Global Terrestrial Observing System

Coastal GTOS

Strategic design and phase 1 implementation plan:

Section 4.4 Vulnerability of ecosystem services in deltaic systems

The complete document is available from: http://www.fao.org/gtos/pubs.html

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Executive summary

The primary goal of the Coastal Module of the Global Terrestrial Observing System is to detect, assess and predict global and large-scale regional change associated with land-based, wetland and freshwater ecosystems along coasts.

The coastal zone contains a wide variety of ecosystems that are both important ecologically and highly valued by humans. Biodiversity and productivity are often high, and the processing of energy and materials links terrestrial ecosystems with marine waters and the atmosphere. A significant portion of the human population resides in the coastal zone or uses its resources. Some of the most densely populated areas on earth are along the coast, positioned with high vulnerability to natural disasters.

The coast presents a particular challenge to assessing global change. The discontinuity between the land and ocean provides complexities that challenge the efforts of global observing systems. There is a clear need for information about the coastal zone from an integrated socio-ecological perspective within the observing system framework.

This plan for the Coastal Module of GTOS (C-GTOS) describes the strategic design for a mature observing system and identifies ways to implement that strategy during the initial phase of the programme.

The plan recognizes the need to develop the observing system into a mature and sustainable programme through a series of achievable products. C-GTOS has the following goals:

- Meet the general GTOS mandate.
- Identify users and establish products appropriate to user needs.
- Establish a regime for observing, assessing and predicting global and large-scale regional change for select ecological and associated socio-economic issues.
- Identify a select group of critical, tractable issues to address in the near term, as well as in the long term.
- Link remote and ground-based observations in the coastal zone.
- Provide mechanisms to communicate products to users and receive feedback
- Promote capacity to observe, assess and predict change.

Early efforts by the panel of scientific experts participating in the C-GTOS workshops focused on (i) definitions of the "coast" and factors that affect differences in definitions and (ii) the selection of appropriate analytical frameworks for choosing critical indicators and assessment tools. Because of the complexity of the environment and the different needs of perceived users, it was decided not to rely on a single definition of the coastal zone, but to maintain definitional flexibility. Potential users variously define the coastal zone in terms of four criteria: (i) management units; (ii) human use dynamics; (iii) area of extent, and (iv) ecosystem functionality. These categories helped structure the design of the plan. The central framework is the Driver-Pressure-State-Impact-Response, which focuses on the interrelationship between human society and environmental issues.

The structure of C-GTOS reflects its interface with the Coastal Module of the Global Ocean Observing System, other research and observing system programmes, and the proposed coastal theme of the Integrated Global Observation Strategy (IGOS). Potential users were identified with consideration of those proposed by the Coastal Module of GOOS. Users, or stakeholders, drive the development of C-GTOS. They are the sources

of interest in the issues and variables, the recipients of products from the observing systems and, in some cases, the providers of the observations and financial support.

Observing systems require both field (*in situ*) and remote sensing (satellite and aerial photography) data collected on an ongoing basis. Experts at the workshops selected global and large-scale regional themes and identified a suite of variables and indicators for each. These variables and indicators include (i) human dimensions, land use, land cover and critical habitat alteration; (ii) sediment loss and delivery; (iii) water cycle and water quality and (iv) effects of sea level change, storms and flooding.

Data are harmonized, developed into various information products and communicated to users. At each of these steps, the use of existing and proposed information systems and frameworks is required. The plan identifies these needs, necessary policies and future actions, as well as some first phase implementation products that address data requirements. The GTOS Terrestrial Environmental Monitoring Sites (TEMS) project is one of the information systems identified as central to the identification and cataloguing of data and to the communication of information. TEMS is envisioned as requiring major enhancement to accommodate the needs of C-GTOS. Considerable effort has been made to identify needed enhancements. Many C-GTOS information products will require the distribution and use of geographic information products via the Web, as well as the use of cost-effective PC-based software. C-GTOS will build on existing Web-based information systems such as GeoNetwork of the Food and Agriculture Organization and PC-based products that will also extend information management capacities in developing countries. The volume of data required for C-GTOS and the need to convert those data into information products will require access to advanced informatics techniques and significant capacity development. The information products can be used by stakeholders for policy- and decision-making, and their feedback will provide further information on C-GTOS user needs, in turn providing opportunities for modifications in data collection.

The first phase of C-GTOS will build on a set of readily achievable products that are designed to provide tests of concept for the observing system. These products were chosen based on the needs of the programme and representation of the aforementioned topics of concern. The first phase implementation products are titled as follows:

- enhancement of TEMS;
- distribution and the rate of change of population, urbanization and land use in the coastal environment;
- vulnerability of ecosystem services in deltaic systems;
- management of conservation and cultural sites in the coastal zone;
- distribution of sites appropriate for analyses of delivery systems.

Both initial implementation and development of the mature system have a number of components. Milestones and timelines are proposed for each of the components associated with initial implementation. Beyond these targets, several programmatic elements are required for the development of a mature system. First, it is important to evaluate existing and needed capacity and training in information management, data processing and interpretation (modelling tools), and outreach (including the TEMS and GTOS Web sites). Second, C-GTOS must establish a number of components essential to effective implementation, including a user advisory group, the ability to perform measurements, training and capacity building, product delivery, linkages to other global observing systems and assessments and sustainable funding. Third, the activities of C-GTOS must be integrated with policy and management processes to improve coastal decision-making and resource management. Finally, maintaining programme quality over time will require a process of review and assessment of outcome measures and performance indicators.

Ultimately, the mature C-GTOS is envisioned as being fully interactive and complementary with the coastal activities of GOOS and GCOS. This integration is being fostered through the joint participation of scientific experts involved in the development of the GTOS Coastal Module, and coastal observations within both GOOS and GCOS. In particular, through the development of the integrative Coastal Theme for IGOS. The mature system will require considerable development of capacity in many ways because of the complexity of the landscape and issues of the coast. The approach described in this plan builds on success of priority products to generate the capability, goodwill and enthusiasm of the international community to support a mature observing system.

4.4 *Vulnerability of ecosystem services in deltaic systems*

4.4.1 Overview

The information age has brought the capability to generate huge datasets in almost every area of human endeavour – business, government, genetics and health care, to name a few. The very existence of global observing systems is proposed based on the collection, management, analysis and communication of such datasets. The need to process the vast streams of data has resulted in the development of a new science – the science of informatics. This discipline uses modern computational tools to examine large datasets for patterns, to classify and arrange data and information, to improve understanding of this information and to communicate this in improved and novel ways. This priority product assesses some necessary aspects of informatics for observing system needs through the example of deltaic systems and functional typologies.

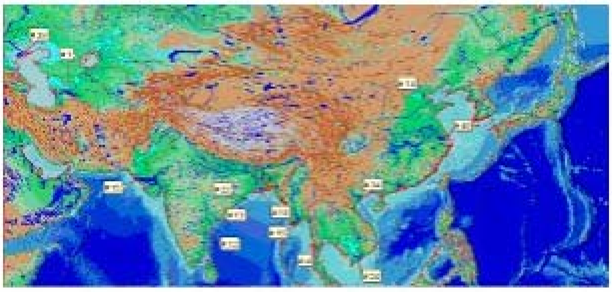

Figure 7. Position of major deltas for which extensive datasets exist

A recent study (Coleman, Huh and DeWitt, 2003) suggests that deltaic systems around the world may be losing land at a global rate of 16 percent per decade owing to a combination of factors. If true, this will have significant implications for human ecological and socio-economic systems and large numbers of people. The drivers of this change seem to be cumulative and include climate change and processes affecting sediment dynamics (e.g. changes in river discharge and hydrologic base level due to dams, sea level and energy change, land-cover change and other factors). Changes in organic production due to climate change may be responsible for the observed land loss, which is occurring mostly in the interior part of deltas (Coleman, personal communication, 2004). The expected impact of sea level rise would be to increase the rate of land loss through coastal erosion and accelerated subsidence. Hydrologic diversions, for example from dams, decrease sediment delivery and thus further tip the scales towards land loss. The world may be losing many of its deltas and along with them many important coastal ecosystem functions.

Data associated with these studies (Hart, 2001; Coleman, Huh and DeWitt, 2003) provide a valuable resource for: (i) development of informatics tools, and (ii) assessments of impacts on ecological services (system-level functions of importance to humanity) and related land use. We propose a series of digital maps, constructed through informatics models, showing the vulnerability of ecological services (and/or opportunities) associated with land use in deltaic systems worldwide, in relation to actual and projected effects of climate and sea level change and alteration of sediment regimes due to the presence of dams. The effort would focus on a subset of the approximately 50 deltaic systems identified for global assessment, for which there are suitable data available (approximately seven to ten deltas at this time). Distribution models will be developed to estimate the extent and kind of potential impacts from combined pressures, in terms of vulnerability and suitability of specific functions in each delta (e.g. goods and services from mangroves, aquaculture, agriculture and other delta-specific land uses). A general cluster of ecological services (functions) related to traditional land use should also be produced, to provide a comparative index of ecological vulnerability for deltaic regions. This project would thus support and demonstrate the overall DPSIR and functional typology frameworks of C-GTOS (presented earlier).

4.4.2 Introduction

According to the latest IPCC report: *"deltas that are deteriorating as a result of sediment starvation, subsidence, and other stresses are particularly susceptible to accelerated inundation, shoreline recession, wetland deterioration, and interior land loss (Bijlsma et al., 1996; Day 1997). River deltas are among the most valuable, heavily populated, and vulnerable coastal systems in the world. Deltas develop where rivers deposit more sediment at the shore than can be carried away by waves. Deltas are particularly at risk from climate change, partly because of natural processes and partly because of human-induced stresses. Human activities such as draining for agricultural development; levee building to prevent flooding; and canalization, damming, and dyking of rivers to impede sediment transfers have made deltas more vulnerable to sea level rise. Where local rates of subsidence and relative sea level rise are not balanced by sediment accumulation, flooding and marine processes will dominate...In the case of largely regulated deltas...significant land loss on the outer delta can result from wave erosion... If vertical accretion rates resulting from sediment delivery and in situ organic matter production (for example in mangrove systems) do not keep pace with sea level rise, water logging of wetland soils will lead to death of emergent vegetation, a rapid loss of elevation because of decomposition of the belowground root mass, and, ultimately, submergence and erosion of the substrate (Cahoon and Lynch, 1997). In some situations, saltwater intrusion into freshwater aquifers also is a potentially major problem."* (Excerpts from IPCC report, Chapter 6: McCarthy *et al.*, 2001).

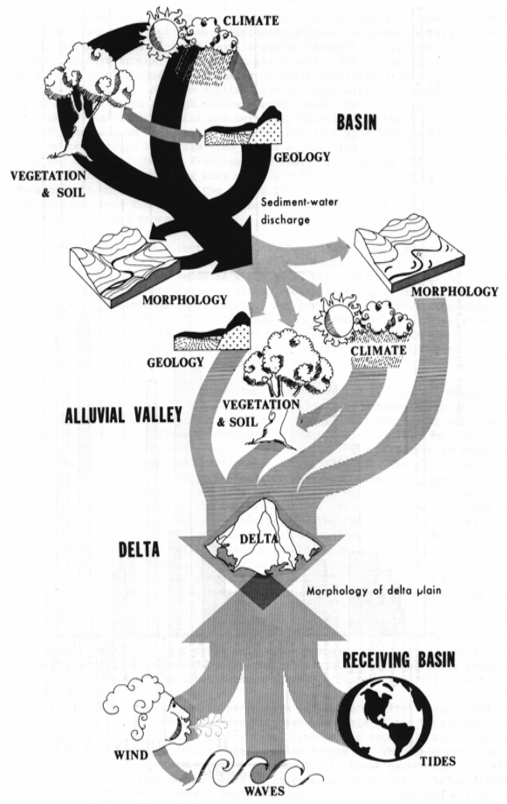

Figure 8. Conceptual model of a deltaic system (Coleman, Huh and DeWitt, 2003)

The effects of anthropogenic alterations of freshwater flow and sediment transport on integrated functions are inadequately modelled in most development plans affecting deltas (Kingsford, 2000). These effects combine with those of climate and sea level change (McCarthy *et al.*, 2001) to increase risks to ecological services and land use potential on which many people depend. Deltas have been identified by the IPCC as ecological areas that are among the most vulnerable to climate-induced sea level change. Furthermore, in perhaps no other system is the C-GTOS functional definition of "coast" better met than in deltas, which are systems that exist as a result of the equal dynamic influence of land and sea processes.

Whereas it is common to classify, analyse, and map ecosystem units on structural criteria (Allee *et al.*, 2000), integrated science may benefit more from the perspective of functional units, whereby geographic extent is not specified as a fixed boundary in the unit definition but is predicted from a model representing functional classifications. Mapping functions of interest in this way can more effectively support assessment of multiple impacts because it can generate highly adaptive information. It also represents an opportunity to apply informatics to the observing system process by modelling patterns and developing visualization schemes for those patterns. Establishing a flexible functional mapping capability would benefit integrated ecosystem research and assessments related to climate change, as identified in the goals of the IPCC and corresponding national programmes. Such assessments seek to characterize systems from an integrated physical, ecological and societal perspective (Pulwarty, 2000), and as a result they require innovative and flexible tools (Huston, 2002; MA, 2003).

4.4.3 Project description

The main product will be a series of digital maps that demonstrate informatics and spatial modelling methods for estimating ecological functions. A limited group of deltas will be modelled and mapped, but the number will grow as part of an effort to promote data sharing and international cooperation. Mapping will then be instituted as an operational part of the mature C-GTOS by being periodically and systematically updated. Thus, this project begins as a research effort but is intended to evolve into an operational component of C-GTOS.

Mapping and analysis will produce indices of condition of deltas. A spatial index of land loss or gain potential can be produced considering actual and projected effects of climate and sea level change, changes in organic deposition, stabilization by land cover, and alteration of sediment loss and delivery and hydrological base-level change resulting from the presence of dams and other water diversions. This index, with other constraints, can then be used to model and map vulnerability and suitability of land use practices in deltaic systems, within various scenarios of sea level change and dam development. For example, this approach can show the feasibility of promoting certain land uses that increase organic deposition or substrate stabilization and that may thereby partly compensate for conditions of deltaic deterioration.

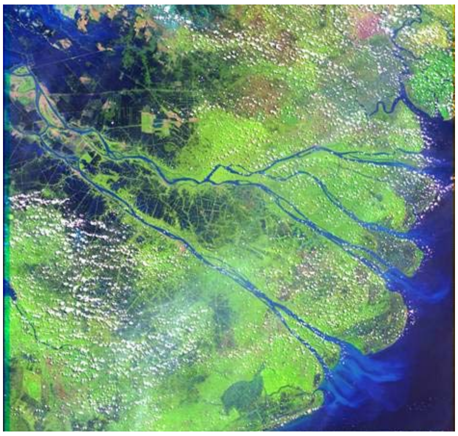

Figure 9. Landsat imagery of deltaic system

A general cluster of ecological services (functions) related to traditional land use will also be produced to provide a comparative index of ecological vulnerability for deltaic regions. Such an index could be added, for example, to UNEP Division of Early Warning and Assessment's (DEWA) proposed "Coastal Vulnerability Index".

Available data and modelling tools make it feasible to do vulnerability analysis for a subset of factors influencing sustainability of ecological services and those deltas for which consistent data have been compiled. This capability will be extensible in the future as new data are organized and made available. Data for this project are available from an initial World Deltas Database, the World Commission on Dams and other sources of important contextual data on elevation, climate, tides, etc., as described below. All project data will be made available from C-GTOS partners and/or the TEMS database.

This effort would help establish a standard set of measures for deltaic systems, focusing on local geologic environments (state variables), natural habitats, human land use, ecosystem services, and significant system drivers. These measures would quantify specific processes of water flow, salinity, sediment loss and delivery, geology and hydrology, organic deposition, stabilizing vegetation, wave and tidal energy, etc., to support future assessment and monitoring. The project would aim at establishing international collaboration on data sharing and research for continuing integrated studies and assessments of deltaic systems. Additional models may be developed as the database grows, to map the suitability and vulnerability of more specific deltaic functions in each delta (e.g. goods and services from mangroves, aquaculture and agriculture, industrial development, habitation, and other delta-specific land uses) under different conditions. This work is needed in view of the cumulative effects of environmental change and human pressures, which may be particularly severe in deltaic regions and for which deltas may be suitable sentinel or early-warning systems.

4.4.4 Methods

Methods exist and are being enhanced to model and map ecosystem functions based on Habitat Suitability Modelling techniques (Rubec *et al.*, 1999; Kineman, 2004). Functions, unlike geographic entities, have only implied geography based on the distributions of their determining or limiting factors and the means by which these factors interact and change over time. They are naturally complex, highly variable, and both context and system dependent; yet we must know them to assess impacts of climate change and human activity on those things that matter most to society. The number of functions of interest is not fixed but is determined by the intersection of natural ecology, human ecology and scientific or management interests. These definitions are dynamic, and hence the most suitable method for mapping them is to employ a model that is not restricted by prior classifications, including geographic units, and that as a result is easily iterated with changing conditions and criteria.

A functional taxonomy (or typology) can be developed for deltas in keeping with the general recommendations in the C-GTOS plan. The desired indices (representing functions of interest) can be modelled and mapped from a generalized "niche" model, using observational data to define the niche dimensions, or controlling variables. This approach requires data for multiple semi-independent variables that define the suitability for ecological functions. Statistical estimates or other available knowledge (including expert knowledge) are used to define mathematical response functions for each controlling variable, which are then combined by the model. Functional response and niche theory (Heglund, 2002; Pykh and Pykh, 2000; Hirzel *et al.*, 2002; Guisan and Zimmermann, 2000; Austin, 2002; Bernert *et al.*, 1997) can be applied to expand the concept of Habitat Suitability Modelling (Schamberger and O'Neil, 1986) for this purpose, combining GIS and spatial modelling capabilities (Peterson and Vieglais, 2001; Rubec *et al.*, 1999).

The proposed project adapts such methods to mapping generalized functional classifications, demonstrating this as a new operational capability. It will produce a corresponding series of maps showing the potential distribution of land use suitability in deltaic ecosystems, as well as integrated indices of their comparative vulnerabilities to the combined drivers stated above. A limitation of this approach is that it does not model dynamics directly, although certain kinds of dynamical changes will be estimated by iterating the technique on those factors that provide feedbacks (such as land cover). Advantages include model simplicity, the integration of data and statistical measures with expert knowledge, and high adaptability and extensibility of the technique.

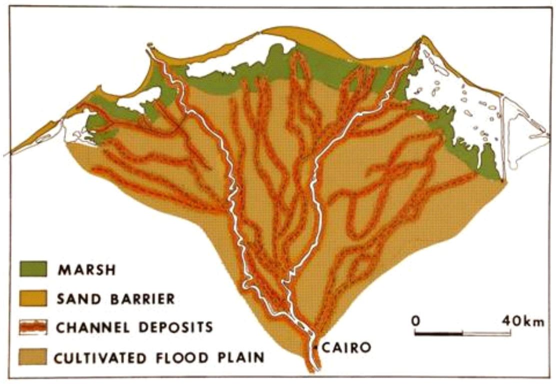

Figure 10. Land cover in the Nile delta

The steps for this project include:

- identifying the functional cluster to be mapped and its component functions (as described above), documenting definitions;
- decomposing the selected function into the physical, biotic and societal factors that most efficiently determine or indicate the spatial (and temporal) distribution of that function in the study region;
- determining physical, biotic and societal response functions for each component controlling the distribution and obtaining the needed data sets;
- constructing niche models for each of the functional components using a suitability model approach;
- linking component models to constitute the functional cluster model;
- producing desired maps from the models, iterating where spatial constraints interact;
- preserving these steps in automated procedures employing appropriate off-the-shelf software.

4.4.5 Data availability

World Deltas Database

Approximately 42 major deltas of the world have been surveyed, and seven of these have been studied in depth with respect to their structural and functional characteristics, natural and cultural land use and processes that determine their stability with respect to sediment loss and delivery and/or sea level change. These data are being made available for general use through national and world data centres. In a typical deltaic analysis, physical subenvironments, drainage basins, land use and other factors are identified and mapped, and hydrologic and sediment balance analyses are performed. The figures in this proposal show examples from currently available data for world deltas, which, combined with other data sources listed below, provide the foundation for the proposed project (Figure 7; Figure 8; Figure 9; Figure 10).

World Commission on Dams

Data on the location, properties, and effects of dams on river flow and sediment loss and delivery are available from the World Commission on Dams.

Digital Elevation Models

Elevation data are currently available from public sources as follows:

- 30 arc-second topography for Antarctica, Asia, Australia, China, and India.
- 3 arc-second (~90 m) coastal elevation and bathymetry for the United States (National Ocean Service/Geophysical Data System).
- 3 arc-second (~90 m) topography for the United States, Canada, Greenland, Europe,

Russia, coastal Africa (except 30 sec for Libya, Somalia, and Ethiopia).

- 1 arc-second (~30 m) topography for Hawaii and Alaska.

Other Data Sources

This effort should be pursued in collaboration with other national and international centres and sources of data, both scientific and cultural, such as the LOICZ delta initiative (http://www.deltasnetwork.nl).

The TEMS Database

Considerable relevant data are accessible through TEMS, and further data will be added by this effort. As TEMS is a metadata server, links from the Web site directly to the primary custodians of the data are provided as part of the TEMS system.

4.4.6 Desired products

- A Web site for world deltas data and research products, presenting applications and examples from this demonstration effort, the general strategy for functional analysis of coastal deltas, and interactive maps with downloadable data.
- Digital maps for a representative number of deltas around the world showing vulnerability of specified ecosystem services (related to land use), to the combined impact of sea level rise and alterations in hydrology and sediment delivery due to dams.
- Models that produce each of the above maps and that can be altered to test assumptions, incorporate new data or ask new questions.
- A full report of methods, results and recommended development pathways. This includes an assessment of the application of informatics to observing system processes.
- Routine periodic updates of products and analysis of change. The maps and indices will be periodically updated as part of an operational, mature C-GTOS.

4.4.7 Importance to GTOS

Functional ecology is the basis for ecosystem geography at all scales. Process and pattern have mutually reinforcing aspects, such that one cannot be determined without the other. The US National Academy of Sciences report *Global Change and Ecosystems Research* (National Academy of Sciences, 2000b) determined that "changes in the structure and function of natural ecosystems," particularly in response to changes in the distribution of human population, are among the most significant changes requiring investigation. The recent US Climate Change Science Program (Moss *et al.* , 2002) strategic plan for "Improving Connections Between Science and Society" identifies a range of ecosystem research and data needs, emphasizing the question: "how do natural and human-induced changes in the environment interact to affect the structure and functioning of ecosystems at a range of spatial and temporal scales, including those functions that can in turn influence regional and global climate?" Illustrative research questions in the USCCSP emphasize "the effects of multiple environmental changes on the structure, functioning, and biodiversity of terrestrial and aquatic ecosystems..." Regarding modelling needs, it emphasizes the need for: "spatially explicit ecosystem models capable of representing complex interactions between diverse ecosystems and the physical/chemical environment" – particularly "for examining the impact of management and policy decisions on a wide range of ecosystems..." The recent IPCC report (McCarthy *et al.*, 2001) recommends priority research into "adaptation options and (adaptation) capacity for coastal zones and marine ecosystems". These programmes are speaking with one voice to recommend stronger ecosystem studies aimed at the functional level. This recommendation represents the evolution of global change science to its current stage, where cumulative effects of complementary causes must now be considered and appropriate tools for doing that must be developed.

4.4.8 Importance generally

Land and sea are linked together in the coastal zone in an intricate network of cross-boundary interactions that underlie ecosystem function. Recent assessment reports (World Resources Institute, 2002; Gitay, 2001; The Heinz Center, 2002) indicate that high rates of change in coastal ecosystem function are of major concern both internationally and nationally as anthropogenic and natural change combine inharmoniously to disrupt and either temporarily or permanently degrade ecosystem goods and services. The human-altered mosaic of coastal ecosystems increasingly restricts policy and management options for responding to these changes.

The World Resources Institute summarized the status of information on coastal ecosystems in their report *Pilot Analysis of Global Ecosystems* (Burke et al., 2001), making the following recommendations:

- Information on the location and extent of coastal ecosystems is very incomplete and inconsistent at the global level.
- Historical data describing previous extent of habitats, against which we might hope to measure change, are very limited. Where no historical data exist, the possibility of predictive mapping should be considered, using existing climatic, oceanographic and topographic data combined with biogeographic information.
- There is an urgent need for better and more consistent classification schemes and datasets characterizing the world's coasts.

These problems are typified in the problems facing the sustainable management of deltaic systems, which represent microcosms and early warning systems for many of these issues.

4.4.9 Anticipated users

The unique combination of data resources and methodological development represented in this demonstration effort is intended to catalyse or support an international focus on assessment of deltaic ecosystems that will continue to develop data and model sharing as an evolving community. Many of these potential users have been previously identified for C-GTOS (section 1.4.1). Finally, users of the general approach are expected from other science and management communities involved in the coastal zone, and methods should be applicable to similar mapping needs for ecosystems in other biomes.

4.4.10 Timeline and implementation options

The proposed demonstration should be feasible as a short-term (1- to 2-year) effort conducted by a small spatial ecological modelling team. The participants in this C-GTOS planning effort are familiar with, and in several cases represent, suitable capabilities and facilities for producing the proposed product and can thus either participate in production or help guide it. Work may also be combined with existing projects to explore such informatics needs for regional integrated ecosystem assessments. Management of the deltas database is currently being discussed. Various proposals have been submitted to develop the proposed spatial modelling capabilities for other applications. Synergistic support can thus strengthen a request for proposals on this topic. The efforts will continue throughout the development of C-GTOS through the periodic (every 5-10 years) updating of maps and indices.

Table 14. Web sites and organizations providing additional information on deltas

Web sites and organizations	URL
World Commission on Dams	http://www.dams.org/
Smithsonian Deltas-Global Climate Change Program	http://www.nmnh.si.edu/paleo/deltas/
NASA Geomorphology from Space (Ch. 5: Deltas)	http://daac.gsfc.nasa.gov/www/geomorphology/
Indian Deltas (Prof. G.F. Hart)	http://www.geol.lsu.edu/deltaweb/ http://www.geol.lsu.edu/deltaweb/INDIARPT/india.htm
World Conservation Monitoring Centre	http://www.unep-wcmc.org/
Ramsar Convention on Wetlands	http://www.ramsar.org/
World Resources Institute	http://www.wri.org/
San Francisco Bay – Sacramento/San Joaquin Delta GIS	http://www.regis.berkeley.edu/baydelta.html
Environmental Atlas of the Lake Ponchetrain Basin	http://pubs.usgs.gov/of/2002/of02-206/index.html
Louisiana Statewide GIS	http://atlas.lsu.edu/search/searchAtlas.htm