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Biodiversity and Ecosystem Informatics - BDEI - Planning Workshop on Biodiversity and Ecosystem Informatics for the Indian River Lagoon, Florida

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There were other collaborators from several other organizations who participated in the workshop.

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Books or Other One-time Publications

Web/Internet Site

URL(s):

http://www.intsys.maine.edu/bdei/workshop.html

Description:

Other Specific Products

Contributions

Contributions within Discipline:

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Final report

BDEI: Planning Workshop on Biodiversity and Ecosystem Informatics for the Indian River Lagoon, Florida

Report of an NSF-funded workshop that examined biodiversity research in the Indian River Lagoon system and the informatics tools and technology applications available to researchers

Held at the DoubleTree Hotel Cocoa Beach, Florida,
February 7 - 8, 2002

Sponsored by
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Planning Workshop on Biodiversity and Ecosystem Informatics for the Indian River Lagoon, Florida

EXECUTIVE SUMMARY

In February 2002, a workshop on biodiversity and ecosystem informatics (BDEI) was held in Cocoa Beach, Florida to discuss and plan for meeting the future research goals and technology needs for investigations into the biodiversity, biocomplexity, and ecosystem dynamics of the Indian River Lagoon, Florida, one of the most biologically diverse estuaries in the continental United States. This report synthesizes the discussions and concerns of workshop participants, and lays out a plan for future discussion and direction in the development of integrated ecosystem research, and for continued growth and development of novel BDEI tools that will aid these investigations.

It is increasingly recognized that the stability and health of the environment is dependent upon factors related to the biodiversity and the complexity of ecosystems. Biodiversity and biocomplexity contribute trillions of dollars directly to the global economy via fisheries, forestry, agriculture, ecotourism, drug development, and other means (President's Committee of Advisors 1998, Alonso et al. 2000, Maier et al. 2000, Schnase 2000). Biodiversity also makes indirect economic contributions via plant pollination, air and water purification, modification of the global climate, flood control, nitrogen fixation, storm buffering, and nutrient recycling (Schnase 2000, Alonso et al. 2001, Maier et al. 2001). Advances in computer science and information technology have presented both new opportunities and new challenges as biologists, environmental scientists, resource managers, and policy makers attempt to cope with the increasing need to investigate, understand, and disseminate highly complex ecological and physical processes that are responsible for maintaining biodiversity and biocomplexity in ecosystems.

The Indian River Lagoon (IRL) is part of the longest barrier island complex in the United States, occupying more than 30% of Florida's east coast, from Ponce de Leon Inlet in the Mosquito Lagoon to Jupiter Inlet near West Palm Beach, a distance of approximately 156 miles. A complex mosaic of diverse habitats, including seagrass beds, mangrove forests and *Spartina* marshes; oyster and worm reefs; sand and mud flats; and hard bottoms (coquina limestone), supports unsurpassed biodiversity in the IRL. While the true level of biodiversity in the IRL system is still under investigation, in excess of 3,000 species of plants, animals and protists have been inventoried to date.

There are a variety of public, research, academic and non-profit agencies and institutions that have research interests in the IRL system. Many have compiled long-term datasets, which reflect many years of investigation into organism and population biology, physical processes, and ecology of the IRL. It is recognized among the various organizations that the development of novel approaches to biodiversity research, interagency cooperation, and the sharing of data and metadata can promote synergies among biologists, environmental scientists, computer scientists, information technologists, resource managers and policy makers, and can assist in creating higher-order knowledge that may be easily visualized and presented in a coherent manner. The significance of novel BDEI research tools and new technologies is invaluable to this effort. BDEI offers promise in identifying and addressing complex biological and environmental questions, while simultaneously furthering developments in information technology. Through the use of informatics tools, stakeholders may begin to compile, compare, and integrate disparate datasets,

overcoming problems with spatial and temporal scales, data formats, standardization, taxonomic conventions, terminology and other factors.

Twenty-five researchers representing a diversity of fields participated in the workshop. Biologists, ecologists, resource managers, and systematists came together with specialists in remote sensing, spatial information systems, computer sciences, and intelligent systems to discuss the opportunities and challenges of applying informatics tools and techniques to ongoing and future ecological research centering on the IRL. Ecological topics discussed included an examination of the spatial heterogeneity of ecological resources in the IRL; regional geomorphology; social and physical factors that affect the IRL ecosystem; coastal wetlands; changes in seagrass coverage with changes in land use; species inventories; taxonomic issues in data collection and presentation; tools and issues surrounding data storage and use; and the types of biological and physical data available to the research community. Informatics topics presented included methods for integrating heterogeneous datasets; tools and methods for automated change detection; digital imagery; geospatial databases; analysis and modeling of ecosystem processes using fuzzy logic, neural networks and other algorithms; statistical approaches to ecosystem modeling; and agent-based data collection and processing.

Three areas of synergy between biological/environmental science and computer science/ information technology were addressed in sub-group discussions: acquisition and conversion of data and metadata; analysis and synthesis of data and metadata; and dissemination of data and metadata. Some of the specific topics addressed by the sub-groups included:

Acquisition of Data and Metadata

- Assessing the relevance of available IRL datasets and identifying their availability and accessibility to the wider research community.
- Improving methods for collecting, organizing and archiving data.
- Digitizing conventional IRL data, especially any long-term datasets and imagery that exist, for simplified storage and improved accessibility via the Internet.
- Improving methods for incorporating taxonomic change into existing datasets.
- Improving the ability to integrate existing heterogeneous datasets across agencies by implementing or improving data and metadata standards.
- Addressing knowledge gaps in the currently available datasets with respect to the geographic area or phenomena particular to the IRL.
- Implementing ontology and structure for the data.
- Utilizing efficient remote sensing techniques for data acquisition, including but not limited to underwater remote sensing.

Analysis and Synthesis of Data and Metadata

- Identifying the major forcing functions of biodiversity in the Indian River Lagoon at multiple spatial and temporal scales.
- Identifying the long-term trends in biological data and formulating functional relationships.
- Performing efficient spatiotemporal analysis of datasets.

- Developing an integrated model or set of models to link physical, chemical, biological, social and economic processes at multiple scales for predicting and forecasting changes in biological diversity.
- Linking informatics tools with process-based models.
- Exploring the application of advanced informatics tools (neural networks, artificial intelligence (AI), change analysis, etc.) to improve process-based simulation/forecasting.
- Exploring applications of advanced computing power and distributed computing.
- Applying advanced visualization techniques to enhance usability of research results by scientists, policy makers and the public.

Dissemination of Data and Metadata

- Enhancing inter-institutional cooperation in order to facilitate data sharing and integration through the use of the Internet, collaboration and communication between organizations that are stakeholders in IRL research.
- Developing clear protocols for how data may be accessed and utilized by participating agencies.
- Developing work groups for determining standards for data and metadata collection.
- Developing web-based applications for integration of data and metadata from various sources.
- Creating a web-based directory of researchers and their areas of expertise.
- Visualizing a consortium of various users with access to summary data, or narrative summaries rather than actual data.

Conclusion

The primary result from the various presentations and discussions was to create a methodological avenue to integrate methods of ecological data collection with informatics tools and protocols in order to address some of the important questions focusing on the biodiversity of the IRL. Based on the outcomes of both formal and informal discussions at the workshop, members of the biological community are in the process of exchanging data collected from the IRL with researchers from computer science, spatial information and intelligent systems in order to facilitate more effective and efficient data management, visualization, modeling, analysis and synthesis. A series of short and long term goals for future research and collaboration is presented in the later sections.

Although there are many disparate data sets for the IRL area that lie within the purview of the local, state and federal agencies, universities, and some private organizations, at least three areas emerged from the workshop as being readily appropriate for informatics techniques. These are 1) the biological and taxonomic dataset from the Indian River Lagoon Species Inventory, maintained by the Smithsonian Marine Station at Fort Pierce, 2) ichthyological data from long-term IRL studies maintained by NASA KSC/Dynamac Corporation, and 3) long-term submerged aquatic vegetation data and water quality data of the St. Johns River Water Management District, South Florida Water Management District, and NASA KSC/Dynamac Corporation. These data are of the spatial and temporal extent compatible for application of informatics analysis techniques.

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I. INTRODUCTION

A workshop on biodiversity and ecosystem informatics (BDEI) was held in February 2002 at the Doubletree Hotel in Cocoa Beach, Florida. The purpose of this workshop was to provide the necessary venue and resources to foster synergistic interdisciplinary collaboration required to advance research into biodiversity and ecosystem dynamics of the Indian River Lagoon (IRL), Florida by using novel techniques in informatics. Twenty five researchers from diverse fields of biological sciences, ecological sciences, remote sensing, spatial information systems, computer sciences, and intelligent systems met to identify and discuss the issues and challenges facing the long-term sustainability of the IRL ecosystem, and explored the possibilities of applying computational intelligence and data management techniques to these problems. A major tenet of the workshop was that the wealth of ecological information that exists for the IRL can and should be integrated into regional land-use and estuarine management models. This report summarizes the discussions and recommendations made at the workshop. For additional information about the workshop please visit: http://www.intsys.maine.edu/bdei/workshop.html.

A. BACKGROUND

The Indian River Lagoon (Fig. 1), Florida, is one of the nation's most biologically diverse estuarine systems, providing habitat for thousands of different species of animals and plants, some of which are rare, threatened, or endangered. The IRL system is a shallow mesohaline estuary, which actually consists of 3 lagoons: the Mosquito Lagoon which originates in Volusia County, the Banana River in Brevard County, and the Indian River Lagoon, which spans nearly the entire coastal extent of Brevard, Indian River, St. Lucie and Martin Counties. The IRL occupies more than 30% of Florida's east coast, extending 253 km (156 miles) from Ponce de Leon Inlet in the Mosquito Lagoon (latitude 29 degrees 05 minutes N) to Jupiter Inlet near West Palm Beach (26 degrees 58 minutes N). The feature that helps distinguish the IRL system from other estuarine systems, and also accounts for much of its high biological diversity, is its unique geographical location, which straddles the zone of overlap between the temperate Carolinian, and the subtropical Caribbean biological provinces. Thus, the northern reaches of the IRL, from Ponce Inlet to approximately Cape Canaveral are significantly more temperate in nature, while its southern reaches, from Cape Canaveral south to Jupiter Inlet, are subtropical to tropical. In the IRL then, as perhaps nowhere else in the continental United States, temperate and tropical species coexist and thrive.

The coastal area in the vicinity of the IRL system has one of the highest human population growth rates within the United States, due to both natural increase and migration. United States Census Bureau data show that between 1990 and 2000, the population of Florida grew by more than 3 million people, a 23.5% increase over 10 years. This figure equates to a staggering increase of 834 people per day being born in, or moving to the State of Florida. The Florida Demographic Summary states that when census demographics are further examined, natural increase in the population accounts for only 14.7% of the total, while migration of new residents accounts for 85.3%, or 711 people per day. It should also be noted that this figure represents new permanent residents only; seasonal residents and tourists are excluded from census totals, yet certainly impact the environment of the IRL system. Approximately 70 million tourists visit the state of Florida each year, influencing both the economy and natural resources of the region.

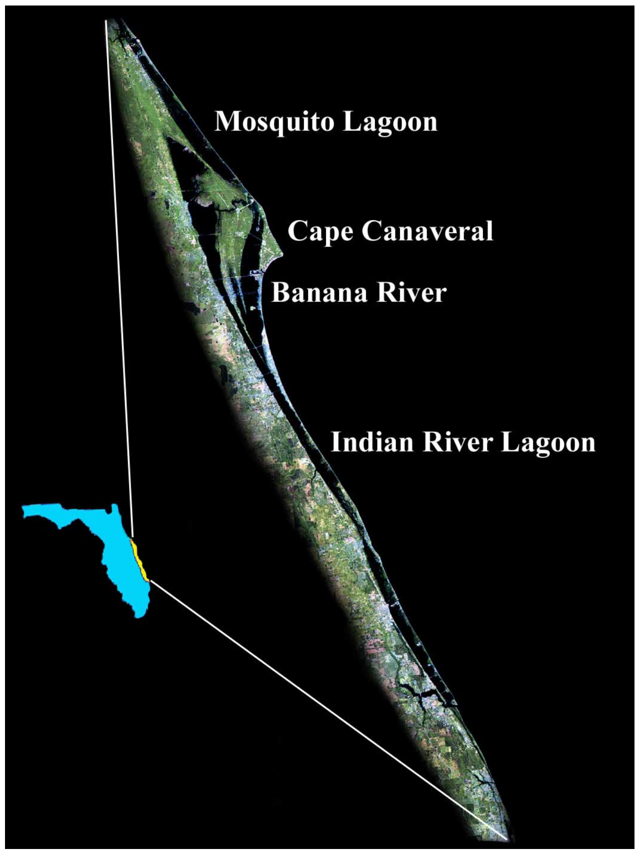

Figure 1: The geographical location of the Indian River Lagoon system in east central Florida

The lagoonal system has thus come under extraordinary pressures from anthropogenic impacts. Impoundment of wetlands for mosquito control, habitat loss and fragmentation due to development, freshwater inputs from stormwater management practices, surface water runoff, nutrification from point and non-point sources, inputs of chemicals and pathogens from both agricultural practices and urban development, and the introduction of invasive species are some of the many environmental problems and challenges that affect biodiversity and ecosystem processes within the IRL system. The problem for researchers, resource managers and policy makers thus becomes one of how to maintain and conserve the vast biodiversity of the IRL ecosystem in the face of ever-increasing population growth and development pressures.

The 5 counties bordering the IRL receive tremendous economic benefit from its presence. Commercial and recreational activities around the immediate vicinity of the IRL support approximately 20,000 jobs and generate over $250 million dollars in annual income. Citrus agriculture in the IRL accounts for over 2 billion dollars per year, while recreational activities such as boating, fishing, water sports, hunting and ecotourism generate approximately $465 million dollars annually. Commercial fishing enterprises in the IRL and along the Florida coast generate approximately $150 million dollars in revenues, and account for nearly 15% of the national fish and shellfish harvest. Real estate leasing and sales along the lagoon account for over $825 million dollars in annual revenue (St. Johns River Water Management District, unpublished).

Much of the northern portion of the IRL lies within Kennedy Space Center (KSC) and Cape Canaveral Space Launch Complex operated by NASA and the U.S. Air Force. This area is also the site of the Merritt Island National Wildlife Refuge (MINWR) and Canaveral National Seashore. The central and southern portions of the IRL include Pelican Island National Wildlife Refuge (the first refuge in the National Wildlife Refuge System); Archie Carr National Wildlife Refuge, which was set aside to protect one of the largest populations of nesting sea turtles in the world; numerous Florida State Parks, as well as many public beaches and small reserves. Additionally, each of the 5 counties within the IRL region has implemented successful, voter-approved land acquisition programs that have established an exceptional natural areas network along the IRL and its tributaries. The IRL has also been named as an Estuary of National Significance by the Environmental Protection Agency's National Estuary Program (NEP). The focus of the NEP is to ensure the health and diversity within estuaries by partnering with numerous municipalities and counties to address the common challenges faced in virtually all estuarine systems: excessive nutrient, pathogen, and chemical inputs, habitat loss and degradation, introduction of exotic species, and alterations of natural flow regimes. The National Oceanographic and Atmospheric Administration has also nominated the IRL as a National Estuarine Research Program site.

Researchers at Kennedy Space Center (KSC), the Smithsonian Marine Station at Fort Pierce, St. Johns River Water Management District, The Army Corps. of Engineers, South Florida Water Management District, Florida Marine Research Institution, Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission, as well as numerous academic institutions and other agencies have developed impressive datasets addressing many areas of concern in the IRL. Many of these datasets reflect long-term ecosystem monitoring that addresses change in lagoonal species and environmental conditions over time; while others address environmental changes and ecosystem dynamics. A closer examination of the research collection of just one of these organizations highlights the importance of collaboration, data integration, and inter-agency cooperation. KSC, for example, has compiled environmental data collected equivalent cumulatively to a period of over 200 years. These data include biotic and abiotic parameters, with associated metadata. Some of the biotic data include long-term vegetation data, herbarium collections, long-term submerged aquatic vegetation data collected by St. Johns River Water Management Districts and KSC/Dynamac Corporation, wetlands data, Florida manatee population studies, sea turtle nesting success and density data, lagoonal fish population studies, radio tracking data of gopher tortoise and indigo snake habitat utilization, and wading bird population studies. Some of the abiotic data include rain chemistry, air quality, long-term water quality, soil chemistry, groundwater well chemistry, long-term rocket launch exhaust depositional patterns, meteorological conditions, solid waste management sites numerous remotely sensed landscape data. All the metadata entered into the KSC database possesses detailed documentation. Those data that are defined as thematic or athematic adhere to the Federal Geographic Data Committee's (FGDC) metadata standards. Additionally, the Earth Systems Modeling and Data Management Laboratory at KSC maintains an archive of aerial imagery extending from 1943, and supports numerous online thematic and athematic data.

Other organizations have accumulated equally impressive data sets that help define the IRL system's biodiversity and ecosystem processes. However, the different goals and responsibilities of each organization have resulted in differences in the methodology and focus of the data collected. Within each organization, data are acquired at different temporal and spatial scales by numerous investigators, and exist in many formats. Among organizations, data is stored in a variety of formats, from text, spreadsheets, desktop databases such as Microsoft Access, Oracle tables, SAS, satellite images, aerial photos, as well as other data formats. Further, data are commonly stored and maintained in stand-alone systems, each having its own standards, vocabulary, syntax, scale and associated metadata. One notable exception is the 30-year Indian River Lagoon and statewide cetacean stranding database assembled and archived by Hubbs-SeaWorld Research Institute (HSWRI). These stranding data are provided to HSWRI in standard National Marine Fisheries Service (NMFS) data format by marine mammal stranding teams authorized by NMFS. In 2000, HSWRI developed the "*Indian River Lagoon Dolphin Stranding Information System*" to quality control the historical data, standardize methodology of data synthesis, develop IRL GIS maps, enhance interagency communication and reporting and provide a framework for data analysis.

While each stakeholding organization has devoted considerable research effort into developing the tools to interpret and model ecosystem processes, there remains a strong need to develop the robust informatics tools that will assist agencies in collaborations to integrate, analyze, synthesize and interpret their widely disparate datasets. In order for IRL researchers to truly understand the ecosystem dynamics affecting biodiversity in the system, they must first overcome current problems in acquisition, use and long term archiving, integration, analysis, synthesis, and visualization of the data.

Novel informatics tools are promising for effectively researching and managing the vast biodiversity of the IRL. Informatics tools will provide some of the resources needed to support ecological forecasting and will assist IRL researchers in generating higher-order knowledge from the vast amounts of data they have collected, thus allowing them to address more effectively issues such as species population dynamics and habitat loss, effects of invasive species, effects of global change on ecosystem processes, and restoration of lost or degraded habitats.

B. Workshop Organization

The BDEI workshop was organized in both presentation and discussion format. The chair, in his opening remarks, highlighted the main objectives of the workshop and solicited presenters to identify research problems addressed by their individual organizations, their significance to the IRL ecosystem, current approaches used, and the fundamental issues which confront their research with respect to data collection, retrieval, visualization, analysis, synthesis, management and modeling. Plenary sessions were designed such that IRL researchers could describe the scope of research undertaken by their various organizations, and outline their needs for informatics tools and technology. Speakers addressed key issues affecting biodiversity and ecosystem dynamics of the Indian River Lagoon and identified areas where the application of novel computational intelligence, spatial information, remote sensing and data management techniques could assist in resolving some of these issues. The attached workshop schedule and abstracts list the details regarding individual presentations and organizational concerns.

II. Topics

The topics presented by the speakers were divided into two main categories: those related to the biological and ecological aspects of the IRL system and those related to information sciences.

A. Biological and Ecological Topics

There were 8 presentations addressing different biological and ecological aspects of the Indian River Lagoon (IRL) system. These included the following topics:

- The aquatic diversity, regional geomorphology, biogeographical transition zones, and spatial heterogeneity of the IRL area, including those areas, which can be viewed as biodiversity “hotspots”.
- Biocomplexity within the IRL system, with a focus on the human factors involved in managing for the sustainability of biodiversity resources within the IRL.
- The types of data and metadata available in historic collections, such as those of natural history museums, academic institutions and personal research collections; and the value of digitizing this information in order to make it accessible to researchers on the Internet.
- The tools and methodologies used in taxonomy and systematics, including the value of systematic collections to the study of biodiversity.
- An examination of the physical processes which drive geomorphology, spatial heterogeneity, and temporal dynamics within the IRL, and how these processes in turn affect biodiversity and species distribution within the system.
- A long-term overview of how seagrass coverage within the IRL has changed in conjunction with changes in land use, development, water quality, and sedimentation rates.

- An overview of the IRL species inventory: its history, methods, database organization, knowledge gaps, web development, and potential as a research and educational tool.
- An examination of the state of coastal wetlands in the vicinity of the IRL following alteration (impoundment) of these wetlands for mosquito control, and agency attempts at rehabilitation and restoration following opening and reattachment of impounded areas.

A running theme throughout the presentations was that while a great deal of data has been acquired to define the IRL system's biodiversity and ecosystem processes, the data were collected by different researchers exist at different temporal and spatial scales and are stored in disparate formats. The available datasets lie within the purview of local, state and federal agencies, universities, and some private organizations. Speakers pointed out problems they encounter with data accessibility and retrieval for process-oriented research. They presented their views on the future directions needed for effective dissemination and centralization of data and stressed the need for development of new predictive tools for risk assessment, analysis, and ecological forecasting.

B. Information Sciences Topics

There were 6 presentations that focused on informatics techniques that could be effectively applied to existing datasets for the Indian River Lagoon. The topics included:

- Various methods for utilizing computational intelligence in modeling complex ecosystems.
- Integration of heterogeneous data at structural and semantic levels.
- Automated change detection techniques using digital imagery to update geospatial databases.
- Analysis and modeling of ecosystem processes using neural networks, fuzzy systems, and genetic algorithms.
- Integrated modeling and synthesis of complex ecosystems using statistical approaches, agent based models and intelligent information processing techniques.
- A newly developed three-dimensional model of the IRL ecosystem that integrates characteristics such as hydrodynamics, waves, sediment transport, water quality, light attenuation, and seagrass distribution.

Several examples were given to show how computational intelligence could be effectively utilized in collecting and analyzing biodiversity and ecological data; and further, how these computational tools could be applied in visualizing data, synthesis of data, and in forecasting. An integrated modeling system incorporating a three dimensional hydrodynamic model, a wave model, a 3-D sediment transport model, a 3-D water quality model, a light attenuation model and a sea-grass model for the Indian River Lagoon was described. In addition, DNA sequencing algorithms were also explored as a potential aid in addressing taxonomic conflicts and identification issues for different species.

III. SUMMARY OF DISCUSSIONS

The workshop was useful in opening avenues of collaboration between researchers from diverse fields to advance research into biodiversity and ecosystem dynamics of the IRL. Participants from each group were able to gain an understanding of the specific areas in which informatics tools and methods could be employed in addressing specific IRL research needs. Participants agreed that computational intelligence techniques such as neural networks, fuzzy logic, and genetic algorithms would provide insight into identifying and understanding underlying patterns in data that would reflect temporal and spatial dynamics pertinent to real ecological patterns/processes inherent in the IRL ecosystem. They were also able to identify within their own areas of expertise where the application of intelligent processing systems could prove valuable, particularly in expanding ecosystem models of the IRL that incorporate physical, chemical, biological and socioeconomic factors into an integrated assessment tool.

Although there are many disparate data sets for the IRL area that lie within the purview of the local, state and federal agencies, universities and some private organizations, at least three areas emerged as being readily appropriate for informatics techniques. These are 1) the biological and taxonomic dataset from the Indian River Lagoon Species Inventory, maintained by the Smithsonian Marine Station at Ft. Pierce, 2) ichthyological data from long-term IRL studies maintained by NASA KSC/Dynamac Corporation and 3) long-term submerged aquatic vegetation data and water quality data of the St. Johns River Water Management District, South Florida Water Management District, and NASA KSC/Dynamac Corporation. These data are of the spatial and temporal extent compatible for application of informatics tools.

A. Group Summaries and Recommendations

On a national level, the Biodiversity and Ecosystems Panel of the President's Committee of Advisors on Science and Technology (PCAST) recognized in their 1998 report, "*Teaming with Life: Investing in Science to Understand and Use America's Living Capital",* the urgent need to improve the national biological information infrastructure (NBII) and promote the development of a next-generation of systems able to maximize use of and openly share information generated by biodiversity and ecosystems research. With this goal in mind, 3 main focus areas were chosen for discussion: 1) Acquisition and Conversion of Data and Metadata; 2) Analysis and Synthesis of Data and Metadata; and 3) Dissemination of Data and Metadata. Work groups discussed the current problems in the format of the collected data, methods of data collection, data analysis and the need for effective dissemination of the data from the Indian River Lagoon, and formulated their recommendations for future discussion and planning. The working groups recognized that biodiversity and ecosystems data are developed in response to particular research needs and goals, and that there are many logistical challenges to overcome in promoting collaboration and data integration among agencies and institutions. However, as it is recognized that the complexity of biodiversity and ecosystems dynamics are reflected in the vast amounts of research undertaken and archived annually, it is also recognized that the development of novel approaches to data collection, integration and analysis will be vitally important to our ability to create higher-order knowledge from raw data. The salient points of discussion are outlined below.

1. ACQUISITION AND CONVERSION OF DATA AND METADATA

The objective of this group was to examine the research needs for improved data collection methods, and to propose effective recommendations for future data collection techniques, centralization and accessibility. Much of the data for the Indian River Lagoon is collected by state, federal, academic and private institutions. Many of these organizations have accumulated large volumes of biological information and data, sometimes over long time periods. Improved methods for organizing, storing and retrieving these records are extremely critical. There is a need to convert data and documentation into metric-quality digital formats. New techniques are needed in collecting data from the field and also to collect, store and transmit data from the field. Taxonomic data present a particular challenge to utilizing historic records, as much species-specific information may not be readily identifiable due to changes in species names and taxonomy. There is also a need to improve research productivity by integrating different versions of available data in a simplified format. The recommendations of Group 1 are listed in the following action items:

- **Assess the types and relevance of available IRL datasets, and identify their availability and accessibility to the wider research community:** Individual organizations collect data in the IRL that are specific to the needs of their respective research and management goals. In promoting synergistic opportunities and data sharing among research organizations, it is necessary to assess the relevance of individual datasets and determine their value in addressing biodiversity research in the IRL. Comprehensive datasets addressing biodiversity and ecosystem dynamics could then be made available to other members of the research community.
- **Improve methods for collecting, organizing and archiving data:** A fundamental objective in studying biodiversity and ecosystem informatics is to create a degree of higher-order understanding and knowledge from disparate datasets. IRL data and metadata has been collected over the course of many years by a wide variety of research organizations, each having its own individual data requirements and uses. A need exists to improve data and metadata standards to improve the usability of integrated data within and between agencies.
- **Convert historical data into digital format** Much of the biodiversity and ecosystem information for the IRL is housed in non-digital formats such as paper journal articles, books, unpublished manuscripts, field notes, agency reports, and imagery. Our knowledge of ecosystem dynamics in the IRL will be vastly improved as the formats of these informational infrastructures are upgraded to digital formats. This process may be especially true for historical aerial photographs of the IRL, which show changes in land use, development patterns, seagrass cover, and watershed change over time.

- **Improve methods for integrating taxonomic changes into datasets:** As our knowledge of particular species evolves over years of investigation, distinct species have often been merged together or split into several new species. Unfortunately, data management practices, particularly those associated with non-digital data, have not kept pace with taxonomic changes. Thus, historical datasets will require further processing before they can reflect current naming conventions and taxonomic modifications.
- **Improve data and metadata standards:** In developing collaborations among institutions and agencies, developing common standards for data and metadata collection must be addressed. Common data standards will improve the ease with which data may be extracted or shared; will speed data processing time, and will facilitate the integration of disparate datasets, overcoming problems with spatial and temporal scales, data formats, standardization, taxonomic conventions, semantics, and other factors.
- **Address knowledge gaps in available data and metadata:** Once a common data/metadata collection and storage strategy is developed, it must next be applied to historical datasets, with researchers filling in knowledge gaps in the data structure where possible in order to facilitate data sharing and extraction.
- **Implement ontology and structure for the data:** New technologies will demand the institution of new methods in collecting and analyzing data. In the development of these technologies, it is essential that the needs of all stakeholders (scientists, resource managers, policy makers, and the public) be addressed in order to maximize the value and relevance of the data to all concerned.
- **Utilize efficient remote sensing techniques for data acquisition:** Institutions and agencies performing biodiversity and ecosystems research in the IRL will undoubtedly be capturing physical and geographical data. The use of efficient remote sensing and agent-based technologies will aid researchers not only in improving the quality and accuracy of data collected, but will also assist in eliminating problems of scale, measurement, and standardization among agencies wishing to collaborate.

2. ANALYSIS AND SYNTHESIS OF DATA AND METADATA

Due to the diverse nature and expanse of IRL data, integrated information is essential for a comprehensive understanding of the patterns and ecological processes affecting the biodiversity of the IRL. Biologists and ecologists concerned with understanding biodiversity do not often have the luxury of exploring single aspects of species biology. Biodiversity and the processes that affect it span a number of interdisciplinary areas: anthropogenic factors, physical factors, reproductive factors, physiological factors, behavioral factors etc. To address these issues and how they affect biodiversity and ecosystem functioning, scientists have collected vast amounts of data, and are regularly challenged to forecast change, perform risk analysis, and predict results. It is essential then that adaptive technological processes be developed to assist in these efforts. The evolution from data to information to knowledge is only possible through effective data management and improvements in computational technology. The recommendations of Group 2 are listed in the following action items.

- **Identify the major forcing functions of biodiversity in the Indian River Lagoon:** An understanding of the driving forces operating within the IRL and how they affect biodiversity is essential before we attempt to build the next generation of infrastructure that will measure and model these forces. This requirement must be addressed at different spatial and temporal scales, and include methods or standards for validating model outcomes. In this way, integrated models which link physical, chemical, biological and socioeconomic processes can be developed to forecast changes in biodiversity within the IRL.
- **Identify long-term trends in biological data and formulate functional relationships:** Examinations of existing datasets must be performed in order to identify any apparent trends in the data. Where found, these trends should be further examined to determine if valid cause-effect relationships can be drawn between biological observations and physical, chemical, hydrological, or other processes. This knowledge can then be modeled and considered throughout the course of future research.
- **Perform efficient spatiotemporal analysis of datasets:** Effective methods of integrating and interpreting spatiotemporal data can be applied to existing datasets in order to give researchers a comprehensive overview of change through time in the IRL system. This will allow older records to be meaningfully compared with newer records, and will increase the record of documentation of observed changes in the IRL.
- **Develop integrated models:** An integrated model, or set of models that link physical, chemical, biological, social and economic processes at multiple temporal and spatial scales will allow for effective prediction and forecasting of the environmental changes that affect biological diversity.
- **Improve process-based simulation/modeling through the development of advanced informatics tools:** The use of computational intelligence techniques such as neural networks and fuzzy systems, offer great promise in allowing researchers to improve existing models and explore new questions surrounding ecosystem dynamics and biodiversity.
- **Explore applications of advanced computing power and distributed computing:** Some of the large datasets and ecological models that may be useful in addressing any number of research questions could be easily managed through the use of more powerful computers and distributed computing. Use of advance computational technologies will make it possible for researchers to examine increasingly vast amounts of information in relatively short periods of time.
- **Apply advanced visualization techniques to enhance usability of research results:** The usefulness of datasets, imagery, field observations and experimental results is in part determined by how they are presented. Scientists, resource

managers, policy makers and the public may all benefit from the use of advance techniques that allow for better visualization of data and experimental results.

3. DISSEMINATION OF DATA AND METADATA

Resource managers, policy makers, educators, non-governmental organizations, industry and others require visualization of natural processes and management actions over time in order to better understand biodiversity and ecosystem data and the various relationships among data. The objective of this group was to offer suggestions to better characterize the needs and requirements of data users; to provide data management guidelines and improve avenues of interdisciplinary communication among scientists, resource managers, decision makers and the general public; and to investigate methods of sharing various resources that would enable collaborative research, not only among various members of the biological community, but also among biologists, ecologists and researchers from computer science, spatial information, remote sensing and intelligent systems. The recommendations of Group 3 are listed in the following action items:

- **Enhance inter-institutional cooperation:** Facilitating collaboration, data sharing, and data integration among the various stakeholding agencies responsible for researching and managing biodiversity in the IRL could be much more easily accomplished through the use of informatics tools and technologies. Use of the Internet is one obvious avenue through which collaboration and communication between organizations can be enhanced, and data shared.
- **Develop clear protocols for data use and sharing:** In laying the groundwork for inter-agency cooperation and data sharing, clear protocols must be developed which outline how data may be accessed and utilized by participating agencies. Task forces that are assembled at the onset of new collaborative efforts could most easily address the logistical issues involved in data sharing.
- **Develop work groups for determining standards for data and metadata collection**: Data management guidelines that include standards for data and metadata are essential to effective data sharing. In order to be optimally meaningful, datasets that are to be shared among institutions must also share a common frame of reference for data and metadata. Agencies interested in collaboration and data sharing should establish work groups to identify a common data structure for future research efforts, and investigate ways to bridge the use of different data standards, semantics, scaling and spatial references in disparate datasets.
- **Develop web-based applications for integration of data and metadata from various sources:** Use of the Internet and the development of web-based applications will be invaluable in the integration of various datasets housed and maintained by the various agencies that perform IRL biodiversity and ecosystem dynamics research. In this manner, agencies and institutions would be minimally impacted by decisions to share data with other agencies. Institutions would

continue to store and update their individual datasets, while simultaneously making them available to a consortium of users via the Internet.

- **Create a web-based directory of researchers and their areas of expertise:** In developing interdisciplinary workgroups and collaborations among agencies, it will be helpful from the outset to identify the specific research areas of the staff involved. Thus, as research plans are developed, personnel from one institution could consult with staff from other institutions who may be familiar with the types of research questions being investigated. Use of this process may also help diminish duplication of effort among agencies.
- **Visualize a consortium of various users with access to data**: As agencies consult with one another to identify common areas where data sharing and research collaboration may be helpful, it will also be necessary to build the computing infrastructure that will make collaboration as simple as possible. Building a web-based application that would allow users from various agencies access to data and publications would facilitate this process. It can be foreseen that a consortium of users interested in many aspects of IRL research and results would also have many different technology requirements. Biologists and other researchers developing informatics tools, for example, would need to access raw data; resource managers might require data summaries or research reports explaining experimental results; and policy makers may require only an executive summary. Casual browsers could also be admitted to the system to access data summaries, or narratives that explain research or experimental outcomes.

IV. CONCLUSION

Presentations and discussions from the workshop were valuable in identifying the important research issues central to improving our knowledge of the IRL, its biodiversity, and ecosystem dynamics. The workshop brought together researchers from biological and ecological sciences, remote sensing, spatial information, computer science and intelligent systems from different agencies, universities and organizations. Perhaps for the first time, biologists and ecologists were introduced to novel technologies and methods useful in studying biodiversity, and were given the opportunity to foresee how these technologies could be applied to their own research. The workshop also created preliminary methodological avenues useful in addressing both research questions and the possible informatics applications that could be applied. Based on the recommendations of participants, biologists and ecologists will soon be providing IRL datasets to other researchers from computer science, spatial information and intelligent systems who will begin the development of robust informatics tools which will assist researchers in effective data collection, management, analysis, synthesis, and ecosystem modeling.

Full implementation of the research agenda for furthering our knowledge of the biodiversity and ecosystem dynamics of the Indian River Lagoon will require a number of commitments and much planning. Some of the short and long term action items that will further these efforts are:

- Definition of a clear research agenda for investigating IRL biodiversity and ecosystem dynamics.
- Securing a commitment from researchers to a highly coordinated, long-term IRL monitoring and research effort.
- Identification of research needs and data/metadata requirements.
- Coordination among agencies and institutions and centralization of IRL data availability and access.
- Development of multi-disciplinary planning and working groups to encourage collaboration and research.
- Integration of socioeconomic and sociopolitical considerations into scientific research initiatives and data collection.
- Development and testing of innovative models that integrate various facets of IRL ecosystem dynamics, biodiversity considerations, and other factors.
- Development of improved or novel technologies to improve ecological forecasting.
- Identification and procurement of adequate funding and the potential to leverage resources in order to drive this effort.

V. WORKSHOP COMMITTEE

Chair

- Dr. Mohamad Musavi, Intelligent Systems Laboratory, Department of Electrical and Computer Engineering, University of Maine, Orono.

Organizing Committee and Collaborators

- Dr. Richard Miller and Dr. Greg Carter, NASA Stennis Space Center, Mississippi.
- Dr. Ross Hinkle and Dr. R. Grant Gilmore, Dynamac Corporation, Kennedy Space Center, Florida.
- Dr. Anson Hines, Smithsonian Environmental Research Center, Edgewater, Maryland.
- Dr. Bjorn Tunberg and Kathleen Hill, Smithsonian Marine Station, Fort Pierce, Florida.
- Dr. Habtom Ressom, Dr. Cristian Domnisoru, and Padma Natarajan, Intelligent Systems Laboratory, Department of Electrical and Computer Engineering, University of Maine, Orono, Maine.
- Dr. George Markowsky and Dr. Thomas J. Wheeler, Department of Computer Science, University of Maine, Orono, Maine.
- Dr. Anthony Stefanidis, National Center for Geographic Information and Analysis, Department of Spatial Information Science and Engineering, University of Maine, Orono, Maine.

Workshop Coordinators

- Padma Natarajan, Dr. Habtom Ressom, and Dr. Cristian Domnisoru, Intelligent Systems Laboratory, University of Maine, Orono.
- Kathleen Hill, Smithsonian Marine Station, Fort Pierce, Florida.

VI. WORKSHOP PARTICIPANTS

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Dr. Robert Day St. Johns River Water Management District Indian River Lagoon Program 525 Community College Parkway SE Palm Bay, FL, 32909	Dr. Mary Rice Smithsonian Marine Station at Fort Pierce 701 Seaway Drive Ft. Pierce, FL 34949
Dr. Duane De Freese Hubbs-SeaWorld Research Institute 6295 Sea Harbor Drive Orlando, FL, 32821-8043	Dr. Peter Sheng University of Florida Coastal and Oceanographic Engineering Department Gainesville, FL 32611-6590
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VII. WORKSHOP SCHEDULE

BDEI WORKSHOP

Biodiversity and Ecosystem Informatics
for the Indian River Lagoon, Florida

February 7 – 8, 2002
Cocoa Beach, Florida

Workshop Schedule:

Thursday Feb. 7:

7:00 – 8:00 a.m. Continental Breakfast
8:00 – 8:30 a.m. Registration

SESSION I:
8:30 – 8:45 a.m. Welcome, conference goals. Dr. Mohamad Musavi
8:45 – 9:15 a.m. "Evolution of regional biocomplexity: aquatic diversity "hot spots", community patchiness along physical gradients." Dr. Grant Gilmore
9:15 – 9:45 a.m. "Understanding the biocomplexity of the Indian River Lagoon system – bridging the gap to sustainability." Dr. Ross Hinkle, Dr. Duane De Freese
9:45 – 10:15 a.m. Discussion
10:15 – 10:30 a.m. Tea/Coffee Break

SESSION II:
10:30 – 11:00 a.m. "Biodiversity informatics: natural history collections, natural history data." Dr. Anna Weitzman
11:00 – 11:30 a.m. "The value of systematic collections in biodiversity studies." Dr. Paula Mikkelsen
11:30 – 12:00 noon Discussion
12:00 – 1:00 p.m. Lunch Break

SESSION III:
1:10 – 1:25 p.m. "Spatial heterogeneity in the Indian River Lagoon: driving forces." Dr. Robert Virnstein
1:25 – 1:50 p.m. "Long-term and short-term seagrass change versus land use change." Dr. Robert Virnstein
1:50 – 2:05 p.m. "IRL coastal wetland rehabilitation and collaborative research to improve management." Ronald Brockmeyer
2:05 – 2:35 p.m. "The Indian River Lagoon species inventory: history, accomplishments and future directions." Kathleen Hill

2:35 – 3:00 p.m.	Discussion
3:00 – 3:10 p.m.	Tea/Coffee Break

SESSION IV:

3:15 – 3:50 p.m.	"Agent-based models of complex ecosystems." Dr. George Markowsky
3:50 – 4:15 p.m.	"Issues related to database management techniques: integration of heterogeneous databases at the structural and semantic levels." Dr. Thomas Wheeler
4:15 – 4:45 p.m.	"Automated change detection techniques using digital imagery to update geospatial databases." Dr. Anthony Stefanidis, Dr. Peggy Agouris
4:45 – 5:00 p.m.	Discussion
7:00 p.m.	Banquet

Friday Feb. 8:

7:00 – 8:00 a.m.	Continental Breakfast

SESSION I:

8:00 – 8:45 a.m.	"Computational intelligence and its applications in ecological modeling." Dr. Habtom Ressom
8:45 – 9:15 a.m.	"Application of computational intelligence in biodiversity." Dr. Cristian Domnisoru
9:15 – 10:15 a.m.	Discussion
10:15 – 10:30 a.m.	Tea/Coffee Break

SESSION II:

10:30 – 11:00 a.m.	"An integrated modeling system of the Indian River Lagoon." Dr. Peter Sheng
11:00 – 11:30 a.m.	TBA
11:30 – 12:00 noon	Discussion
12:00 – 1:00 p.m.	Lunch Break

SESSION III:

1:10 – 3:00 p.m.	Discussion
3:00 – 3:15 P.M.	Tea/Coffee Break

SESSION IV:

3:15 – 4:00 p.m.	Research agenda formulation
4:00 p.m.	Closing remarks. Dr. Mohamad Musavi

VIII. REFERENCES

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IX. ABSTRACTS

Evolution of regional biocomplexity: Aquatic diversity " Hot Spots", community patchiness along physical gradients

Dr. R. Grant Gilmore, Jr.
Dynamac Corporation, Kennedy Space Center
&
Dr. Anson H. Hines, Jr.
Smithsonian Environmental Research Center

The Indian River Lagoon (IRL) system of east central Florida has been recognized as containing the richest aquatic biota within the United States. To date 289 aquatic plant species, 555 protists, 1,785 animal species have been recorded from the Lagoon and its oligohaline tributaries. The 2,629 species of aquatic organisms are not distributed evenly throughout the entire ecosystem. There are broad biogeographical transitions along the 233 km axis of the Lagoon with distinct changes from numerical dominance of tropical species to dominance of warm temperate species. Within the tropical - subtropical species zones there are also major biota changes along salinity and tidal gradients associated with ocean inlets. Species trophic and phyletic guilds associated with specific habitats remain constant and well defined, yet species composition within these guilds change significantly along physical gradients. The most pronounced biota change occurs along tidal, salinity and winter temperature gradients associated with ocean inlets. These changes take place even though the predominate habitat types and habitat species composition does not change. For instance, there are significant seagrass meadow faunal changes on this gradient even though the meadow always consists of manatee grass, *Syringodium filiforme*. This process creates locations where species diversity is particularly high. Unfortunately, the locations of highest aquatic species diversity have received some of the greatest recurrent human impact and often receive no protection from environmental insults relative to locations of the IRL, which have far lower biocomplexity. Consequently, a number of locations supporting the highest aquatic biocomplexity within the Indian River Lagoon ecosystem have been destroyed during the past decade.

Understanding the Biocomplexity of the Indian River Lagoon System - Bridging the Gap to Sustainability

Dr. C. Ross Hinkle
Dynamac Corporation, Kennedy Space Center
&
Dr. Duane E. De Freese
Hubbs-SeaWorld Research Institute

Knowledge of the biological diversity of the IRL system has emerged from studies conducted by numerous researchers from many organizations over many years. However, understanding its biocomplexity (i.e., the complex interactions and interdependencies among living organisms and the environments that affect, sustain and are modified by them) and the sustainability of its high biological diversity remains a significant challenge. Natural ecological dynamics on the scale of days to thousands of years and cumulative human cultural dynamics, particularly over the past 400-500 years, have shaped the system we see today. Understanding the biocomplexity of the IRL requires interdisciplinary efforts that include scientists from biological, physical and social sciences. Research activities span many temporal and spatial scales, represent multiple levels of biological organization, and cross conceptual boundaries. Clear and effective links between research findings and environmental decision-making are paramount. The sustainability of the system is heavily tied to the predictive information regarding the forcing functions that drive the system and the level of understanding of biocomplexity that goes into management and regulatory decisions designed to sustain this system.

Biodiversity Informatics: Natural History Collections, Natural History Data

Dr. Anna Weitzman
National Museum of Natural History
Smithsonian

Some of the benefits of having data on Natural History collections digitized, integrated, and available:

1. Natural History collections are vouchers for the wide variety of research that has been done. As such they provide links to the past and allow re-analysis and thus reproducible science.
2. Natural History collections are reinterpreted and reexamined using new technologies as they become available.
3. Current technology allows us to share widely information about collections and research in new and different ways.
4. Current technology will allow us to update and correct data in more cost effective fashions.

The purpose of the natural history collections is not the accumulation of a long list of specimens, cataloged and ordered on shelves and in cabinets; the purpose is the scientific understanding that studies of these specimens and objects unlock and the increase the predictive statements that can be made because of the knowledge gained from their study.

Natural history collections document the best information available for the biodiversity of a specific place when western civilization first visited that place, and they also provide "point in time" data for much of the last 150-200 years. They also voucher many kinds of studies—ecological studies, molecular studies, samples made for commercial reasons, material from the National Cancer Institute, and so on.

The information from natural history collections, especially when data from collections worldwide are combined, is vital to understanding the complexity of the world around us. At the Smithsonian's National Museum of Natural History, one of our important goals for the future is to get all information related to all the collections into electronic form and readily accessible. As we do so, it will become an increasingly useful reference tool for the world. The data will be used by scientists, students, the general public, and various U.S. and foreign government and regulatory agencies and non-governmental organizations associated with the use of biological resources (in the U.S. for example, Departments of Interior, Agriculture, Commerce, and State in interactions in this country and with foreign nations, the World Bank, Conservation International, and so on).

Current technology allows us to capture and link information about all of the collections. Having the data in these forms will, for example, allow scientists to analyze changes in biota that turn out to be linked to changes in human populations and to make assessments of what humans can expect to happen in the future, given the kinds of changes that have affected global climate.

The challenges that face us as we make natural history collections databases available widely include the collection of the data in electronic form. The databasing of our biological collections that number some 83 million at NMNH alone is a daunting task to say the least. However, the more interesting scientific challenge is how to link these data to the myriad of other data, such as physical data, molecular sequence data, survey and plot data, etc., that, when combined, will allow us to better understand the world around us. A well-developed system of databases with these and other linkages will be crucial for developing sustainable use of critical areas, be they recreational, such as national parks and forests, and national seashores for that matter, or for minimizing the effect of exploitation of biological resources.

The value of systematic collections in biodiversity studies

Dr. Paula M. Mikkelsen
American Museum of Natural History, New York

Despite the universal recognition of the ecological and esthetic value of high levels of marine biodiversity, conservation still largely focuses on cnidarians, fish, sponges, and algae. These span a wide taxonomic range and can be monitored non-invasively. But this biodiversity picture is dismally incomplete. As in the terrestrial ecosystems, the overwhelming majority of species and clades in coral reefs and other complex marine habitats are cryptic. Worms, mollusks, echinoderms, and crustaceans are numerically dominant, form the trophic underpinning, and play pivotal ecological roles. Other than a few charismatic species (starfish, conchs, Christmas tree worms), they are underestimated and overassumed. Proper inventory of invertebrate taxa requires factors not routinely employed in conservation: destructive sampling and systematic expertise. Yet scientifically robust results can be achieved with minimal damage and investment, and lead to recognition of key species, for which monitoring schemes can be developed. Echinoderms and mollusks provide examples of recent surveys yielding significant results. Acquiring systematic expertise for inventorying marine invertebrates continues to be seriously limiting. Invertebrate systematic work requires access to extensive specimen collections, laboratories, and libraries, all best represented in museums. After decades of de-emphasizing systematics, the cohort of trained systematists is aging and facing non-replacement. In today's climate of biodiversity interest, new initiatives (NSF-PEET) are training the next generation. The Convention on Biological Diversity is promoting systematic inventory to help balance conservation and sustainable development, since reefs sustain the lives of millions of people yet are increasingly under threat. International initiatives (Diversitas, SA2000) are key to developing new programs to document reef biodiversity. Programmatic and financial support for inventories is the next requirement.

Spatial heterogeneity in Indian River Lagoon: driving forces

Dr. Robert Virnstein
St Johns River Water Management District

Seagrass habitats and associated communities in Indian River Lagoon, Florida, are spatially heterogeneous. There are several driving factors: (1) Youth: the IRL is only 5-6,000 years old. (2) Latitude: a span of >2 degrees. (3) Flushing and circulation: some segments are 95 km and 5 causeways removed from the nearest inlet. Salinity and temperature at a single site can range from 5-40 C and 5-50 ppt. (4) Tidal amplitude: from about 1 m near inlets to <5 cm. (5) Multiple tributaries draining different basin types: from hardwood swamps to agriculture to cities. (6) Multiple inlets: opening to ocean waters that are sub-tropical to warm-temperate; Sebastian Inlet is only 54 years old. (7) Geology: not river-dominated; rather, sediments have multiple sources. (8) Level of development/protection: from near pristine, with surrounding basins publicly owned, to extensively developed with stormwater a major problem. (9) Shallow, with a high surface-to-volume ratio of nearly 1 m2 per m3; boundary conditions thus play a disproportionately large role compared to water masses. In response, seagrass and associated communities show vast spatial differences and asynchronous temporal patterns. So what? Management, e.g., setting seagrass restoration targets or pollutant load reduction goals, needs to address this spatial heterogeneity. Also, mean values over large spatial areas may be meaningless; rather, data analyses need to be spatially explicit.

Long-term and short-term seagrass change versus land use change

Robert W. Virnstein and Edward W. Carter, IV, et al.
St. Johns River Water Management District

A. Long-term seagrass change versus land use change

As the basis for seagrass restoration, it is usually assumed that increasing urbanization leads to increased runoff, decline in water quality, and decline in seagrass. The Indian River Lagoon basin provides an excellent test estuary because some areas have remained nearly pristine, while other areas have become highly urbanized. Several factors allow analysis of 20 distinct segments over a wide gradient of development and seagrass health. Over a 50+-year period, some Lagoon segments have lost over 90% of seagrass acreage. In other segments, seagrass actually increased as much as 100%, presumably due to opening of Sebastian Inlet. Based on a simple runoff model, increases since 1943 in loadings of Nitrogen, Phosphorus, and Total Suspended Solids ranged from near zero to over 500%. Large seagrass losses occurred with increased loadings of: N >120%; P >160%; or TSS >300%. In the 4 segments (a 90-km section of the Lagoon) with loadings increases above these levels, seagrass decreased 60 to 90% over this time period.

This spatial analysis, using GIS, provides a powerful tool for graphically representing complex spatial patterns. Changes in seagrass were spatially and quantitatively related to changes in pollutant loadings over time, and areas were identified for either preservation or restoration. Analytical challenges remain, however. Maps are snapshots in time. But runoff and water quality change continuously. How are such disparate data best handled?

B. Is seagrass improving or declining in Indian River Lagoon? Yes! A primary method for monitoring seagrass in Indian River Lagoon is mapping based on aerial photographs. We have now mapped seagrass for 1943, 1986, 1989, 1992, 1994,1996, and 1999. Plans are in place for 2002 mapping.

What trends do we see? It depends! Since 1943, most segments of the Lagoon have lost seagrass (<20% overall). But some segments (around Cape Canaveral, protected by NASA ownership) have stayed the same; others have even increased. In segments with the highest historic losses (>70% in the Melbourne/Cocoa area), we have seen some recovery in the last decade. An additional intensive seagrass monitoring method is twice-a-year field monitoring of fixed transects from shore to the edge of the seagrass bed. In some of those areas with the highest long-term losses, beds have recently expanded. These same areas also have the greatest year-to-year fluctuations in coverage and the lowest species diversity of sea grasses. Yes, some areas have improved, but some areas still have a long way to recovery. Again, these measurements are snapshots in time. Serial auto-correlations remain an analytical challenge.

IRL coastal wetland rehabilitation and collaborative research to improve management

Brockmeyer, Ronald E., Jr.
St. Johns River Water Management District

Estuarine wetlands in the Indian River Lagoon (IRL) system have been severely impacted. Approximately 40,000 acres of IRL wetlands were impounded for mosquito control mostly during the 1950's and 60's. Most of these impounded estuarine wetlands are located within the Merritt Island National Wildlife Refuge (MINWR) and Kennedy Space Center. The objectives of the IRL Coastal Wetlands project include 1) restoration / rehabilitation of impacted wetlands, 2) appropriate management of reconnected wetlands, and 3) planting of shoreline vegetation. The primary emphasis has been impoundment reconnection with over 22,000 acres of these wetlands reconnected or enhanced. These results bring the total area of impoundments reconnected, breached, or restored Lagoon-wide by all parties to over 27,500 acres. Within SJRWMD, the total District-funded rehabilitation area now exceeds 18,700 acres toward the ultimate goal of 33,000 acres. A major land-acquisition effort is underway to accomplish this goal. Restoration of wetlands impacted by other activities such as dragline ditching is also occurring.

Reconnection by culverts, however, is recognized as only the first step in restoring the ecosystem functions of these impounded wetlands. Appropriate management is critical. Previous research has demonstrated the benefits of reconnecting wetlands to the estuary for fisheries and emergent wetland vegetation, but the benefit to other wetland components is less well documented.

In order to optimize the benefits of reconnection and provide appropriate management, the MINWR staff has been facilitating a broad research effort (now called the Wetlands Initiative at MINWR) led by SJRWMD to directly compare the effects of various restoration and management strategies on a comprehensive list of wetland functions, flora, and fauna. The team has been successful at gathering experts and funding to conduct this 3-5 year study. The Initiative has 18 participating agencies and researchers with major support provided by EPA, USFWS, USGS, NASA, Florida DEP, and SJRWMD.

Mangrove shoreline plantings using the encased planting method are being implement by the Environmental Learning Center. Several thousand mangroves have been planted at 28 sites utilizing over 1700 hours of volunteer labor over the past 5 years.

The Indian River Lagoon Species Inventory:
History, Accomplishments and Future Directions

Kathleen Hill
Smithsonian Marine Station at Fort Pierce

The Indian River Lagoon (IRL) had often been purported to be one of the most diverse estuaries in the United States; however, evidence to support this status was lacking. Following the Biodiversity of the IRL Conference, held in February, 1994, Dr. Hilary Swain and several colleagues, with funding from SJRWMD and the National Estuary Program, compiled a preliminary species inventory for the IRL, listing 2,493 species of plants, animals and protists documented to occur in the IRL, and provided the first documentation of the IRL's high biodiversity. However, comparisons with other locations remain difficult as significant inventories do not exist for all comparable regions.

In 1997, the Smithsonian Marine Station at Fort Pierce became the depository for the IRL Species Inventory in an effort to enhance the utility of the inventory by expanding the taxonomic database with relevant ecological information, and then to make this information easily accessible by means of the Internet. The inventory was converted into database format, with fields added to address life history, occurrence and range, associated species, community ecology, physical tolerances, and endangered, threatened or invasive status. From available ecological data, approximately 40 species narratives were generated on a pilot website to show how biologically relevant information could be dispensed via the Internet. Subsequent funding allowed continued expansion of the IRL Species Inventory and further development of the website as an educational and public outreach tool. To date, an additional 500 species have been added to the masterlist; approximately 210 expanded species reports are available on the website; explanatory materials, common names, and an interactive on-line glossary have been added to promote use by educators and students; and the addition of habitat information allows viewers to browse species information by occurrence within specific habitats.

Though the IRL Species Inventory is now a successful tool for education and outreach efforts, we are interested in increasing its utility as a research tool. We plan not only to fill the gaps in our knowledge for unrepresented and underrepresented groups, but also have the goal of increasing our collaboration with other agencies and educational institutions in order to consolidate species lists, occurrence information and density estimates into a single, cohesive IRL species inventory database. By doing so, the utility and scientific integrity of the IRL Species Inventory will be greatly improved, allowing its continued use not only as a valuable educational and outreach tool; but also as a definitive resource for environmental management and preservation of the vast biodiversity of the IRL.

Agent-based Models of Complex Ecosystems

Dr. George Markowsky
University of Maine

This talk will survey the basic concepts of agent-based computing, and how these concepts can be applied to modeling complex systems of all types, including ecosystems. Some simple tools will be described that can be used for constructing simple models that exhibit complex behavior.

Issues related to database management techniques, integration of heterogenous databases at the structural and semantic levels

Dr. Thomas J. Wheeler
University of Maine

In a number of multidisciplinary research efforts in fields with similar problems to ours, system architecture, abstract interfaces to disparate data sources and data integration have been seen as core problems and a consensus is beginning to emerge on an architecture and techniques to effectively integrate data. A quick overview is that a common architectural view is emerging which structures these systems as distributed federations, using Mediators to integrate each federation's data and Wrappers to hide and transform each data source's data formats and schemes. Technology that is commonly used is XML (and related standards like RDF), agent based systems, ontologies, and object and object/relational databases.

This talk will provide some insight into these problems and identify the important associated issues, provide an overview as to the architecture which shows the most promise to accommodating these issues, and show how some of our research can leverage the above approach to develop the flexible, capable system structure this application needs.

Automated change detection techniques using digital imagery to update geospatial databases

Dr. Anthony Stefanidis & Dr. Peggy Agouris
University of Maine

The automation of object extraction from digital imagery has been a key research issue in digital photogrammetry and computer vision. In the spatiotemporal context of modern GIS, with constantly changing environments and periodic database revisions, change detection is becoming increasingly important. In this paper we present our work on the development of automated change detection techniques to update geospatial databases. We present models and demos from our work on two approaches: differential template matching (most suitable for buildings), and differential snakes (most suitable for roads and other elongated features). These two novel approaches integrate object extraction and image-based geospatial change detection, into a single, fully automated process.

Computational intelligence and its applications in ecological modeling

Dr. Habtom Ressom
University of Maine

Ecological modeling has grown rapidly in the past few decades. Several approaches have been used to build an ecological model, ranging from numerical, mathematical, and statistical methods to biologically inspired computational techniques. This presentation will give a brief introduction to computational intelligence techniques such as artificial neural networks, fuzzy logic systems, and genetic algorithms. Some of the major applications of these techniques will be mentioned including data classification, pattern recognition, function approximation, prediction, process modeling and control. Furthermore, several projects involving computational intelligence in ecological analysis, synthesis, and forecasting will be described. In particular, the use of artificial neural networks for estimating chlorophyll-a concentration from remote sensing data and for developing a primary productivity model will be discussed.

Applications of computational intelligence in biodiversity

Dr. Cristian Domnisoru
University of Maine

The diversity of life forms and their respective distinctive ways of expression and interaction could be reflected at the DNA level. Proteins with similar shapes and identical functions can have different chemical compositions. Also, organisms that look similar to each other can have very different genetic information. It is possible that the key for understanding the biodiversity in general is to be found at the genetic level. We can compare two organisms by their approach in feeding, reproducing, moving in the habitat, raising offspring and other criteria. How do we compare two DNA sequences? A presentation of current techniques for two and multiple sequence alignment and comparison are presented. In particular, a presentation of our DNA database for base calling accuracy assessment is given.

An insight into the comparison problematic is presented. The fact that the same feature in two organisms is similar has the same importance with the case when the same feature is different? From a genetic perspective, the differences between organisms are much less informative than the similarities. How do we incorporate this into a general frame for comparing DNA sequences?

Issues related to applications of computational intelligence are presented. It is known that sampling species' distribution is expensive. What sample size is needed for an accurate modeling? An example from our investigation in DNA base calling modeling is discussed.

An Integrated Modeling System of the Indian River Lagoon

Dr. Y. Peter Sheng
University of Florida

An integrated modeling system, CH3D-IMS, has been applied to the Indian River Lagoon and validated with field data collected in 1998. The integrated modeling system consists of a three-dimensional hydrodynamic model, a wave model, a 3-D sediment transport model, a 3-D water quality model, a light attenuation model, and a seagrass model. The integrated modeling system is linked to the field data through a GIS database of the Indian River Lagoon. Both the framework and the results of the integrated modeling system will be presented. The integrated modeling system can be used to assess the response of the IRL ecosystem to changes in external loading and/or climate.

Final report

BDEI: Planning Workshop on Biodiversity and Ecosystem Informatics for the Indian River Lagoon, Florida

Report of an NSF-funded workshop that examined biodiversity research in the Indian River Lagoon system and the informatics tools and technology applications available to researchers

Held at the DoubleTree Hotel Cocoa Beach, Florida, February 7 - 8, 2002

Sponsored by
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Planning Workshop on Biodiversity and Ecosystem Informatics for the Indian River Lagoon, Florida

EXECUTIVE SUMMARY

In February 2002, a workshop on biodiversity and ecosystem informatics (BDEI) was held in Cocoa Beach, Florida to discuss and plan for meeting the future research goals and technology needs for investigations into the biodiversity, biocomplexity, and ecosystem dynamics of the Indian River Lagoon, Florida, one of the most biologically diverse estuaries in the continental United States. This report synthesizes the discussions and concerns of workshop participants, and lays out a plan for future discussion and direction in the development of integrated ecosystem research, and for continued growth and development of novel BDEI tools that will aid these investigations.

It is increasingly recognized that the stability and health of the environment is dependent upon factors related to the biodiversity and the complexity of ecosystems. Biodiversity and biocomplexity contribute trillions of dollars directly to the global economy via fisheries, forestry, agriculture, ecotourism, drug development, and other means (President's Committee of Advisors 1998, Alonso et al. 2000, Maier et al. 2000, Schnase 2000). Biodiversity also makes indirect economic contributions via plant pollination, air and water purification, modification of the global climate, flood control, nitrogen fixation, storm buffering, and nutrient recycling (Schnase 2000, Alonso et al. 2001, Maier et al. 2001). Advances in computer science and information technology have presented both new opportunities and new challenges as biologists, environmental scientists, resource managers, and policy makers attempt to cope with the increasing need to investigate, understand, and disseminate highly complex ecological and physical processes that are responsible for maintaining biodiversity and biocomplexity in ecosystems.

The Indian River Lagoon (IRL) is part of the longest barrier island complex in the United States, occupying more than 30% of Florida's east coast, from Ponce de Leon Inlet in the Mosquito Lagoon to Jupiter Inlet near West Palm Beach, a distance of approximately 156 miles. A complex mosaic of diverse habitats, including seagrass beds, mangrove forests and *Spartina* marshes; oyster and worm reefs; sand and mud flats; and hard bottoms (coquina limestone), supports unsurpassed biodiversity in the IRL. While the true level of biodiversity in the IRL system is still under investigation, in excess of 3,000 species of plants, animals and protists have been inventoried to date.

There are a variety of public, research, academic and non-profit agencies and institutions that have research interests in the IRL system. Many have compiled long-term datasets, which reflect many years of investigation into organism and population biology, physical processes, and ecology of the IRL. It is recognized among the various organizations that the development of novel approaches to biodiversity research, interagency cooperation, and the sharing of data and metadata can promote synergies among biologists, environmental scientists, computer scientists, information technologists, resource managers and policy makers, and can assist in creating higher-order knowledge that may be easily visualized and presented in a coherent manner. The significance of novel BDEI research tools and new technologies is invaluable to this effort. BDEI offers promise in identifying and addressing complex biological and environmental questions, while simultaneously furthering developments in information technology. Through the use of informatics tools, stakeholders may begin to compile, compare, and integrate disparate datasets,

overcoming problems with spatial and temporal scales, data formats, standardization, taxonomic conventions, terminology and other factors.

Twenty-five researchers representing a diversity of fields participated in the workshop. Biologists, ecologists, resource managers, and systematists came together with specialists in remote sensing, spatial information systems, computer sciences, and intelligent systems to discuss the opportunities and challenges of applying informatics tools and techniques to ongoing and future ecological research centering on the IRL. Ecological topics discussed included an examination of the spatial heterogeneity of ecological resources in the IRL; regional geomorphology; social and physical factors that affect the IRL ecosystem; coastal wetlands; changes in seagrass coverage with changes in land use; species inventories; taxonomic issues in data collection and presentation; tools and issues surrounding data storage and use; and the types of biological and physical data available to the research community. Informatics topics presented included methods for integrating heterogeneous datasets; tools and methods for automated change detection; digital imagery; geospatial databases; analysis and modeling of ecosystem processes using fuzzy logic, neural networks and other algorithms; statistical approaches to ecosystem modeling; and agent-based data collection and processing.

Three areas of synergy between biological/environmental science and computer science/ information technology were addressed in sub-group discussions: acquisition and conversion of data and metadata; analysis and synthesis of data and metadata; and dissemination of data and metadata. Some of the specific topics addressed by the sub-groups included:

Acquisition of Data and Metadata

- Assessing the relevance of available IRL datasets and identifying their availability and accessibility to the wider research community.
- Improving methods for collecting, organizing and archiving data.
- Digitizing conventional IRL data, especially any long-term datasets and imagery that exist, for simplified storage and improved accessibility via the Internet.
- Improving methods for incorporating taxonomic change into existing datasets.
- Improving the ability to integrate existing heterogeneous datasets across agencies by implementing or improving data and metadata standards.
- Addressing knowledge gaps in the currently available datasets with respect to the geographic area or phenomena particular to the IRL.
- Implementing ontology and structure for the data.
- Utilizing efficient remote sensing techniques for data acquisition, including but not limited to underwater remote sensing.

Analysis and Synthesis of Data and Metadata

- Identifying the major forcing functions of biodiversity in the Indian River Lagoon at multiple spatial and temporal scales.
- Identifying the long-term trends in biological data and formulating functional relationships.
- Performing efficient spatiotemporal analysis of datasets.

- Developing an integrated model or set of models to link physical, chemical, biological, social and economic processes at multiple scales for predicting and forecasting changes in biological diversity.
- Linking informatics tools with process-based models.
- Exploring the application of advanced informatics tools (neural networks, artificial intelligence (AI), change analysis, etc.) to improve process-based simulation/forecasting.
- Exploring applications of advanced computing power and distributed computing.
- Applying advanced visualization techniques to enhance usability of research results by scientists, policy makers and the public.

Dissemination of Data and Metadata

- Enhancing inter-institutional cooperation in order to facilitate data sharing and integration through the use of the Internet, collaboration and communication between organizations that are stakeholders in IRL research.
- Developing clear protocols for how data may be accessed and utilized by participating agencies.
- Developing work groups for determining standards for data and metadata collection.
- Developing web-based applications for integration of data and metadata from various sources.
- Creating a web-based directory of researchers and their areas of expertise.
- Visualizing a consortium of various users with access to summary data, or narrative summaries rather than actual data.

Conclusion

The primary result from the various presentations and discussions was to create a methodological avenue to integrate methods of ecological data collection with informatics tools and protocols in order to address some of the important questions focusing on the biodiversity of the IRL. Based on the outcomes of both formal and informal discussions at the workshop, members of the biological community are in the process of exchanging data collected from the IRL with researchers from computer science, spatial information and intelligent systems in order to facilitate more effective and efficient data management, visualization, modeling, analysis and synthesis. A series of short and long term goals for future research and collaboration is presented in the later sections.

Although there are many disparate data sets for the IRL area that lie within the purview of the local, state and federal agencies, universities, and some private organizations, at least three areas emerged from the workshop as being readily appropriate for informatics techniques. These are 1) the biological and taxonomic dataset from the Indian River Lagoon Species Inventory, maintained by the Smithsonian Marine Station at Fort Pierce, 2) ichthyological data from long-term IRL studies maintained by NASA KSC/Dynamac Corporation, and 3) long-term submerged aquatic vegetation data and water quality data of the St. Johns River Water Management District, South Florida Water Management District, and NASA KSC/Dynamac Corporation. These data are of the spatial and temporal extent compatible for application of informatics analysis techniques.

Table of Contents

I. INTRODUCTION

A workshop on biodiversity and ecosystem informatics (BDEI) was held in February 2002 at the Doubletree Hotel in Cocoa Beach, Florida. The purpose of this workshop was to provide the necessary venue and resources to foster synergistic interdisciplinary collaboration required to advance research into biodiversity and ecosystem dynamics of the Indian River Lagoon (IRL), Florida by using novel techniques in informatics. Twenty five researchers from diverse fields of biological sciences, ecological sciences, remote sensing, spatial information systems, computer sciences, and intelligent systems met to identify and discuss the issues and challenges facing the long-term sustainability of the IRL ecosystem, and explored the possibilities of applying computational intelligence and data management techniques to these problems. A major tenet of the workshop was that the wealth of ecological information that exists for the IRL can and should be integrated into regional land-use and estuarine management models. This report summarizes the discussions and recommendations made at the workshop. For additional information about the workshop please visit: http://www.intsys.maine.edu/bdei/workshop.html.

A. BACKGROUND

The Indian River Lagoon (Fig. 1), Florida, is one of the nation's most biologically diverse estuarine systems, providing habitat for thousands of different species of animals and plants, some of which are rare, threatened, or endangered. The IRL system is a shallow mesohaline estuary, which actually consists of 3 lagoons: the Mosquito Lagoon which originates in Volusia County, the Banana River in Brevard County, and the Indian River Lagoon, which spans nearly the entire coastal extent of Brevard, Indian River, St. Lucie and Martin Counties. The IRL occupies more than 30% of Florida's east coast, extending 253 km (156 miles) from Ponce de Leon Inlet in the Mosquito Lagoon (latitude 29 degrees 05 minutes N) to Jupiter Inlet near West Palm Beach (26 degrees 58 minutes N). The feature that helps distinguish the IRL system from other estuarine systems, and also accounts for much of its high biological diversity, is its unique geographical location, which straddles the zone of overlap between the temperate Carolinian, and the subtropical Caribbean biological provinces. Thus, the northern reaches of the IRL, from Ponce Inlet to approximately Cape Canaveral are significantly more temperate in nature, while its southern reaches, from Cape Canaveral south to Jupiter Inlet, are subtropical to tropical. In the IRL then, as perhaps nowhere else in the continental United States, temperate and tropical species coexist and thrive.

The coastal area in the vicinity of the IRL system has one of the highest human population growth rates within the United States, due to both natural increase and migration. United States Census Bureau data show that between 1990 and 2000, the population of Florida grew by more than 3 million people, a 23.5% increase over 10 years. This figure equates to a staggering increase of 834 people per day being born in, or moving to the State of Florida. The Florida Demographic Summary states that when census demographics are further examined, natural increase in the population accounts for only 14.7% of the total, while migration of new residents accounts for 85.3%, or 711 people per day. It should also be noted that this figure represents new permanent residents only; seasonal residents and tourists are excluded from census totals, yet certainly impact the environment of the IRL system. Approximately 70 million tourists visit the state of Florida each year, influencing both the economy and natural resources of the region.

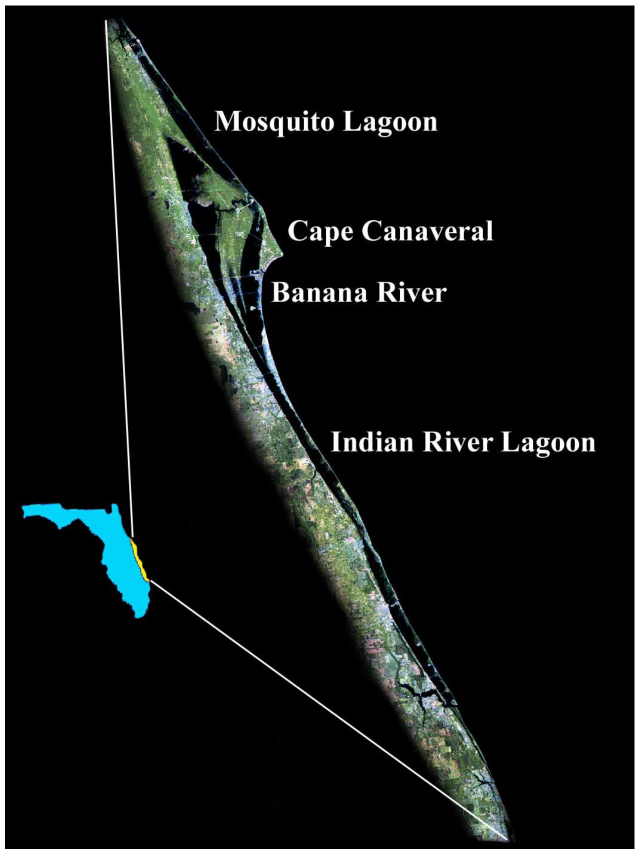

Figure 1: The geographical location of the Indian River Lagoon system in east central Florida

The lagoonal system has thus come under extraordinary pressures from anthropogenic impacts. Impoundment of wetlands for mosquito control, habitat loss and fragmentation due to development, freshwater inputs from stormwater management practices, surface water runoff, nutrification from point and non-point sources, inputs of chemicals and pathogens from both agricultural practices and urban development, and the introduction of invasive species are some of the many environmental problems and challenges that affect biodiversity and ecosystem processes within the IRL system. The problem for researchers, resource managers and policy makers thus becomes one of how to maintain and conserve the vast biodiversity of the IRL ecosystem in the face of ever-increasing population growth and development pressures.

The 5 counties bordering the IRL receive tremendous economic benefit from its presence. Commercial and recreational activities around the immediate vicinity of the IRL support approximately 20,000 jobs and generate over $250 million dollars in annual income. Citrus agriculture in the IRL accounts for over 2 billion dollars per year, while recreational activities such as boating, fishing, water sports, hunting and ecotourism generate approximately $465 million dollars annually. Commercial fishing enterprises in the IRL and along the Florida coast generate approximately $150 million dollars in revenues, and account for nearly 15% of the national fish and shellfish harvest. Real estate leasing and sales along the lagoon account for over $825 million dollars in annual revenue (St. Johns River Water Management District, unpublished).

Much of the northern portion of the IRL lies within Kennedy Space Center (KSC) and Cape Canaveral Space Launch Complex operated by NASA and the U.S. Air Force. This area is also the site of the Merritt Island National Wildlife Refuge (MINWR) and Canaveral National Seashore. The central and southern portions of the IRL include Pelican Island National Wildlife Refuge (the first refuge in the National Wildlife Refuge System); Archie Carr National Wildlife Refuge, which was set aside to protect one of the largest populations of nesting sea turtles in the world; numerous Florida State Parks, as well as many public beaches and small reserves. Additionally, each of the 5 counties within the IRL region has implemented successful, voter-approved land acquisition programs that have established an exceptional natural areas network along the IRL and its tributaries. The IRL has also been named as an Estuary of National Significance by the Environmental Protection Agency's National Estuary Program (NEP). The focus of the NEP is to ensure the health and diversity within estuaries by partnering with numerous municipalities and counties to address the common challenges faced in virtually all estuarine systems: excessive nutrient, pathogen, and chemical inputs, habitat loss and degradation, introduction of exotic species, and alterations of natural flow regimes. The National Oceanographic and Atmospheric Administration has also nominated the IRL as a National Estuarine Research Program site.

Researchers at Kennedy Space Center (KSC), the Smithsonian Marine Station at Fort Pierce, St. Johns River Water Management District, The Army Corps. of Engineers, South Florida Water Management District, Florida Marine Research Institution, Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission, as well as numerous academic institutions and other agencies have developed impressive datasets addressing many areas of concern in the IRL. Many of these datasets reflect long-term ecosystem monitoring that addresses change in lagoonal species and environmental conditions over time; while others address environmental changes and ecosystem dynamics. A closer examination of the research collection of just one of these organizations highlights the importance of collaboration, data integration, and inter-agency cooperation. KSC, for example, has compiled environmental data collected equivalent cumulatively to a period of over 200 years. These data include biotic and abiotic parameters, with associated metadata. Some of the biotic data include long-term vegetation data, herbarium collections, long-term submerged aquatic vegetation data collected by St. Johns River Water Management Districts and KSC/Dynamac Corporation, wetlands data, Florida manatee population studies, sea turtle nesting success and density data, lagoonal fish population studies, radio tracking data of gopher tortoise and indigo snake habitat utilization, and wading bird population studies. Some of the abiotic data include rain chemistry, air quality, long-term water quality, soil chemistry, groundwater well chemistry, long-term rocket launch exhaust depositional patterns, meteorological conditions, solid waste management sites numerous remotely sensed landscape data. All the metadata entered into the KSC database possesses detailed documentation. Those data that are defined as thematic or athematic adhere to the Federal Geographic Data Committee's (FGDC) metadata standards. Additionally, the Earth Systems Modeling and Data Management Laboratory at KSC maintains an archive of aerial imagery extending from 1943, and supports numerous online thematic and athematic data.

Other organizations have accumulated equally impressive data sets that help define the IRL system's biodiversity and ecosystem processes. However, the different goals and responsibilities of each organization have resulted in differences in the methodology and focus of the data collected. Within each organization, data are acquired at different temporal and spatial scales by numerous investigators, and exist in many formats. Among organizations, data is stored in a variety of formats, from text, spreadsheets, desktop databases such as Microsoft Access, Oracle tables, SAS, satellite images, aerial photos, as well as other data formats. Further, data are commonly stored and maintained in stand-alone systems, each having its own standards, vocabulary, syntax, scale and associated metadata. One notable exception is the 30-year Indian River Lagoon and statewide cetacean stranding database assembled and archived by Hubbs-SeaWorld Research Institute (HSWRI). These stranding data are provided to HSWRI in standard National Marine Fisheries Service (NMFS) data format by marine mammal stranding teams authorized by NMFS. In 2000, HSWRI developed the "*Indian River Lagoon Dolphin Stranding Information System*" to quality control the historical data, standardize methodology of data synthesis, develop IRL GIS maps, enhance interagency communication and reporting and provide a framework for data analysis.

While each stakeholding organization has devoted considerable research effort into developing the tools to interpret and model ecosystem processes, there remains a strong need to develop the robust informatics tools that will assist agencies in collaborations to integrate, analyze, synthesize and interpret their widely disparate datasets. In order for IRL researchers to truly understand the ecosystem dynamics affecting biodiversity in the system, they must first overcome current problems in acquisition, use and long term archiving, integration, analysis, synthesis, and visualization of the data.

Novel informatics tools are promising for effectively researching and managing the vast biodiversity of the IRL. Informatics tools will provide some of the resources needed to support ecological forecasting and will assist IRL researchers in generating higher-order knowledge from the vast amounts of data they have collected, thus allowing them to address more effectively issues such as species population dynamics and habitat loss, effects of invasive species, effects of global change on ecosystem processes, and restoration of lost or degraded habitats.

B. WORKSHOP ORGANIZATION

The BDEI workshop was organized in both presentation and discussion format. The chair, in his opening remarks, highlighted the main objectives of the workshop and solicited presenters to identify research problems addressed by their individual organizations, their significance to the IRL ecosystem, current approaches used, and the fundamental issues which confront their research with respect to data collection, retrieval, visualization, analysis, synthesis, management and modeling. Plenary sessions were designed such that IRL researchers could describe the scope of research undertaken by their various organizations, and outline their needs for informatics tools and technology. Speakers addressed key issues affecting biodiversity and ecosystem dynamics of the Indian River Lagoon and identified areas where the application of novel computational intelligence, spatial information, remote sensing and data management techniques could assist in resolving some of these issues. The attached workshop schedule and abstracts list the details regarding individual presentations and organizational concerns.

II. Topics

The topics presented by the speakers were divided into two main categories: those related to the biological and ecological aspects of the IRL system and those related to information sciences.

A. BIOLOGICAL AND ECOLOGICAL TOPICS

There were 8 presentations addressing different biological and ecological aspects of the Indian River Lagoon (IRL) system. These included the following topics:

- The aquatic diversity, regional geomorphology, biogeographical transition zones, and spatial heterogeneity of the IRL area, including those areas, which can be viewed as biodiversity "hotspots".
- Biocomplexity within the IRL system, with a focus on the human factors involved in managing for the sustainability of biodiversity resources within the IRL.
- The types of data and metadata available in historic collections, such as those of natural history museums, academic institutions and personal research collections; and the value of digitizing this information in order to make it accessible to researchers on the Internet.
- The tools and methodologies used in taxonomy and systematics, including the value of systematic collections to the study of biodiversity.
- An examination of the physical processes which drive geomorphology, spatial heterogeneity, and temporal dynamics within the IRL, and how these processes in turn affect biodiversity and species distribution within the system.
- A long-term overview of how seagrass coverage within the IRL has changed in conjunction with changes in land use, development, water quality, and sedimentation rates.

- An overview of the IRL species inventory: its history, methods, database organization, knowledge gaps, web development, and potential as a research and educational tool.
- An examination of the state of coastal wetlands in the vicinity of the IRL following alteration (impoundment) of these wetlands for mosquito control, and agency attempts at rehabilitation and restoration following opening and reattachment of impounded areas.

A running theme throughout the presentations was that while a great deal of data has been acquired to define the IRL system's biodiversity and ecosystem processes, the data were collected by different researchers exist at different temporal and spatial scales and are stored in disparate formats. The available datasets lie within the purview of local, state and federal agencies, universities, and some private organizations. Speakers pointed out problems they encounter with data accessibility and retrieval for process-oriented research. They presented their views on the future directions needed for effective dissemination and centralization of data and stressed the need for development of new predictive tools for risk assessment, analysis, and ecological forecasting.

B. INFORMATION SCIENCES TOPICS

There were 6 presentations that focused on informatics techniques that could be effectively applied to existing datasets for the Indian River Lagoon. The topics included:

- Various methods for utilizing computational intelligence in modeling complex ecosystems.
- Integration of heterogeneous data at structural and semantic levels.
- Automated change detection techniques using digital imagery to update geospatial databases.
- Analysis and modeling of ecosystem processes using neural networks, fuzzy systems, and genetic algorithms.
- Integrated modeling and synthesis of complex ecosystems using statistical approaches, agent based models and intelligent information processing techniques.
- A newly developed three-dimensional model of the IRL ecosystem that integrates characteristics such as hydrodynamics, waves, sediment transport, water quality, light attenuation, and seagrass distribution.

Several examples were given to show how computational intelligence could be effectively utilized in collecting and analyzing biodiversity and ecological data; and further, how these computational tools could be applied in visualizing data, synthesis of data, and in forecasting. An integrated modeling system incorporating a three dimensional hydrodynamic model, a wave model, a 3-D sediment transport model, a 3-D water quality model, a light attenuation model and a sea-grass model for the Indian River Lagoon was described. In addition, DNA sequencing algorithms were also explored as a potential aid in addressing taxonomic conflicts and identification issues for different species.

III. SUMMARY OF DISCUSSIONS

The workshop was useful in opening avenues of collaboration between researchers from diverse fields to advance research into biodiversity and ecosystem dynamics of the IRL. Participants from each group were able to gain an understanding of the specific areas in which informatics tools and methods could be employed in addressing specific IRL research needs. Participants agreed that computational intelligence techniques such as neural networks, fuzzy logic, and genetic algorithms would provide insight into identifying and understanding underlying patterns in data that would reflect temporal and spatial dynamics pertinent to real ecological patterns/processes inherent in the IRL ecosystem. They were also able to identify within their own areas of expertise where the application of intelligent processing systems could prove valuable, particularly in expanding ecosystem models of the IRL that incorporate physical, chemical, biological and socioeconomic factors into an integrated assessment tool.

Although there are many disparate data sets for the IRL area that lie within the purview of the local, state and federal agencies, universities and some private organizations, at least three areas emerged as being readily appropriate for informatics techniques. These are 1) the biological and taxonomic dataset from the Indian River Lagoon Species Inventory, maintained by the Smithsonian Marine Station at Ft. Pierce, 2) ichthyological data from long-term IRL studies maintained by NASA KSC/Dynamac Corporation and 3) long-term submerged aquatic vegetation data and water quality data of the St. Johns River Water Management District, South Florida Water Management District, and NASA KSC/Dynamac Corporation. These data are of the spatial and temporal extent compatible for application of informatics tools.

A. GROUP SUMMARIES AND RECOMMENDATIONS

On a national level, the Biodiversity and Ecosystems Panel of the President's Committee of Advisors on Science and Technology (PCAST) recognized in their 1998 report, "*Teaming with Life: Investing in Science to Understand and Use America's Living Capital",* the urgent need to improve the national biological information infrastructure (NBII) and promote the development of a next-generation of systems able to maximize use of and openly share information generated by biodiversity and ecosystems research. With this goal in mind, 3 main focus areas were chosen for discussion: 1) Acquisition and Conversion of Data and Metadata; 2) Analysis and Synthesis of Data and Metadata; and 3) Dissemination of Data and Metadata. Work groups discussed the current problems in the format of the collected data, methods of data collection, data analysis and the need for effective dissemination of the data from the Indian River Lagoon, and formulated their recommendations for future discussion and planning. The working groups recognized that biodiversity and ecosystems data are developed in response to particular research needs and goals, and that there are many logistical challenges to overcome in promoting collaboration and data integration among agencies and institutions. However, as it is recognized that the complexity of biodiversity and ecosystems dynamics are reflected in the vast amounts of research undertaken and archived annually, it is also recognized that the development of novel approaches to data collection, integration and analysis will be vitally important to our ability to create higher-order knowledge from raw data. The salient points of discussion are outlined below.

1. Acquisition and Conversion of Data and Metadata

The objective of this group was to examine the research needs for improved data collection methods, and to propose effective recommendations for future data collection techniques, centralization and accessibility. Much of the data for the Indian River Lagoon is collected by state, federal, academic and private institutions. Many of these organizations have accumulated large volumes of biological information and data, sometimes over long time periods. Improved methods for organizing, storing and retrieving these records are extremely critical. There is a need to convert data and documentation into metric-quality digital formats. New techniques are needed in collecting data from the field and also to collect, store and transmit data from the field. Taxonomic data present a particular challenge to utilizing historic records, as much species-specific information may not be readily identifiable due to changes in species names and taxonomy. There is also a need to improve research productivity by integrating different versions of available data in a simplified format. The recommendations of Group 1 are listed in the following action items:

- **Assess the types and relevance of available IRL datasets, and identify their availability and accessibility to the wider research community:** Individual organizations collect data in the IRL that are specific to the needs of their respective research and management goals. In promoting synergistic opportunities and data sharing among research organizations, it is necessary to assess the relevance of individual datasets and determine their value in addressing biodiversity research in the IRL. Comprehensive datasets addressing biodiversity and ecosystem dynamics could then be made available to other members of the research community.
- **Improve methods for collecting, organizing and archiving data:** A fundamental objective in studying biodiversity and ecosystem informatics is to create a degree of higher-order understanding and knowledge from disparate datasets. IRL data and metadata has been collected over the course of many years by a wide variety of research organizations, each having its own individual data requirements and uses. A need exists to improve data and metadata standards to improve the usability of integrated data within and between agencies.
- **Convert historical data into digital format** Much of the biodiversity and ecosystem information for the IRL is housed in non-digital formats such as paper journal articles, books, unpublished manuscripts, field notes, agency reports, and imagery. Our knowledge of ecosystem dynamics in the IRL will be vastly improved as the formats of these informational infrastructures are upgraded to digital formats. This process may be especially true for historical aerial photographs of the IRL, which show changes in land use, development patterns, seagrass cover, and watershed change over time.

- **Improve methods for integrating taxonomic changes into datasets:** As our knowledge of particular species evolves over years of investigation, distinct species have often been merged together or split into several new species. Unfortunately, data management practices, particularly those associated with non-digital data, have not kept pace with taxonomic changes. Thus, historical datasets will require further processing before they can reflect current naming conventions and taxonomic modifications.
- **Improve data and metadata standards:** In developing collaborations among institutions and agencies, developing common standards for data and metadata collection must be addressed. Common data standards will improve the ease with which data may be extracted or shared; will speed data processing time, and will facilitate the integration of disparate datasets, overcoming problems with spatial and temporal scales, data formats, standardization, taxonomic conventions, semantics, and other factors.
- **Address knowledge gaps in available data and metadata:** Once a common data/metadata collection and storage strategy is developed, it must next be applied to historical datasets, with researchers filling in knowledge gaps in the data structure where possible in order to facilitate data sharing and extraction.
- **Implement ontology and structure for the data:** New technologies will demand the institution of new methods in collecting and analyzing data. In the development of these technologies, it is essential that the needs of all stakeholders (scientists, resource managers, policy makers, and the public) be addressed in order to maximize the value and relevance of the data to all concerned.
- **Utilize efficient remote sensing techniques for data acquisition:** Institutions and agencies performing biodiversity and ecosystems research in the IRL will undoubtedly be capturing physical and geographical data. The use of efficient remote sensing and agent-based technologies will aid researchers not only in improving the quality and accuracy of data collected, but will also assist in eliminating problems of scale, measurement, and standardization among agencies wishing to collaborate.

2. ANALYSIS AND SYNTHESIS OF DATA AND METADATA

Due to the diverse nature and expanse of IRL data, integrated information is essential for a comprehensive understanding of the patterns and ecological processes affecting the biodiversity of the IRL. Biologists and ecologists concerned with understanding biodiversity do not often have the luxury of exploring single aspects of species biology. Biodiversity and the processes that affect it span a number of interdisciplinary areas: anthropogenic factors, physical factors, reproductive factors, physiological factors, behavioral factors etc. To address these issues and how they affect biodiversity and ecosystem functioning, scientists have collected vast amounts of data, and are regularly challenged to forecast change, perform risk analysis, and predict results. It is essential then that adaptive technological processes be developed to assist in these efforts. The evolution from data to information to knowledge is only possible through effective data management and improvements in computational technology. The recommendations of Group 2 are listed in the following action items.

- **Identify the major forcing functions of biodiversity in the Indian River Lagoon:** An understanding of the driving forces operating within the IRL and how they affect biodiversity is essential before we attempt to build the next generation of infrastructure that will measure and model these forces. This requirement must be addressed at different spatial and temporal scales, and include methods or standards for validating model outcomes. In this way, integrated models which link physical, chemical, biological and socioeconomic processes can be developed to forecast changes in biodiversity within the IRL.
- **Identify long-term trends in biological data and formulate functional relationships:** Examinations of existing datasets must be performed in order to identify any apparent trends in the data. Where found, these trends should be further examined to determine if valid cause-effect relationships can be drawn between biological observations and physical, chemical, hydrological, or other processes. This knowledge can then be modeled and considered throughout the course of future research.
- **Perform efficient spatiotemporal analysis of datasets:** Effective methods of integrating and interpreting spatiotemporal data can be applied to existing datasets in order to give researchers a comprehensive overview of change through time in the IRL system. This will allow older records to be meaningfully compared with newer records, and will increase the record of documentation of observed changes in the IRL.
- **Develop integrated models:** An integrated model, or set of models that link physical, chemical, biological, social and economic processes at multiple temporal and spatial scales will allow for effective prediction and forecasting of the environmental changes that affect biological diversity.
- **Improve process-based simulation/modeling through the development of advanced informatics tools:** The use of computational intelligence techniques such as neural networks and fuzzy systems, offer great promise in allowing researchers to improve existing models and explore new questions surrounding ecosystem dynamics and biodiversity.
- **Explore applications of advanced computing power and distributed computing:** Some of the large datasets and ecological models that may be useful in addressing any number of research questions could be easily managed through the use of more powerful computers and distributed computing. Use of advance computational technologies will make it possible for researchers to examine increasingly vast amounts of information in relatively short periods of time.
- **Apply advanced visualization techniques to enhance usability of research results:** The usefulness of datasets, imagery, field observations and experimental results is in part determined by how they are presented. Scientists, resource

managers, policy makers and the public may all benefit from the use of advance techniques that allow for better visualization of data and experimental results.

3. DISSEMINATION OF DATA AND METADATA

Resource managers, policy makers, educators, non-governmental organizations, industry and others require visualization of natural processes and management actions over time in order to better understand biodiversity and ecosystem data and the various relationships among data. The objective of this group was to offer suggestions to better characterize the needs and requirements of data users; to provide data management guidelines and improve avenues of interdisciplinary communication among scientists, resource managers, decision makers and the general public; and to investigate methods of sharing various resources that would enable collaborative research, not only among various members of the biological community, but also among biologists, ecologists and researchers from computer science, spatial information, remote sensing and intelligent systems. The recommendations of Group 3 are listed in the following action items:

- **Enhance inter-institutional cooperation:** Facilitating collaboration, data sharing, and data integration among the various stakeholding agencies responsible for researching and managing biodiversity in the IRL could be much more easily accomplished through the use of informatics tools and technologies. Use of the Internet is one obvious avenue through which collaboration and communication between organizations can be enhanced, and data shared.
- **Develop clear protocols for data use and sharing:** In laying the groundwork for inter-agency cooperation and data sharing, clear protocols must be developed which outline how data may be accessed and utilized by participating agencies. Task forces that are assembled at the onset of new collaborative efforts could most easily address the logistical issues involved in data sharing.
- **Develop work groups for determining standards for data and metadata collection**: Data management guidelines that include standards for data and metadata are essential to effective data sharing. In order to be optimally meaningful, datasets that are to be shared among institutions must also share a common frame of reference for data and metadata. Agencies interested in collaboration and data sharing should establish work groups to identify a common data structure for future research efforts, and investigate ways to bridge the use of different data standards, semantics, scaling and spatial references in disparate datasets.
- **Develop web-based applications for integration of data and metadata from various sources:** Use of the Internet and the development of web-based applications will be invaluable in the integration of various datasets housed and maintained by the various agencies that perform IRL biodiversity and ecosystem dynamics research. In this manner, agencies and institutions would be minimally impacted by decisions to share data with other agencies. Institutions would

continue to store and update their individual datasets, while simultaneously making them available to a consortium of users via the Internet.

- **Create a web-based directory of researchers and their areas of expertise:** In developing interdisciplinary workgroups and collaborations among agencies, it will be helpful from the outset to identify the specific research areas of the staff involved. Thus, as research plans are developed, personnel from one institution could consult with staff from other institutions who may be familiar with the types of research questions being investigated. Use of this process may also help diminish duplication of effort among agencies.
- **Visualize a consortium of various users with access to data**: As agencies consult with one another to identify common areas where data sharing and research collaboration may be helpful, it will also be necessary to build the computing infrastructure that will make collaboration as simple as possible. Building a web-based application that would allow users from various agencies access to data and publications would facilitate this process. It can be foreseen that a consortium of users interested in many aspects of IRL research and results would also have many different technology requirements. Biologists and other researchers developing informatics tools, for example, would need to access raw data; resource managers might require data summaries or research reports explaining experimental results; and policy makers may require only an executive summary. Casual browsers could also be admitted to the system to access data summaries, or narratives that explain research or experimental outcomes.

IV. CONCLUSION

Presentations and discussions from the workshop were valuable in identifying the important research issues central to improving our knowledge of the IRL, its biodiversity, and ecosystem dynamics. The workshop brought together researchers from biological and ecological sciences, remote sensing, spatial information, computer science and intelligent systems from different agencies, universities and organizations. Perhaps for the first time, biologists and ecologists were introduced to novel technologies and methods useful in studying biodiversity, and were given the opportunity to foresee how these technologies could be applied to their own research. The workshop also created preliminary methodological avenues useful in addressing both research questions and the possible informatics applications that could be applied. Based on the recommendations of participants, biologists and ecologists will soon be providing IRL datasets to other researchers from computer science, spatial information and intelligent systems who will begin the development of robust informatics tools which will assist researchers in effective data collection, management, analysis, synthesis, and ecosystem modeling.

Full implementation of the research agenda for furthering our knowledge of the biodiversity and ecosystem dynamics of the Indian River Lagoon will require a number of commitments and much planning. Some of the short and long term action items that will further these efforts are:

- Definition of a clear research agenda for investigating IRL biodiversity and ecosystem dynamics.
- Securing a commitment from researchers to a highly coordinated, long-term IRL monitoring and research effort.
- Identification of research needs and data/metadata requirements.
- Coordination among agencies and institutions and centralization of IRL data availability and access.
- Development of multi-disciplinary planning and working groups to encourage collaboration and research.
- Integration of socioeconomic and sociopolitical considerations into scientific research initiatives and data collection.
- Development and testing of innovative models that integrate various facets of IRL ecosystem dynamics, biodiversity considerations, and other factors.
- Development of improved or novel technologies to improve ecological forecasting.
- Identification and procurement of adequate funding and the potential to leverage resources in order to drive this effort.

V. WORKSHOP COMMITTEE

Chair

- Dr. Mohamad Musavi, Intelligent Systems Laboratory, Department of Electrical and Computer Engineering, University of Maine, Orono.

Organizing Committee and Collaborators

- Dr. Richard Miller and Dr. Greg Carter, NASA Stennis Space Center, Mississippi.
- Dr. Ross Hinkle and Dr. R. Grant Gilmore, Dynamac Corporation, Kennedy Space Center, Florida.
- Dr. Anson Hines, Smithsonian Environmental Research Center, Edgewater, Maryland.
- Dr. Bjorn Tunberg and Kathleen Hill, Smithsonian Marine Station, Fort Pierce, Florida.
- Dr. Habtom Ressom, Dr. Cristian Domnisoru, and Padma Natarajan, Intelligent Systems Laboratory, Department of Electrical and Computer Engineering, University of Maine, Orono, Maine.
- Dr. George Markowsky and Dr. Thomas J. Wheeler, Department of Computer Science, University of Maine, Orono, Maine.
- Dr. Anthony Stefanidis, National Center for Geographic Information and Analysis, Department of Spatial Information Science and Engineering, University of Maine, Orono, Maine.

Workshop Coordinators

- Padma Natarajan, Dr. Habtom Ressom, and Dr. Cristian Domnisoru, Intelligent Systems Laboratory, University of Maine, Orono.
- Kathleen Hill, Smithsonian Marine Station, Fort Pierce, Florida.

VI. WORKSHOP PARTICIPANTS

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Dr. Robert Day St. Johns River Water Management District Indian River Lagoon Program 525 Community College Parkway SE Palm Bay, FL, 32909	Dr. Mary Rice Smithsonian Marine Station at Fort Pierce 701 Seaway Drive Ft. Pierce, FL 34949
Dr. Duane De Freese Hubbs-SeaWorld Research Institute 6295 Sea Harbor Drive Orlando, FL, 32821-8043	Dr. Peter Sheng University of Florida Coastal and Oceanographic Engineering Department Gainesville, FL 32611-6590
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VII. WORKSHOP SCHEDULE

BDEI WORKSHOP

Biodiversity and Ecosystem Informatics
for the Indian River Lagoon, Florida

February 7 – 8, 2002
Cocoa Beach, Florida

Workshop Schedule:

Thursday Feb. 7:

7:00 – 8:00 a.m. Continental Breakfast
8:00 – 8:30 a.m. Registration

SESSION I:

8:30 – 8:45 a.m. Welcome, conference goals. Dr. Mohamad Musavi
8:45 – 9:15 a.m. "Evolution of regional biocomplexity: aquatic diversity "hot spots", community patchiness along physical gradients." Dr. Grant Gilmore
9:15 – 9:45 a.m. "Understanding the biocomplexity of the Indian River Lagoon system – bridging the gap to sustainability." Dr. Ross Hinkle, Dr. Duane De Freese
9:45 – 10:15 a.m. Discussion
10:15 – 10:30 a.m. Tea/Coffee Break

SESSION II:

10:30 – 11:00 a.m. "Biodiversity informatics: natural history collections, natural history data." Dr. Anna Weitzman
11:00 – 11:30 a.m. "The value of systematic collections in biodiversity studies." Dr. Paula Mikkelsen
11:30 – 12:00 noon Discussion
12:00 – 1:00 p.m. Lunch Break

SESSION III:

1:10 – 1:25 p.m. "Spatial heterogeneity in the Indian River Lagoon: driving forces." Dr. Robert Virnstein
1:25 – 1:50 p.m. "Long-term and short-term seagrass change versus land use change." Dr. Robert Virnstein
1:50 – 2:05 p.m. "IRL coastal wetland rehabilitation and collaborative research to improve management." Ronald Brockmeyer
2:05 – 2:35 p.m. "The Indian River Lagoon species inventory: history, accomplishments and future directions." Kathleen Hill

2:35 – 3:00 p.m.	Discussion
3:00 – 3:10 p.m.	Tea/Coffee Break

SESSION IV:

3:15 – 3:50 p.m.	"Agent-based models of complex ecosystems." Dr. George Markowsky
3:50 – 4:15 p.m.	"Issues related to database management techniques: integration of heterogeneous databases at the structural and semantic levels." Dr. Thomas Wheeler
4:15 – 4:45 p.m.	"Automated change detection techniques using digital imagery to update geospatial databases." Dr. Anthony Stefanidis, Dr. Peggy Agouris
4:45 – 5:00 p.m.	Discussion
7:00 p.m.	Banquet

Friday Feb. 8:

7:00 – 8:00 a.m.	Continental Breakfast

SESSION I:

8:00 – 8:45 a.m.	"Computational intelligence and its applications in ecological modeling." Dr. Habtom Ressom
8:45 – 9:15 a.m.	"Application of computational intelligence in biodiversity." Dr. Cristian Domnisoru
9:15 – 10:15 a.m.	Discussion
10:15 – 10:30 a.m.	Tea/Coffee Break

SESSION II:

10:30 – 11:00 a.m.	"An integrated modeling system of the Indian River Lagoon." Dr. Peter Sheng
11:00 – 11:30 a.m.	TBA
11:30 – 12:00 noon	Discussion
12:00 – 1:00 p.m.	Lunch Break

SESSION III:

1:10 – 3:00 p.m.	Discussion
3:00 – 3:15 P.M.	Tea/Coffee Break

SESSION IV:

3:15 – 4:00 p.m.	Research agenda formulation
4:00 p.m.	Closing remarks. Dr. Mohamad Musavi

VIII. REFERENCES

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IX. ABSTRACTS

Evolution of regional biocomplexity: Aquatic diversity " Hot Spots", community patchiness along physical gradients

Dr. R. Grant Gilmore, Jr.
Dynamac Corporation, Kennedy Space Center
&
Dr. Anson H. Hines, Jr.
Smithsonian Environmental Research Center

The Indian River Lagoon (IRL) system of east central Florida has been recognized as containing the richest aquatic biota within the United States. To date 289 aquatic plant species, 555 protists, 1,785 animal species have been recorded from the Lagoon and its oligohaline tributaries. The 2,629 species of aquatic organisms are not distributed evenly throughout the entire ecosystem. There are broad biogeographical transitions along the 233 km axis of the Lagoon with distinct changes from numerical dominance of tropical species to dominance of warm temperate species. Within the tropical - subtropical species zones there are also major biota changes along salinity and tidal gradients associated with ocean inlets. Species trophic and phyletic guilds associated with specific habitats remain constant and well defined, yet species composition within these guilds change significantly along physical gradients. The most pronounced biota change occurs along tidal, salinity and winter temperature gradients associated with ocean inlets. These changes take place even though the predominate habitat types and habitat species composition does not change. For instance, there are significant seagrass meadow faunal changes on this gradient even though the meadow always consists of manatee grass, *Syringodium filiforme*. This process creates locations where species diversity is particularly high. Unfortunately, the locations of highest aquatic species diversity have received some of the greatest recurrent human impact and often receive no protection from environmental insults relative to locations of the IRL, which have far lower biocomplexity. Consequently, a number of locations supporting the highest aquatic biocomplexity within the Indian River Lagoon ecosystem have been destroyed during the past decade.

Understanding the Biocomplexity of the Indian River Lagoon System - Bridging the Gap to Sustainability

Dr. C. Ross Hinkle
Dynamac Corporation, Kennedy Space Center
&
Dr. Duane E. De Freese
Hubbs-SeaWorld Research Institute

Knowledge of the biological diversity of the IRL system has emerged from studies conducted by numerous researchers from many organizations over many years. However, understanding its biocomplexity (i.e., the complex interactions and interdependencies among living organisms and the environments that affect, sustain and are modified by them) and the sustainability of its high biological diversity remains a significant challenge. Natural ecological dynamics on the scale of days to thousands of years and cumulative human cultural dynamics, particularly over the past 400-500 years, have shaped the system we see today. Understanding the biocomplexity of the IRL requires interdisciplinary efforts that include scientists from biological, physical and social sciences. Research activities span many temporal and spatial scales, represent multiple levels of biological organization, and cross conceptual boundaries. Clear and effective links between research findings and environmental decision-making are paramount. The sustainability of the system is heavily tied to the predictive information regarding the forcing functions that drive the system and the level of understanding of biocomplexity that goes into management and regulatory decisions designed to sustain this system.

Biodiversity Informatics: Natural History Collections, Natural History Data

Dr. Anna Weitzman
National Museum of Natural History
Smithsonian

Some of the benefits of having data on Natural History collections digitized, integrated, and available:

1. Natural History collections are vouchers for the wide variety of research that has been done. As such they provide links to the past and allow re-analysis and thus reproducible science.
2. Natural History collections are reinterpreted and reexamined using new technologies as they become available.
3. Current technology allows us to share widely information about collections and research in new and different ways.
4. Current technology will allow us to update and correct data in more cost effective fashions.

The purpose of the natural history collections is not the accumulation of a long list of specimens, cataloged and ordered on shelves and in cabinets; the purpose is the scientific understanding that studies of these specimens and objects unlock and the increase the predictive statements that can be made because of the knowledge gained from their study.

Natural history collections document the best information available for the biodiversity of a specific place when western civilization first visited that place, and they also provide "point in time" data for much of the last 150-200 years. They also voucher many kinds of studies—ecological studies, molecular studies, samples made for commercial reasons, material from the National Cancer Institute, and so on.

The information from natural history collections, especially when data from collections worldwide are combined, is vital to understanding the complexity of the world around us. At the Smithsonian's National Museum of Natural History, one of our important goals for the future is to get all information related to all the collections into electronic form and readily accessible. As we do so, it will become an increasingly useful reference tool for the world. The data will be used by scientists, students, the general public, and various U.S. and foreign government and regulatory agencies and non-governmental organizations associated with the use of biological resources (in the U.S. for example, Departments of Interior, Agriculture, Commerce, and State in interactions in this country and with foreign nations, the World Bank, Conservation International, and so on).

Current technology allows us to capture and link information about all of the collections. Having the data in these forms will, for example, allow scientists to analyze changes in biota that turn out to be linked to changes in human populations and to make assessments of what humans can expect to happen in the future, given the kinds of changes that have affected global climate.

The challenges that face us as we make natural history collections databases available widely include the collection of the data in electronic form. The databasing of our biological collections that number some 83 million at NMNH alone is a daunting task to say the least. However, the more interesting scientific challenge is how to link these data to the myriad of other data, such as physical data, molecular sequence data, survey and plot data, etc., that, when combined, will allow us to better understand the world around us. A well-developed system of databases with these and other linkages will be crucial for developing sustainable use of critical areas, be they recreational, such as national parks and forests, and national seashores for that matter, or for minimizing the effect of exploitation of biological resources.

The value of systematic collections in biodiversity studies

Dr. Paula M. Mikkelsen
American Museum of Natural History, New York

Despite the universal recognition of the ecological and esthetic value of high levels of marine biodiversity, conservation still largely focuses on cnidarians, fish, sponges, and algae. These span a wide taxonomic range and can be monitored non-invasively. But this biodiversity picture is dismally incomplete. As in the terrestrial ecosystems, the overwhelming majority of species and clades in coral reefs and other complex marine habitats are cryptic. Worms, mollusks, echinoderms, and crustaceans are numerically dominant, form the trophic underpinning, and play pivotal ecological roles. Other than a few charismatic species (starfish, conchs, Christmas tree worms), they are underestimated and overassumed. Proper inventory of invertebrate taxa requires factors not routinely employed in conservation: destructive sampling and systematic expertise. Yet scientifically robust results can be achieved with minimal damage and investment, and lead to recognition of key species, for which monitoring schemes can be developed. Echinoderms and mollusks provide examples of recent surveys yielding significant results. Acquiring systematic expertise for inventorying marine invertebrates continues to be seriously limiting. Invertebrate systematic work requires access to extensive specimen collections, laboratories, and libraries, all best represented in museums. After decades of de-emphasizing systematics, the cohort of trained systematists is aging and facing non-replacement. In today's climate of biodiversity interest, new initiatives (NSF-PEET) are training the next generation. The Convention on Biological Diversity is promoting systematic inventory to help balance conservation and sustainable development, since reefs sustain the lives of millions of people yet are increasingly under threat. International initiatives (Diversitas, SA2000) are key to developing new programs to document reef biodiversity. Programmatic and financial support for inventories is the next requirement.

Spatial heterogeneity in Indian River Lagoon: driving forces

Dr. Robert Virnstein
St Johns River Water Management District

Seagrass habitats and associated communities in Indian River Lagoon, Florida, are spatially heterogeneous. There are several driving factors: (1) Youth: the IRL is only 5-6,000 years old. (2) Latitude: a span of >2 degrees. (3) Flushing and circulation: some segments are 95 km and 5 causeways removed from the nearest inlet. Salinity and temperature at a single site can range from 5-40 C and 5-50 ppt. (4) Tidal amplitude: from about 1 m near inlets to <5 cm. (5) Multiple tributaries draining different basin types: from hardwood swamps to agriculture to cities. (6) Multiple inlets: opening to ocean waters that are sub-tropical to warm-temperate; Sebastian Inlet is only 54 years old. (7) Geology: not river-dominated; rather, sediments have multiple sources. (8) Level of development/protection: from near pristine, with surrounding basins publicly owned, to extensively developed with stormwater a major problem. (9) Shallow, with a high surface-to-volume ratio of nearly 1 m2 per m3; boundary conditions thus play a disproportionately large role compared to water masses. In response, seagrass and associated communities show vast spatial differences and asynchronous temporal patterns. So what? Management, e.g., setting seagrass restoration targets or pollutant load reduction goals, needs to address this spatial heterogeneity. Also, mean values over large spatial areas may be meaningless; rather, data analyses need to be spatially explicit.

Long-term and short-term seagrass change versus land use change

Robert W. Virnstein and Edward W. Carter, IV, et al.
St. Johns River Water Management District

A. Long-term seagrass change versus land use change

As the basis for seagrass restoration, it is usually assumed that increasing urbanization leads to increased runoff, decline in water quality, and decline in seagrass. The Indian River Lagoon basin provides an excellent test estuary because some areas have remained nearly pristine, while other areas have become highly urbanized. Several factors allow analysis of 20 distinct segments over a wide gradient of development and seagrass health. Over a 50+-year period, some Lagoon segments have lost over 90% of seagrass acreage. In other segments, seagrass actually increased as much as 100%, presumably due to opening of Sebastian Inlet. Based on a simple runoff model, increases since 1943 in loadings of Nitrogen, Phosphorus, and Total Suspended Solids ranged from near zero to over 500%. Large seagrass losses occurred with increased loadings of: N >120%; P >160%; or TSS >300%. In the 4 segments (a 90-km section of the Lagoon) with loadings increases above these levels, seagrass decreased 60 to 90% over this time period.

This spatial analysis, using GIS, provides a powerful tool for graphically representing complex spatial patterns. Changes in seagrass were spatially and quantitatively related to changes in pollutant loadings over time, and areas were identified for either preservation or restoration. Analytical challenges remain, however. Maps are snapshots in time. But runoff and water quality change continuously. How are such disparate data best handled?

B. Is seagrass improving or declining in Indian River Lagoon? Yes! A primary method for monitoring seagrass in Indian River Lagoon is mapping based on aerial photographs. We have now mapped seagrass for 1943, 1986, 1989, 1992, 1994,1996, and 1999. Plans are in place for 2002 mapping.

What trends do we see? It depends! Since 1943, most segments of the Lagoon have lost seagrass (<20% overall). But some segments (around Cape Canaveral, protected by NASA ownership) have stayed the same; others have even increased. In segments with the highest historic losses (>70% in the Melbourne/Cocoa area), we have seen some recovery in the last decade. An additional intensive seagrass monitoring method is twice-a-year field monitoring of fixed transects from shore to the edge of the seagrass bed. In some of those areas with the highest long-term losses, beds have recently expanded. These same areas also have the greatest year-to-year fluctuations in coverage and the lowest species diversity of sea grasses. Yes, some areas have improved, but some areas still have a long way to recovery. Again, these measurements are snapshots in time. Serial auto-correlations remain an analytical challenge.

IRL coastal wetland rehabilitation and collaborative research to improve management

Brockmeyer, Ronald E., Jr.
St. Johns River Water Management District

Estuarine wetlands in the Indian River Lagoon (IRL) system have been severely impacted. Approximately 40,000 acres of IRL wetlands were impounded for mosquito control mostly during the 1950's and 60's. Most of these impounded estuarine wetlands are located within the Merritt Island National Wildlife Refuge (MINWR) and Kennedy Space Center. The objectives of the IRL Coastal Wetlands project include 1) restoration / rehabilitation of impacted wetlands, 2) appropriate management of reconnected wetlands, and 3) planting of shoreline vegetation. The primary emphasis has been impoundment reconnection with over 22,000 acres of these wetlands reconnected or enhanced. These results bring the total area of impoundments reconnected, breached, or restored Lagoon-wide by all parties to over 27,500 acres. Within SJRWMD, the total District-funded rehabilitation area now exceeds 18,700 acres toward the ultimate goal of 33,000 acres. A major land-acquisition effort is underway to accomplish this goal. Restoration of wetlands impacted by other activities such as dragline ditching is also occurring.

Reconnection by culverts, however, is recognized as only the first step in restoring the ecosystem functions of these impounded wetlands. Appropriate management is critical. Previous research has demonstrated the benefits of reconnecting wetlands to the estuary for fisheries and emergent wetland vegetation, but the benefit to other wetland components is less well documented.

In order to optimize the benefits of reconnection and provide appropriate management, the MINWR staff has been facilitating a broad research effort (now called the Wetlands Initiative at MINWR) led by SJRWMD to directly compare the effects of various restoration and management strategies on a comprehensive list of wetland functions, flora, and fauna. The team has been successful at gathering experts and funding to conduct this 3-5 year study. The Initiative has 18 participating agencies and researchers with major support provided by EPA, USFWS, USGS, NASA, Florida DEP, and SJRWMD.

Mangrove shoreline plantings using the encased planting method are being implement by the Environmental Learning Center. Several thousand mangroves have been planted at 28 sites utilizing over 1700 hours of volunteer labor over the past 5 years.

The Indian River Lagoon Species Inventory: History, Accomplishments and Future Directions

Kathleen Hill
Smithsonian Marine Station at Fort Pierce

The Indian River Lagoon (IRL) had often been purported to be one of the most diverse estuaries in the United States; however, evidence to support this status was lacking. Following the Biodiversity of the IRL Conference, held in February, 1994, Dr. Hilary Swain and several colleagues, with funding from SJRWMD and the National Estuary Program, compiled a preliminary species inventory for the IRL, listing 2,493 species of plants, animals and protists documented to occur in the IRL, and provided the first documentation of the IRL's high biodiversity. However, comparisons with other locations remain difficult as significant inventories do not exist for all comparable regions.

In 1997, the Smithsonian Marine Station at Fort Pierce became the depository for the IRL Species Inventory in an effort to enhance the utility of the inventory by expanding the taxonomic database with relevant ecological information, and then to make this information easily accessible by means of the Internet. The inventory was converted into database format, with fields added to address life history, occurrence and range, associated species, community ecology, physical tolerances, and endangered, threatened or invasive status. From available ecological data, approximately 40 species narratives were generated on a pilot website to show how biologically relevant information could be dispensed via the Internet. Subsequent funding allowed continued expansion of the IRL Species Inventory and further development of the website as an educational and public outreach tool. To date, an additional 500 species have been added to the masterlist; approximately 210 expanded species reports are available on the website; explanatory materials, common names, and an interactive on-line glossary have been added to promote use by educators and students; and the addition of habitat information allows viewers to browse species information by occurrence within specific habitats.

Though the IRL Species Inventory is now a successful tool for education and outreach efforts, we are interested in increasing its utility as a research tool. We plan not only to fill the gaps in our knowledge for unrepresented and underrepresented groups, but also have the goal of increasing our collaboration with other agencies and educational institutions in order to consolidate species lists, occurrence information and density estimates into a single, cohesive IRL species inventory database. By doing so, the utility and scientific integrity of the IRL Species Inventory will be greatly improved, allowing its continued use not only as a valuable educational and outreach tool; but also as a definitive resource for environmental management and preservation of the vast biodiversity of the IRL.

Agent-based Models of Complex Ecosystems

Dr. George Markowsky
University of Maine

This talk will survey the basic concepts of agent-based computing, and how these concepts can be applied to modeling complex systems of all types, including ecosystems. Some simple tools will be described that can be used for constructing simple models that exhibit complex behavior.

Issues related to database management techniques, integration of heterogenous databases at the structural and semantic levels

Dr. Thomas J. Wheeler
University of Maine

In a number of multidisciplinary research efforts in fields with similar problems to ours, system architecture, abstract interfaces to disparate data sources and data integration have been seen as core problems and a consensus is beginning to emerge on an architecture and techniques to effectively integrate data. A quick overview is that a common architectural view is emerging which structures these systems as distributed federations, using Mediators to integrate each federation's data and Wrappers to hide and transform each data source's data formats and schemes. Technology that is commonly used is XML (and related standards like RDF), agent based systems, ontologies, and object and object/relational databases.

This talk will provide some insight into these problems and identify the important associated issues, provide an overview as to the architecture which shows the most promise to accommodating these issues, and show how some of our research can leverage the above approach to develop the flexible, capable system structure this application needs.

Automated change detection techniques using digital imagery to update geospatial databases

Dr. Anthony Stefanidis & Dr. Peggy Agouris
University of Maine

The automation of object extraction from digital imagery has been a key research issue in digital photogrammetry and computer vision. In the spatiotemporal context of modern GIS, with constantly changing environments and periodic database revisions, change detection is becoming increasingly important. In this paper we present our work on the development of automated change detection techniques to update geospatial databases. We present models and demos from our work on two approaches: differential template matching (most suitable for buildings), and differential snakes (most suitable for roads and other elongated features). These two novel approaches integrate object extraction and image-based geospatial change detection, into a single, fully automated process.

Computational intelligence and its applications in ecological modeling

Dr. Habtom Ressom
University of Maine

Ecological modeling has grown rapidly in the past few decades. Several approaches have been used to build an ecological model, ranging from numerical, mathematical, and statistical methods to biologically inspired computational techniques. This presentation will give a brief introduction to computational intelligence techniques such as artificial neural networks, fuzzy logic systems, and genetic algorithms. Some of the major applications of these techniques will be mentioned including data classification, pattern recognition, function approximation, prediction, process modeling and control. Furthermore, several projects involving computational intelligence in ecological analysis, synthesis, and forecasting will be described. In particular, the use of artificial neural networks for estimating chlorophyll-a concentration from remote sensing data and for developing a primary productivity model will be discussed.

Applications of computational intelligence in biodiversity

Dr. Cristian Domnisoru
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The diversity of life forms and their respective distinctive ways of expression and interaction could be reflected at the DNA level. Proteins with similar shapes and identical functions can have different chemical compositions. Also, organisms that look similar to each other can have very different genetic information. It is possible that the key for understanding the biodiversity in general is to be found at the genetic level. We can compare two organisms by their approach in feeding, reproducing, moving in the habitat, raising offspring and other criteria. How do we compare two DNA sequences? A presentation of current techniques for two and multiple sequence alignment and comparison are presented. In particular, a presentation of our DNA database for base calling accuracy assessment is given.

An insight into the comparison problematic is presented. The fact that the same feature in two organisms is similar has the same importance with the case when the same feature is different? From a genetic perspective, the differences between organisms are much less informative than the similarities. How do we incorporate this into a general frame for comparing DNA sequences?

Issues related to applications of computational intelligence are presented. It is known that sampling species' distribution is expensive. What sample size is needed for an accurate modeling? An example from our investigation in DNA base calling modeling is discussed.

An Integrated Modeling System of the Indian River Lagoon

Dr. Y. Peter Sheng
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An integrated modeling system, CH3D-IMS, has been applied to the Indian River Lagoon and validated with field data collected in 1998. The integrated modeling system consists of a three-dimensional hydrodynamic model, a wave model, a 3-D sediment transport model, a 3-D water quality model, a light attenuation model, and a seagrass model. The integrated modeling system is linked to the field data through a GIS database of the Indian River Lagoon. Both the framework and the results of the integrated modeling system will be presented. The integrated modeling system can be used to assess the response of the IRL ecosystem to changes in external loading and/or climate.