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Original article

The Gulf of Maine biogeographical information system project: developing a spatial data management framework in support of OBIS

Vers un système d'information biogéographique sur le Golfe du Maine : mise au point d'une architecture de gestion de données spatialisée en support d'Obis

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Abstract

Central to the development of an inventory of marine life and improved conceptual understanding of the mechanisms that dynamically shape species distribution patterns is the implementation of strategies aimed at enhancing assimilation and access to existing biogeographical information. Using the Internet as a medium, the Gulf of Maine Biogeographic Information System (GMBIS) project provides a framework and a set of reusable tools for the integration, visualization, analysis and dissemination of diverse types of biogeographical and oceanographic information. End-to-end viability of this approach is demonstrated in the context of a series of scientific storylines and a pilot application for the Gulf of Maine (GoM), a well-studied ecosystem that has been subject to large-scale perturbation due to overfishing. Databases at the core of the information system include those of the DFO Bedford Institution of Oceanography and Atlantic Reference Center, which are the product of multidisciplinary research efforts over the last several decades. Development of GMBIS may serve not only as a model for OBIS, but it may also provide a tool supporting new international and Canadian directives for integrated marine resource management. This paper summarizes the status of the GMBIS project, currently in its final phase, and outlines possible future directions in information system development for the CoML.

Résumé

Le développement d'une stratégie pour faciliter l'accès et l'assimilation à une information biogéographique est essentiel au développement d'un inventaire sur la vie marine. En utilisant Internet, le Système d'information biogéographique du golfe du Maine a développé une architecture et un ensemble d'outils pour l'intégration, la visualisation, l'analyse et la dissémination de divers types d'informations biogéographiques et océanographiques. La viabilité de cette approche est prouvée dans le cadre d'une application pilote et de scénarios scientifiques pour le golfe du Maine, un écosystème bien étudié, objet d'une perturbation à grande échelle par surpêche. La base de données initiale est celle de l'Institut Bedford et du Centre de référence atlantique, produit de la recherche pluridisciplinaire durant les dernières décennies. Le développement du Système d'information biogéographique du golfe du Maine ne doit pas seulement servir de modèle pour Obis ; il doit également fournir des outils pour des directives canadiennes et internationales pour la gestion intégrée des ressources marines. Cet article fait le point sur ce projet et souligne les directions possibles pour un système d'information pour le programme « Recensement de la vie marine ».

Keywords: Information system; GIS; Biogeography; Biodiversity; Gulf of Maine

Mots clés: Système d'information; Biogéographie; Biodiversité; Golfe du Maine

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1. Introduction

Human activities now rival natural processes in shaping marine ecosystems, a situation exemplified by the status of marine fisheries, which are at a critical juncture world wide due to chronic overexploitation and overcapitalization (Sissenwine and Rosenberg, 1993; Rosenberg et al., 1993). Restoration and sustainable usage of marine resources will likely require a paradigm shift from traditional scientific assessment and management methods to more holistic multispecies and ecosystem-based approaches (Murawski, 1991; ICES, 1999; National Research Council, 1999). Further development and implementation of such approaches, however, necessitates improved fundamental understanding of marine ecosystem function. A prerequisite for this is the comprehensive cataloguing of biological diversity and the study of species distribution patterns in relation to environmental, biotic and anthropogenic factors (May, 1990).

Motivated by these imperatives, the Census of Marine Life (CoML) is an international, multidisciplinary research initiative seeking to assess and explain the diversity, distribution and abundance of marine organisms on a global scale (Aldridge et al., 1999; Bradley, 1999). It is built upon programmatic elements that aspire to: (1) resolve contemporary biogeographical patterns from both existing data of well-studied marine systems and new sampling efforts focusing on poorly characterized ecosystems and taxonomic components, (2) review these patterns also in the context of species biomass distributions reconstructed from historical archives, and (3) project forward on the basis of resulting improved understanding for a future view of the world's oceans under scenarios such as climate change. The extensive scope and scale of this ambitious effort pose numerous conceptual and technical challenges, not least in the area of data management. The Ocean Biogeographic Information System (OBIS) is ultimately envisioned as a virtual repository or global network of interoperable databases coupled via the Internet that support Census activities. Realization of OBIS requires the development of a comprehensive strategy and a set of tools enhancing access to and integration of extensive, multivariate biogeographic and oceanographic datasets held by multiple stakeholders on diverse, distributed platforms and in a variety of formats. The Gulf of Maine Biogeographic Information System (GMBIS) project was formulated to help address some of these critical technical issues.

Funded via NOPP as one of the initial eight CoML pilot projects (Malakoff, 2000; Tsontos and Kiefer, 2000) and currently in its concluding phase, GMBIS is a collaborative venture between the University of Southern California (USC), DFO Maritimes Region (Bedford Institute of Oceanography, BIO, Halifax), the Atlantic Reference Center (ARC, Huntsman Marine Science Centre, St. Andrews), and System Science Applications (SSA). Its basic objective is to develop a generic methodological framework and a set of reusable software tools that can be leveraged for OBIS. Drawing on the extensive data resources of DFO Maritimes, using the Internet as a medium and capitalizing upon advanced database and GIS technologies, GMBIS is a proof-of-concept activity that has assembled and tested a prototype information system facilitating dissemination, integration, and visualization of existing biogeographical and oceanographic information for the Gulf of Maine (GoM). Adoption of a thematic focus in GMBIS demonstrates the end-to-end viability of the information system in supporting biogeographical studies. This takes the form of a series of structured topics around which source data are organized that pertain overall to the distribution of marine populations in relation to environmental variability in the GoM. In addition to providing a technical solution, GMBIS thus facilitates the characterization of biogeographical patterns within the region and promotes improved understanding of marine population distribution and dynamics in terms of bio-physical processes operative over multiple spatio-temporal scales (Powell, 1989; Steele, 1989; Kareiva, 1990; Shepherd and Cushing, 1990; Rapoport, 1994; Levin, 1995) and in terms of underlying interspecific, habitat and fisheries interactions (Murawski, 1991; Langton and Auster, 1999).

The GoM is ideally suited for developing and testing such an approach. Firstly, this area marks a major biographic discontinuity between north and south temperate species (Mahon et al., 1998), making it a natural focus for the development of a biogeographic information system. Secondly, the GoM is a well-studied ecosystem, and one for which extensive, multidisciplinary scientific data exist. Databases maintained by the collaborating DFO institutes form the core of the GMBIS system. These data archives are particularly important because they document the effects of large-scale ecosystem disturbance due to harvesting (Fogarty and Murawski, 1998) and provide the empirical basis for the management and restoration of fisheries resources within this ecologically sensitive area.

Development of GMBIS thus also provides a decision support tool promoting integrated approaches to natural resource management in the Gulf of Maine. It is a timely response to national and international directives such as the 1997 Canadian Oceans Act and the FAO Code of Conduct for Responsible Fisheries, and new directions in groundfish fisheries management being adopted in the region (Sinclair et al., 1999). Ultimately, however, the aim and utility of the GMBIS is to potentially serve as a model of biogeographical information system design and implementation in support of OBIS.

2. Information system development

Effective information system design requires due consideration of constituent data, the particular applications that this information is intended for, and the specific function-

ality and needs of end-users. GMBIS development is characterized by a multifaceted and practical application-driven approach that incorporates these principles in a manner that goes beyond the assembly of just a technical system.

2.1. Thematic focus

Information systems do not exist in isolation from the practical applications they are intended to address. To better illustrate the potential of GMBIS in supporting studies of marine biogeography, a structured thematic approach was adopted and a series of inter-related scientific storylines was developed (Table 1). Overarching themes consider how environmental processes operative in the GoM influence the distribution and dynamics of associated marine populations over a range of spatial and temporal scales. These storylines draw upon insights obtained via involvement of DFO in programs such as US GLOBEC Georges Bank and long-standing research efforts within the GoM in the areas of physical and biological oceanography and fisheries ecology. In addition to demonstrating the effectiveness of the information system in helping to address topical questions on biogeography and the status of marine populations in the region, adoption of a thematic approach has also helped guide and define both the selection of data for inclusion in GMBIS and the types of integrated data products capable of being generated by the system. Significantly, the organization of GMBIS along thematic lines has also inherently resulted in a form of synthesis of existing knowledge on biogeography in the GoM, identified potential gaps in the current information base, and has provided a vehicle for more effective communication of both established research findings and GMBIS achievements in terms of information system development to CoML participants and the broader oceanographic community.

Table 1
Summary of GMBIS scientific storylines that provide a thematic focus centering on the distribution of marine populations in relation to environmental variability in the Gulf of Maine region

Part 1	**The setting**
1a	Large-Scale Topography, Environment and Ecosystem: Scotian Shelf and Gulf of Maine
Subtheme	Midlatitude region with strong subpolar influences
1b	Climatological Seasonal Variation in the Gulf of Maine Region
Subtheme	Strong topographic influences on oceanographic and ecosystem structure
1c	Stock structure and mixing
Subtheme	Interstock mixing in an advective system
1d	Biological distributions in relation to fine-scale seabed structure in example areas
Subtheme	Influences of seabed characteristics on distributions of benthic organisms
1e	Characterization of species diversity in the Gulf of Maine by aggregated taxonomic categories
Subtheme	Influences of topography and environment on biodiversity
Part 2	**Temporal variability**
2a	Past examples of persistent marine population changes in relation to variable subpolar influences
Subtheme	Potential for climate-variability and climate-change impacts on marine populations
2b	Historical interannual variability in drift, growth and survival of Browns Bank haddock early life stages
Subtheme	Potential recruitment predictability associated with temperature/advection-mediated growth and survival
2c	Recent interannual variability in plankton and haddock early life stages on Western/Central Scotian Shelf (WCSS)
Subtheme	Haddock ELS explosion on WCSS in 1999 associated with an environmentally triggered nutrient-plankton trophic cascade
2d	Anomalous interstock scallop exchange and recruitment in the eastern Gulf of Maine in 1985 and 1998

2.2. Core data and information providers

Underlying the GMBIS system are three broad categories of information archives and data sources. Ecosystem databases are maintained by the Bedford Institute of Oceanography in Oracle, running principally on UNIX servers, but also selectively on PC Windows platforms. These databases, established largely to improve the study of and management of transboundary fish stocks within the Northern Atlantic, provide an extensive series of quantitative, spatially referenced data on environmental conditions, species biomass distributions and resource exploitation within the GoM (Table 2). Much of the work undertaken by collaborators at BIO for GMBIS has centered on providing direct access to selected databases (groundfish trawl survey), and extracting and processing subsets of data from the full spectrum of ecosystem databases to demonstrate the various scientific storylines. Examples of these synthetic data products include climatological and interannual views of flow fields and water mass properties over depth, time series of ocean color and thermal satellite imagery, and biological indicators for individual species or guilds of planktonic, nektonic, and benthic organisms in the GoM. A detailed listing of datasets and synthetic data products currently comprising GMBIS is given in Appendix A.

Species/specimen databases associated with GMBIS provide information on biological diversity within the region for a greater range of taxa and additionally offer basic information on species ecology and taxonomy. The primary source is the Atlantic Reference Center (ARC), the designated specimen repository of DFO Maritimes maintaining significant historical museum collection holdings and associated data from the GoM and Northwestern Atlantic. Particular ARC datasets utilized by GMBIS include the ichtyoplankton and deep-sea epibenthic collection databases in addition to the taxonomic reference collection (Table 2 and Appendix A). Much of the work undertaken by ARC under GMBIS has involved making their collection data available electronically on-line by porting to the Specify museums archival system (http://usobi.org/specify/), an MS Access-based application operating on PC Windows environments.

Table 2
Summary of electronically archived data maintained by DFO Bedford Institute of Oceanography and the Atlantic Reference Centre (ARC). GMBIS used a selected subset of these databases and derived synthetic data products to illustrate adopted biogeographic storylines for the Gulf of Maine

Database	Survey type	Period and frequency	Data description
Groundfish	Stratified random Research Trawl	1970–1999; 1–3 year^{-1}	300 Vertebrate and invertebrate species Georeferenced catches (total numbers and weight) Size–frequency distributions Subsample length, weight, age, sex, maturity Temperature–salinity profiles or surface/bottom values
Larval	SSIP/FEP egg and larval surveys	1976–1999	Georeferenced egg/larval abundances 487 Species
	Herring larval surveys	1972–1999	Georeferenced herring larval abundances
Fisheries	ICNAF/NAFO	1969–1999; monthly	Catch statistics for 151 species
	Canadian National Catch Statistics	1960–1999; monthly	Catch statistics for 158 species
	Fishing Vessel Logbooks	1991–1999	Geo-referenced catch records for 158 species
	Fishing Vessel Port Landings	1947–1999	Biological length/age samples for 37 species
	At-Sea Observer records	1977–1999	
Genetic	Population genetics	1993–1999	cDNA and microsatellite gene probe data Commercially harvested species NW Atlantic (scallop, lobster, cod, haddock, herring)
Climate	Hydrographic	1920–1999	Temperature/salinity profiles
SST	Remote Sensing Data		JPL 18 km MCSST (sea surface temperature) SeaWifs Chlorophyll
ODI	Ocean Data Inventory	1965–1999	Current meter and thermograph time series
BIOCHEM	National marine biological and chemical database	1970–1999	BIO nutrient data Approximately 100 chemical parameters
		1960–1999	NW Atlantic Zooplankton samples Continuous Plankton Recorder data (lines E and Z)
ARC	GOM/NW Atlantic specimen data	1900–1999	Ichthyoplankton Deep sea epibenthos Taxonomic reference collection

Further species/specimen datasets tapped by GMBIS derive from web-based sources such as FishNet, Fishbase, and Cephbase, available collectively via the OBIS data server maintained at Rutgers University. These integrated databases generally have data on museum collection specimen identity and sample location either known directly or extracted from the literature, with some also providing information on species natural history. To further demonstrate the potential for using increasingly available certified, on-line sources of biogeographic information, GMBIS additionally accesses complementary information on the genetic character of marine populations. Such genomic information and associated sample metadata are available via GenBank, developed by the National Institute of Health.

2.3. System design

The components comprising GMBIS and the flow of information between the elements of this distributed information system are illustrated in Fig. 1. At the lowest level are the core data previously described that are held on diverse institutional servers and in a range of data archival systems. High volume datasets, not optimally stored within a relational database management system (rDBMS), are maintained and accessed in their native formats via FTP or DODS servers at BIO. These include chlorophyll concentration and SST satellite imagery, and synthetic data products generated at BIO and ARC in support of the scientific storylines. ARC museum collections' data are accessed by GMBIS via the Specify rDBMS on which they are maintained. DFO ecosystem databases are managed, integrated, and disseminated via a network of interconnected Oracle database systems that serve the various DFO Maritime laboratories. Complementary information on species distribution patterns and ecology is accessed directly by GMBIS from the OBIS portal via a context sensitive search mechanism; similar methods also being employed to query GenBank for genomic sample information.

The uppermost tier of the information system is the GMBIS web server (http://netviewer.usc.edu/web/index.html) providing broad, Internet-based access via the project web-site to value-added graphical data products, source data and descriptive GMBIS project information. The PC server computer hosts software tools (ACON and EASy Netviewer GIS) facilitating the assimilation, integration, visualization and dissemination of GMBIS core data by means of uncomplicated, interactive, graphical user interfaces. ACON (A CONtouring) software, which was developed at the Bedford Institute of Oceanography, provides a web-based visualization front-end for an Oracle relational database system by supported ODBC, Oracle SQL/Net and CGI protocols via a script programming language. ACON contains a compiler and interpreter for a virtual machine based on an enhanced version of Extalk, and operates on VAX, UNIX, and PC Windows (95, 98, NT) environments. EASy (Environmental Analysis System), de-

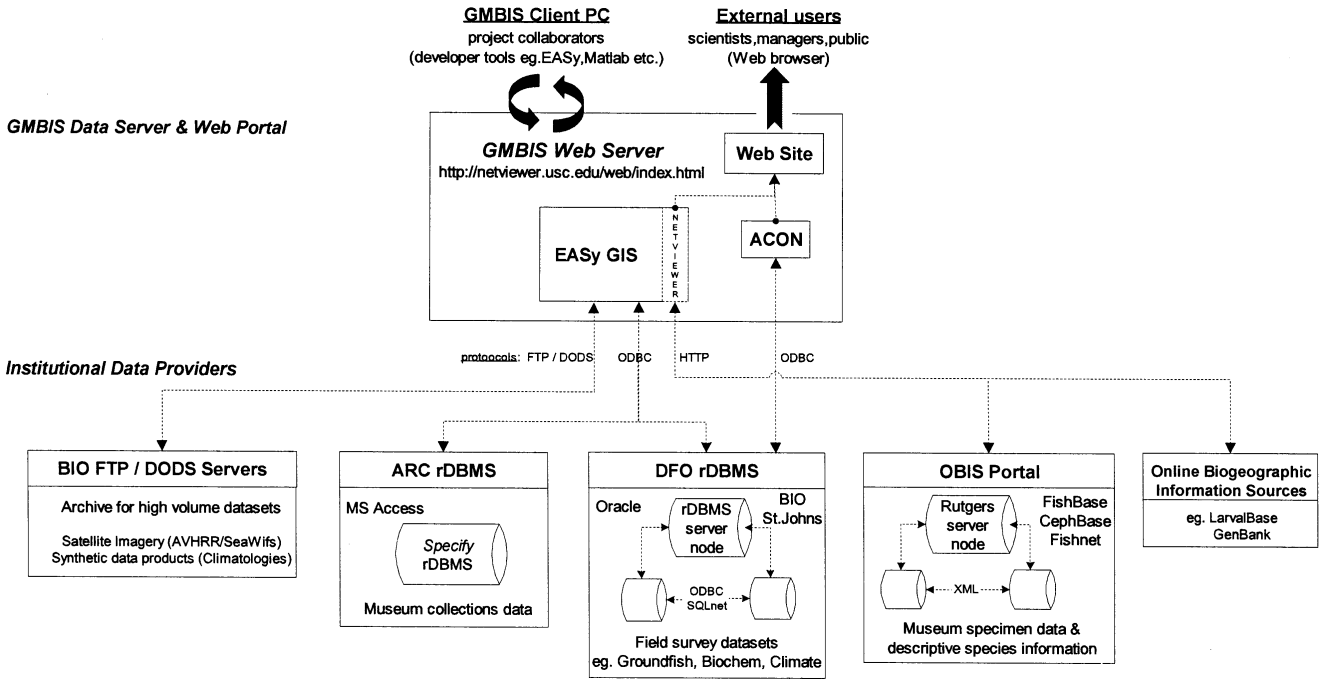

Fig. 1. GMBIS information system design: components and information flow.

veloped by System Science Applications in collaboration with the University of Southern California, is an advanced, geographical information system that has been specifically designed for marine applications and the handling of diverse types of oceanographic data. EASy is a PC Windows-based application (NT, 98, 2000, ME, XP) written principally in C++, but with Fortran, Java and Visual Basic component libraries. EASy supports the complete range of data access protocols implemented by GMBIS data providers, including ODBC (Open Database Connectivity), FTP (File Transfer Protocol), HTTP (Hypertext Transfer Protocol) and DODS (Distributed Ocean Data System) client functionality. It thus facilitates the integration of the full suite of available biogeographic and oceanographic information tapped by GMBIS. EASy's Netviewer Java plug-in component facilitates the deployment of entire GIS applications on the Web such that external GMBIS users having only standard browser software (e.g. MS Internet Explorer) can dynamically operate the GIS, visualize custom mapped GMBIS data product sequences and download source data across the Internet. Use of EASy as a GIS web server via Netviewer requires that the software be hosted on a PC running Microsoft IIS (Internet Information Services) server software. GIS project development is undertaken by GMBIS collaborators, who run EASy from their workstations and access the information system locally (GMBIS clients).

2.4. Component/tool development

During this project, much effort has gone into building components and software tools that provide the GMBIS system with its necessary functionality. In addition to the ARC database development work, collaborators at BIO have worked to further integrate their ecosystem databases, also linking the groundfish survey databases of DFO and NMFS, and rendering them more accessible. The ACON web-interface and toolset has been enhanced, e.g. to permit mapped overlays of groundfish abundance and ARC survey data with bathymetry and temperature data. ACON now also provides an interactive tool for selection and export of displayed data in various formats.

Much of the software development activities have concerned EASy, and the inclusion of more generic database connectivity and data importation and dissemination functionality, in particular. The Virtual database utility allows EASy to function as a portable GIS front end to generic local or remote ODBC compliant rDBMS, such as the DFO distributed Oracle groundfish database, irrespective of their underlying relational model structure. This is achieved by the mapping of key data fields required by the GIS (latitude, longitude, depth, time, observation type, value, and units) to tables and fields housing these data in the source database. An analogous capability has been developed for the importation of both scalar and vector point pattern and polygon data from ASCII or other ODBC compatible flat-file sources. An EASy DODS client capability was developed for GMBIS, and the software now supports an even greater range of imagery data formats (including NetCDF, raster NOAA coastwatch and ESRI vector shapefiles), features that further improve access to oceanographic datasets available on the Web. A generic, context sensitive search capability of web-sites with dynamic database content was developed to facilitate linkage and integration with biogeographic information available on the OBIS portal and other

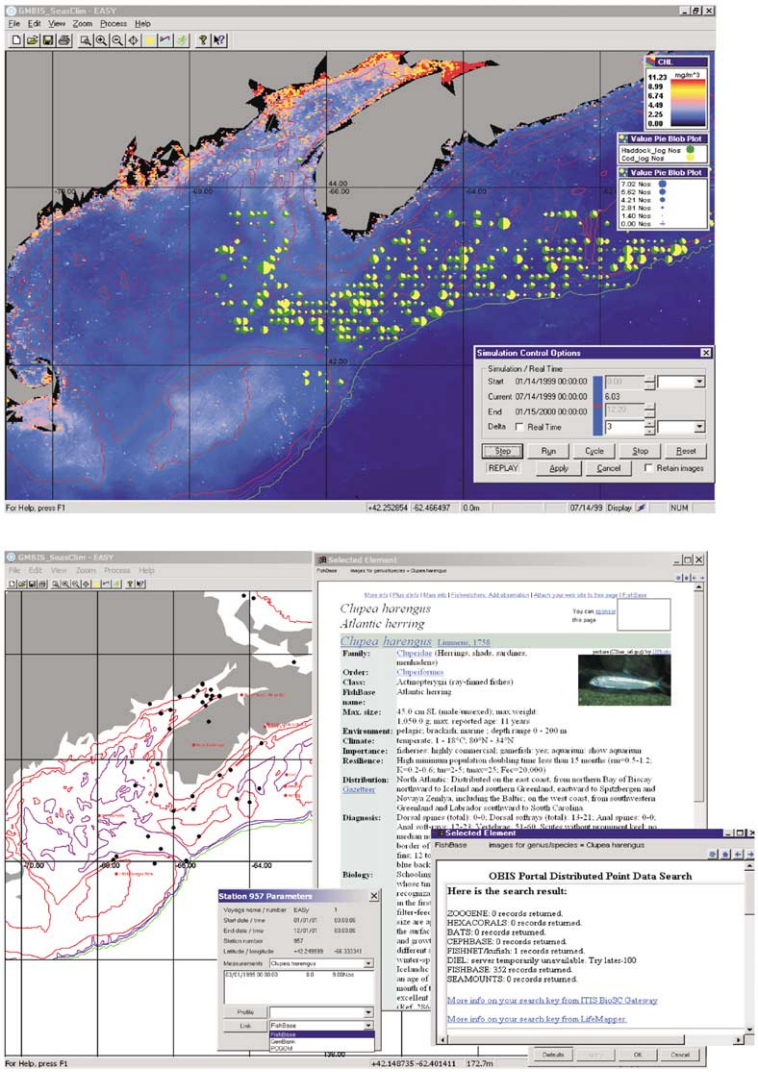

Fig. 2. Sample GMBIS integrated data products generated by EASy GIS. (A) Cod and haddock spatial abundance patterns in summer within the Gulf of Maine derived from DFO groundfish surveys in relation to chlorophyll concentration distributions from SeaWiffs satellite imagery. Abundance data are based on long-term seasonal averages and represented as bubble-pie plots that are overlaid on [CHL-A] false color imagery. Bubble size is proportional to log 10 average abundance at a given locale, relative point species abundances being reflected by the proportion of a symbol filled in green (haddock) and yellow (cod). (B) Spatial distribution of herring (*Clupea harengus*) museum collection samples in the Gulf of Maine (black points on underlying map) from the ARC database. A web-based context sensitive search capability in EASy permits real-time linkage to the Rutgers OBIS portal for querying of hosted museums collection data and species descriptive information. The figure also illustrates natural history information for herring (overlying window) returned by FishBase via such a search of the OBIS site.

relevant sites. Additional enhancements to EASy undertaken for GMBIS include support for multimedia in GIS applications, provision of new spatial data plotting capabilities such as multivariate bubble plots, creation of a visual GIS application development interface, development of a COM interface for dynamic linkage to algorithms and models written in Visual Basic or any other programming language supporting COM, and various improvements to Netviewer, including a tool for the interactive selection and exporting of subsets of mapped data.

2.5. GMBIS outputs

The conventional means by which oceanographic or biogeographic information is currently delivered on the Internet is either as a searchable catalog of prefabricated graphical data products, or when real-time integrated recordset assembly is involved, products are typically provided as hard-to-interpret tabular displays or rudimentary, static maps. The former approach is unsustainable because it is difficult to anticipate and routinely provide the custom graphical outputs required by end-users. Although better in providing dynamic content, the latter approach still falls short of user requirements in terms of being able to interactively interrogate 3D spatial data and view the temporal evolution of data plotted in a variety of ways. The novel approach adopted by GMBIS has been to empower end-users with tools (ACON and EASy/Netviewer) that provide them with advanced, yet uncomplicated GIS functionality across the Internet for the creation of custom maps, dynamic visualization of data sequences, and selection of displayed source data for export without the need for specialized software on the client side. Such an approach is much more useful and maintainable. It can grow incrementally as user requirements evolve with new display functionality being added, and is easily portable to other data providers because of the generic database connectivity tools available and range of data access protocols and information integration methods supported.

An illustration of the types of integrated, graphical data displays that GMBIS provides is given in Fig. 2. The upper panel shows a time-integrated view of groundfish spatial

abundance distributions in the GoM as resolved by DFO surveys in relation to satellite imagery of phytoplankton distributions. The lower panel displays the mapped distribution of herring (*Clupea harengus*) in the GoM from ARC archives. It also demonstrates parallel access to complementary biogeographic data and descriptive natural history information available on-line at the OBIS portal via EASy's Web-link and context sensitive querying capability.

3. Discussion

At its conclusion, the Gulf of Maine Biogeographic Information System project has developed a comprehensive range of products, both technical, archival, and conceptual, that are likely to prove of value to OBIS and the CoML. GMBIS has successfully assembled and tested a prototype information system facilitating dissemination, integration, and visualization of diverse existing biogeographic and oceanographic information for the Gulf of Maine available via DFO Maritimes ecosystems and museum collection databases, the OBIS portal and other certified on-line sources. GMBIS has developed a generic methodological framework for biogeographic information system design and implementation and a set of reusable software tools that can be easily ported and adapted to CoML applications elsewhere. In addition to demonstrating the viability of the technical system, adoption of a thematic focus in GMBIS has aided the communication of project achievements and has inherently resulted in the form of synthesis of knowledge of biogeographic patterns in the GoM in relation to environmental variability, while also highlighting possible gaps in the existing information base.

There is considerable scope for the sustained utilization of the GMBIS system locally and usage of its generic information system model and software tools in other CoML applications. Under the emerging national and international oceans legal framework for marine resources, there is a need for integrated ocean management. GMBIS may be used as a research aid and decision support tool for the implementation of new Canadian ecosystem directives for the ecologically sensitive GoM region. With respect to the CoML, efforts are currently underway to develop a large-scale sampling and multidisciplinary research program (GoMAP, the Gulf of Maine Area Pilot), that would also use new observational technologies to comprehensively map the distribution of a wide range of taxa in relation to their environment. Tools and data management approaches developed by GMBIS will be applied and refined in GoMAP. Additionally, the integrated data products currently delivered by GMBIS may serve both to guide sampling priorities and function as a precursor to the dynamic electronic atlas of the GoM that is envisaged. Finally, some GMBIS components are already being used to support other existing CoML projects. EASy/Netviewer GIS is currently being employed as a data integration, visualization and dissemination tool in the Stanford TOPP (Tagging of Pacific Pelagics) project and the Duke SEAMAP (Spatial Ecological Analysis of Megavertebrate) information system project focusing on marine mammal, bird and turtle data archives. Plans are also underway to employ EASy/Netviewer to expose the extensive ecosystem database for the Chesapeake Bay LMER developed by the TIES (Trophic Interactions in Estuarine Ecosystems) project.

Looking at the future, while GMBIS already affords a useful model and toolset in support of OBIS, it is clear that additional functionality will need to be provided as the CoML increases in scale, as the projects and specific needs of OBIS end-users diversify, and as Internet and software development technologies evolve. Useful extensions of GMBIS would include the development of a generic XML database interface in the GIS to achieve total interoperability with the OBIS data server and facilitate integration with other database systems increasingly implementing XML for information delivery. A further area would be the development of a GIS DODs server capability for the dissemination of integrated data products, given the widespread adoption of DODS by the oceanographic community.

In terms of OBIS, future directions must include the development of a capacity to deal comprehensively with and integrate the full spectrum of information used in biogeographic studies. This includes model data, quantitative biological survey data and diverse types of environmental data in addition to specimen collections type information. Progress is also required in the area of interactive data visualization, and coupling to predictive spatial models of marine biogeographic processes. It is our contention that methods developed by GMBIS can fruitfully be brought to bear in support of OBIS in all these technical areas and be further enhanced by continued close interactions amongst the OBIS development community.

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References

Aldridge, L.A., Bradley, D.L., Butterworth, D., Steele, J.H., 1999. Assessing the global distribution and abundance of marine life: summary of a workshop sponsored by the sloan foundation and the office of naval research, January 13-15 1998, Monterey, California. Oceanography 12 (3), 41–46.

Bradley, D.L., 1999. Assessing the global distribution and abundance of marine organisms. Oceanography 12 (3), 19–20.

Fogarty, M.J., Murawski, S.A., 1998. Large-scale disturbance and the structure of marine systems: fishery impacts on Georges Bank. Ecol. Appl., 6–22.

ICES, Report of the ICES Advisory Committee on the Marine Environment, 1998, 1999. ICES Coop. Res. Rep. 233, 94–220.

Kareiva, P., 1990. Population dynamics in spatially complex environments: theory and data. Phil. Trans. R. Soc. Lond. B 330, 253–259.

Langton, R.W., Auster, P.J., 1999. Marine fishery and habitat interactions: to what extent are fisheries and habitat interdependent? Fisheries 24 (6), 14–21.

Levin, S.A, 1995. The problem of pattern and scale in ecology. In: Powell, T.M., Steele, J.H. (Eds.), Ecological Time Series. Chapman and Hall, New York, pp. 275–326.

Mahon, R., Brown, S.K., Zwanenburg, K.C.T., Atkinson, D.B., Buja, K.R., Claflin, L., Howell, G.H., Monaco, M.E., O'Boyle, R.N., Sinclair, M., 1998. Assemblages of demersal fishes of the east coast of North America. Can. J. Fish. Aquat. Sci. 5S, 1704–1738.

Malakoff, D., 2000. Grants kick off ambitious count of all ocean life. Science 288, 1575–1576.

May, R.M., 1990. How many species? Phil. Trans. R. Soc. Lond. B 330, 293–304.

Murawski, S.A., 1991. Can we manage our multispecies fisheries? Fisheries 16 (5), 5–13.

National Research Council, Sustaining Marine Fisheries, Report of Committee on Ecosystem Management for Sustainable Marine Fisheries, Oceans Studies Board, 1999. 168 p.

Powell, T.M., 1989. Physical and biological scales of variability in lakes, estuaries and the coastal ocean. In: Roughgarden, J., May, R.M., Levin, S.A. (Eds.), Perspectives in Ecological Theory. Princeton University Press, Princeton, pp. 157–176.

Rapoport, E.H., 1994. Remarks on marine and continental biogeography: an areographical viewpoint. Phil. Trans. R. Soc. Lond. B 343, 71–78.

Rosenberg, A.A., Fogarty, M.J., Sissenwine, M.P., Beddington, J.R., Shepherd, J.G., 1993. Achieving sustainable use of renewable resources. Science 262, 828–829.

Shepherd, J.G., Cushing, D.H., 1990. Regulation in fish populations: myth or mirage? Phil. Trans. R. Soc. Lond. B 330, 253–259.

Sinclair, M., O'Boyle, R.N., Burke, D.L., Peacock, F.G., 1999. Groundfish management in transition within the Scotia-Fundy area of Canada. ICES J. Mar. Sci. 56 (6), 1014–1023.

Sissenwine, M.P., Rosenberg, A.A., 1993. Marine fisheries at a critical juncture. Fisheries 18 (10), 6–14.

Steele, J.H., 1989. Scale and coupling in ecological systems. In: Roughgarden, J., May, R.M., Levin, S.A. (Eds.), Perspectives in Ecological Theory. Princeton University Press, Princeton, pp. 157–176.

Tsontos, V.M., Kiefer, D.A., 2000. Development of a dynamic biogeographic information system for the Gulf of Maine. Oceanography 13 (3), 25–30.