem health of aquatic communities using a composite index.
IBLDCS	International Base Line Data Coding System - a hierarchially organized taxonomic and ecological outline developed by TSNL.
IBM	International Business Machines - a large computer manufacturing company centered in Secaucus NY.
ICOIN	Inland waters, Coastal and Ocean Information Network.
LAN	Local Area Network.
LANDSAT	An unmanned earth-orbiting NASA satellite that transmits multispectral images in the 0.4 to 1.1 micrometre range to earth receiving stations.
LCGISN	Louisiana Coastal Geographic Informations System Network.
LORAN	Long Range Navigation - a system using pulsed, low frequency radio waves to aid navigation of ships.
MAC	A Macintosh microcomputer using the Macintosh operating system..
MAPFACTORY	An SDAS for raster-based spatial analysis and image processing used with Macintosh microcomputers.
MAPINFO	A desktop GIS developed by ManInfo Corporation in Troy NY.
MAPLAND	An SDAS developed by Software Illustrated in Pleasanton CA.

MAPVIEWER	An SDAS developed by Golden Software in Golden CO.
MIRG	Marine Industry Group - a consortium representing the oil tanker industry.
MRGIS	Marine Resources Geographic Information System - the statewide coastal marine GIS maintained by the CAMRA Section at FMRI.
NBS	National Biological Service - part of the U.S. Dept. of the Interior.
NM	Nautical Mile.
NMFS	National Marine Fisheries Service - part of NOAA responsible for marine fisheries management.
NOAA	National Oceanic and Atmospheric Administration- part of the U.S. Dept. of Commerce.
NOS	National Ocean Service - part of NOAA.
NRC	National Research Council - in Washington DC.
NRI	Natural Resources Inventory- a program to inventory and map Texas coastal natural resources.
NSDI	National Spatial Data Infrastructure.
NS&T	National Status and Trends - a program to monitor trends in marine resources conducted by NOAA .
OCR	Optical Character Recognition - software that can recognize alpha and numeric characters from a scanner and store them in digitized form on a computer hard disk or optical disk..
OS/2	An operating system used on microcomputers developed by IBM.
ORCA	Ocean Resources Conservation and Assessment - a part of NOAA within the NOS.
PC	Personal Computer - a desktop microcomputer using MicroSoft's-DOS, Windows, or IBM's OS/2 operating system.
RDBMS	Relational Data Base Management System.
RecFIN	Recreational Fisheries Information Network - recreational fisheries data

	collection and data management program conducted by NMFS and cooperating State agencies.
REGARD	An SDAS for statistical and visual analysis of spatial data used with Macintosh microcomputers.
RIM	Resource Impact Map - habitat/fisheries maps created by the CAMRA Section at FMRI.
RMS	Resource Management System - a subsystem of the coupled SDSS-GIS being developed by the Southern Science Center of the NBS.
ROI	Return On Investment.
RS	Remote Sensing - various technologies for gathering data about the earth's surface either from aircraft or from satellites.
R/V	Research Vessel.
SAS	Statistical Analysis System - statistical/analytical software developed by SAS Institute in Carey NC.
SDAS	Spatial Data Analysis Systems - spatial data analysis software with some of the functionality of a GIS.
SDSS	Spatial Decision Support System - a spatial graphical/map display system using summarized information to support decision-making.
SDTS	Spatial Data Transfer Standard.
SEA	Strategic Environmental Assessments- a division within NOAA.
SEAMAP	Southeast Area Monitoring and Assesment Program - a state-federal-university program for the collection, management, and dissemination of fishery independent data.
SPANS	Spatial Analysis System - a GIS developed by Tydac Technologies Inc., in Ottawa, Canada.
SURFACE III	An SDAS that facilitates interpolation and contouring used with Macintosh microcomputers.
SURFER	An SDAS used for mapping point data, contouring and creating 3D plots developed by Golden Software Inc. in Golden CO.

TNRCC	Texas Natural Resource Conservation Commission in Austin TX.
TPWD	Texas Parks and Wildlife Department- in Austin TX.
TSNL	Texas System of Natural Laboratories, Inc.- in Austin TX.
UNIX	A computer operating system capable of providing an interface between applications and hardware, multi-tasking, process tracking, and supporting multiple users on a variety of computer platforms.
USGS	United States Geological Survey - part of the U.S. Dept. of Interior.
VPA	Virtual Population Analysis - an age-structured model for estimating population numbers and/or biomass used in fisheries.
WAIS	Wide Area Information Service - a tool for searching through the Internet using groups of words.
WAN	Wide Area Network.
WRD	Wetlands Resource Database - a multiagency program for the sharing of wetlands GIS coverages over the Internet.
WWW	World-Wide Web - a browser for searching the Internet using hypertext queries.
WVA	Wetland Value Assessment - a part of the RMS in the coupled SDSS-GIS being developed by the Southern Science Centre of the NBS.
XBT	Expendable Bathythermograph - a device deployed on a wire for measuring temperature profiles at sea.

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