Chapter 7

Building Links with the Fishing, Aquaculture and Management Communities

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7.1 Introduction

Globally, fish are an important source of protein, and fisheries and aquaculture are critical to food security in many countries. Effective sustainable management of these fisheries is required at national and international levels so that fish stocks can contribute to meet global nutritional needs. At the international level, marine resource management has moved on from a single species stock assessment and management approach to a more holistic 'Ecosystem Approach to Fisheries' (EAF), or variations on the theme (FAO, 2003; Garcia *et al.*, 2003; Daan *et al.*, 2005; Pitcher *et al.*, 2008). EAF still includes single species stock assessment but is expanded to minimally include the wider impacts of fishing on the ecosystem, the role of the environment on species dynamics, the impacts of other activities and the engagement of stakeholders in the processes leading to decision making (Rice, 2008).

Remote sensing of the ocean is relatively new, but is now being applied globally to many areas of ocean resource use and management. The scale of remote-sensing data makes it suitable for local, regional, national and international studies, with applications to ecosystem approaches to fisheries (Polovina and Howell, 2005; Platt and Sathyendranath, 2008), including the role of the environment on species dynamics, the wider impacts of fishing or other activities on the ecosystem, and more directly in relation to fisheries assessment, management and operations, for example, to generate maps of potential fishing zones (PFZs) for the fishing community (Solanki *et al.*, 2005). Other applications include ecological and process studies of the ocean (Ware and Thomson, 2005; Chassot *et al.*, 2007), climate change, and marine aquaculture. However, the scope of remote sensing is far greater. Wider applications may include coastal issues, oil and gas development, marine protected areas and others.

There is a strong consensus that Earth observation data could play a major role in providing the appropriate information to support fishery management. Operation costs of resource management could be lowered significantly by the availability of improved information on the environmental variables controlling the condition of marine resources through remote sensing. The traditional means to collect marine data by sea-based systems is expensive and time consuming. As a result, the derived information available to key users is often incomplete and inadequate. Despite the potential of satellite data to dramatically improve the monitoring of marine waters and its resources, several constraints to its use have been identified by the operational community, such as inadequate data access and an inadequate system of analyzing and disseminating this information to the communities outside of the research community. The challenge is to develop better links between the remote sensing world and the communities who can use this data, e.g., scientists, the fishing and aquaculture industries, managers and policy makers. These are the people who have the questions and applications that remote sensing can address.

Many applications of remote sensing data use SST, chlorophyll, and sea surface height. Global coverage of satellite-derived time-series of these data extend back at least a decade. The continuity, global coverage, and high temporal and spatial resolution of these datasets make them an important tool for monitoring and characterizing marine ecosystems. However, the huge scale of this data can be a challenge, even to building links with scientists. There are a number of reasons why remote sensing data can be challenging to use:

- Satellite data can be difficult to access, manipulate and process, particularly for people who have never used it before.
- Work required to get relevant parameters can be cumbersome, ie:
  - primary productivity from chlorophyll;
  - front locations from SST fields;
  - climatologies required to generate anomalies;
  - rigorous ‘data mining’ needed to match up satellite data with telemetry records;
  - ‘one-stop’ satellite data shopping desired.
- People are too busy with their regular workloads to find time to familiarize themselves with new analyses.
- Time-series of satellite data are relatively short compared to many fisheries datasets.

The most direct way to overcome these problems are to form interdisciplinary research teams to address key questions (e.g., Platt *et al.*, 2003; Fuentes-Yaco *et al.*, 2007; Chassot *et al.*, 2007; Friedland *et al.*, 2008; Koeller *et al.*, 2009), where remote sensing scientists team up with fisheries scientists. However, there is a limit to this process, and more questions and issues need to be addressed than there are remote sensing scientists to answer them. In the United States, NOAA is developing novel ways to build these linkages, such as training workshops and facilitating data use and access (Section 7.1.1).

This interdisciplinary approach to research can also extend into management of resources. In Florida, USA, the case of the management of industry wastewater in 2003 presents an example of how the various stakeholders, including managers, policy makers, fishing community, scientists, and the general public worked together to address an emergency situation whereby there was a high risk that 1.2 billion gallons of acidic and phosphate-rich wastewater would spill into the nearby Tampa Bay estuary (Section 7.1.2). Remotely-sensed data played a critical role in the successful management of this emergency situation by providing information about currents and possible dispersal sites, and the subsequent monitoring of dispersal of phosphate-rich water which could potentially cause harmful algal blooms.

In some cases, specific tools have been developed that connect scientists and resource managers to satellite data, at the local, national and international level. At the local level, for example, Borstad Associates have developed the Satellite Image Portal to provide a simple, accessible interface for users of Earth observation image data (Section 7.1.3). Its focus is on secondary products of interest to scientists and managers in fisheries and aquaculture sectors. At the national level, the Indian National Centre for Ocean Information Services (INCOIS), provide 'Potential Fishing Zone' (PFZ) advisories to the Indian fishing community. The PFZ advisories are generated using satellite-derived sea surface temperature and ocean-colour data, which fishermen use to maximize efficiency in locating their catch (http://www.incois.gov.in/Incois/advisory_pfz_main.jsp, see Chapter 5 for further details). The Netherlands Agency for Aerospace Programs (NIVR) funds projects through its 'User Support Programme', whose objectives include support for users of Earth observation data and the development of new applications for scientific research, industrial and policy research, and operational use. They partially funded a project which used remotely-sensed chlorophyll-*a* maps derived from MERIS, together with *in situ* data collections and bio-physical modelling, to detect and characterize harmful algal blooms in Dutch coastal waters. The outcome of the project is a prototype system that combines near-real-time forecasting with MERIS and a bio-physical model.

Managing wild populations requires estimates of their abundance. A relatively simple use of remotely-sensed imaging data is being evaluated by biologists of the Marine Mammals Management office (Washington, USA), who are responsible for ensuring that Pacific walrus in Alaska remain within an optimum sustainable population range and that they continue to be a healthy, functioning component of the Bering and Chukchi Seas ecosystems. They are exploring the use of QuickBird high-resolution satellite imagery as a tool for population monitoring of the Pacific walrus, since Pacific walrus are sufficiently large to be detected individually by high-resolution satellite imagery (http://www.csc.noaa.gov/crs/rs_apps/issues/quickbird_walrus.htm).

7.1.1 Building links with resource scientists and managers in the USA

In the United States NOAA has been working on developing linkages between the remote sensing community and fisheries scientists, managers, and policy makers. In 2005 NOAA started holding satellite courses specifically designed for marine resource managers. These courses have two primary benefits. In addition to the primary goal of educating managers about the availability of satellite data, and showing them how to access and utilize the data, the courses provide a better understanding of users' needs and requirements, allowing those needs to be better addressed. There are a number of ways that the accessibility of available satellite data can be enhanced, for example, by data transport procedures that allow data to be subset spatially and temporally, and by client-side applications that directly import satellite data streams into the software traditionally used by resource managers. For example, many marine resource managers use ArcGIS products as decision support tools, however importing satellite data into ArcGIS has traditionally been a cumbersome process at best. To address this problem, NOAA had an ArcGIS extension developed which allows users to browse existing on-line catalogs of satellite data, subset them spatially and temporally, and bring them directly into ArcGIS, resulting in a significant savings of time and energy (tool for importing satellite data in ArcGIS: `www.pfeg.noaa.gov/products/EDC/`). Another example is the process of matching up environmental satellite data with telemetry records of tagged animals to better understand and characterize their habitat. Mining global datasets of satellite chlorophyll, SST or SSH for the synoptic values associated with a telemetry track is a daunting task for most marine biologists unaccustomed to working with large satellite datasets. However, utilizing the data transport capabilities of THREDDS catalogs and OPeNDAP servers, simple scripts (for R and Matlab) have been written to automate this process and are being distributed to marine biologists (`http://coastwatch.pfel.noaa.gov/xtracto/`.

7.1.2 Remote sensing and the management of waste water

The case of the management of industry wastewater in Florida, USA in 2003 presents an example of how the various stakeholders worked together to address an emergency situation.

In early 2001, a phosphate fertilizer plant claimed bankruptcy and left 1.2 billion gallons of acidic and phosphate-rich wastewater unattended in open-air holding ponds, threatening to spill into the nearby Tampa Bay estuary as the ponds gained volume with seasonal Florida rains. Such a disaster occurred in December 1997 when the spill of 50 million gallons of the acidic wastewater from another plant into the Alafia River killed over 1 million fish and severely damaged local wetlands.

The Florida Department of Environmental Protection (FDEP) implemented various methods to manage the wastewater and impending danger to the estuary. Yet, heavy rainfall was expected throughout 2003, forcing FDEP to find fast solutions. In the process of converging on a best solution, FDEP consulted with environmentalists, fishermen, resource managers, and the general public as well as scientists, and obtained an emergency permit from the U.S. Environmental Protection Agency (EPA) to discharge the wastewater into the Gulf of Mexico using barge operations, after treatment (to meet all EPA standards). From 20 July to 30 November 2003, about 248 million gallons of treated wastewater were discharge into the Gulf through 35 barge trips.

Satellite remote sensing played two important roles for this emergency management. Before the dispersal, satellite data were instrumental to help outline the area where the barge would discharge the water (Figure 7.1). This was through the analysis of real-time satellite data to determine the position of the Loop Current, a strong oceanic current that can quickly carry water and materials away. During and after the dispersal, satellite data provided timely and accurate information to evaluate the potential adverse impact of the wastewater discharge on the coastal water environment (e.g., would the discharge stimulate harmful algal blooms?).

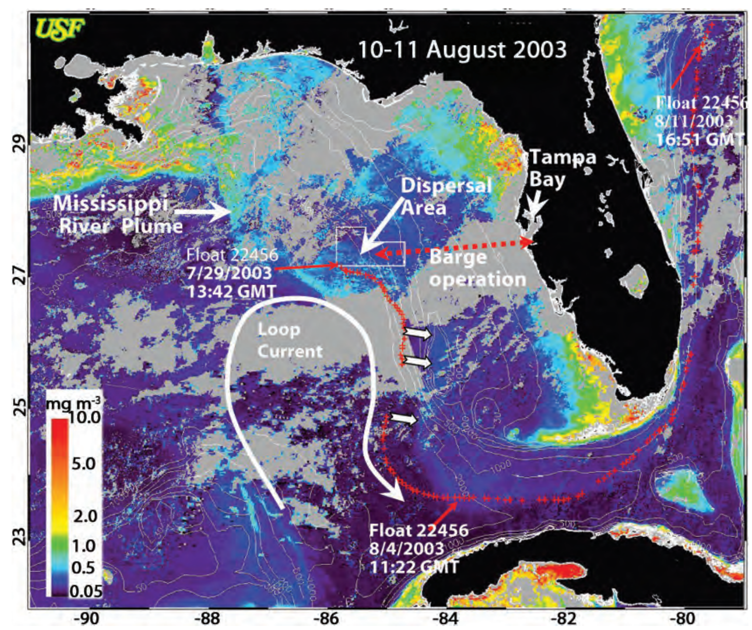

Figure 7.1 MODIS chlorophyll-*a* concentration for 10 to 11 August 2003, when ~27-million gallons of treated wastewater was dispersed in the Gulf of Mexico beginning on 20 July 2003. Overlaid on the image is the track of one Argo drifter (small red crosses) that drifted with the Loop Current. The Loop Current movement direction is indicated by the white arrows.

Over the course of the dispersal operation, satellite data were analyzed daily to examine satellite chlorophyll concentrations and ocean-colour patterns, which were compared with historical conditions during similar periods (Hu and Muller-Karger, 2003). The results showed that there were no anomalous variations in chlorophyll on the west Florida Shelf or waters near the Florida Keys. There was no evidence of enhanced biological activity near or downstream of the discharge area due to the immediate water advection and dilution through the Loop Current. There were only a few cases where increases in chlorophyll concentration (0.01 to 0.02 mg m^{-3}) were detected in a limited area downstream of the dispersal location. These increases were negligible, and indeed could only be detected by MODIS satellite imagery and not by shipboard instruments.

It is clear that the successful management of this emergency situation could only have been achieved through collaborative efforts between the various stakeholders including managers, policy makers, fishing community, scientists, and the general public. Satellite remote sensing plays a significant operational role in monitoring our marine environment and in helping make management decisions.

7.1.3 Borstad Associates/GRIP geographic data portal

The Borstad Associates Ltd./GRIP geographic data portal was designed to provide a simple, accessible interface for users of Earth observation image data. It uses a GIS interface and currently provides 9-km, 8-day CZCS, SeaWiFS and MODIS imagery for the global northwest hemisphere (0 - 90°N, 0 - 180°W), as well as 1-km and 300-m daily MODIS and MERIS imagery for the west coast of Canada, Newfoundland and the Great Lakes (Figure 7.2). The focus is on secondary products of interest to scientists and managers in fisheries and aquaculture sectors, and includes chlorophyll, SST, $nL_w(551)$, K_{490}, and MERIS estimates of yellow substances and total suspended material.

In order to provide data in a timely manner to the user community, the imagery is automatically downloaded and processed on-site daily, with 1-km MERIS reduced resolution data available same day, and SeaWiFS and MODIS with a 2 to 4 week lag. MERIS Full Resolution (FR) products are of greatest interest to the aquaculture industry, since their 300-m spatial resolution provides usable information within the narrow inlets where the majority of British Columbia fish and shellfish farms are located.

Of additional interest to the scientific community is the interactive 'Temporal Profiler', which returns time series of chlorophyll, SST, $nL_w(551)$ or K_{490}, for the currently selected image location. Data values are retrievable in ASCII format by mouse click. Other tools under development include a 'Temporal Transect Profiler', which at present generates contour plots of chlorophyll along a user selected spatial transect over time, and 'Temporal Animations' of SeaWiFS chlorophyll imagery.

At present the most common users of the geographic data portal are oceanographers and fisheries scientists interested in coastal and ocean climate related phenomena. As MERIS high resolution imagery becomes increasingly available, the site is attracting more interest from aquaculture operators and managers. This type of usage is expected to increase now that MERIS FR imagery is accessible in near real

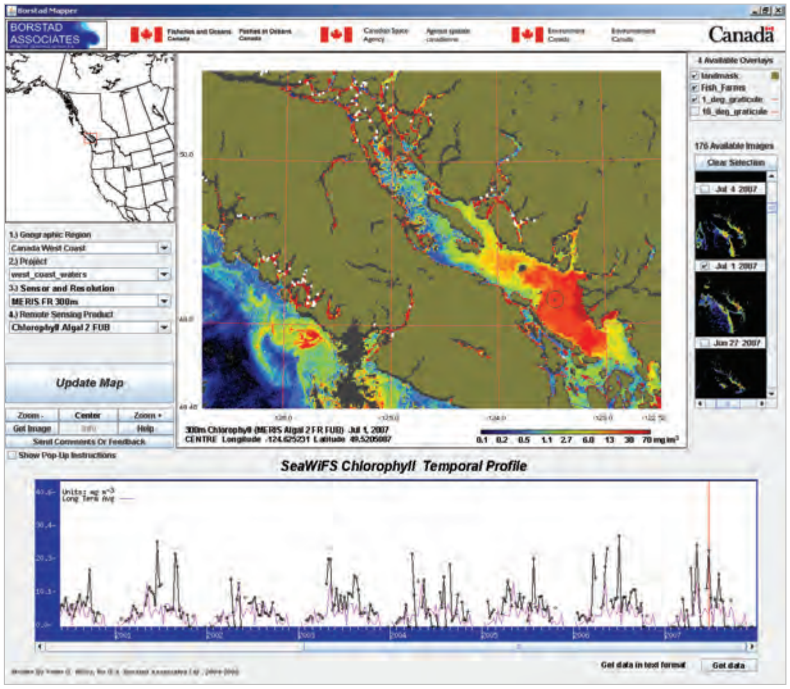

Figure 7.2 GIS interface for the Borstad Associates Ltd./GRIP Geographic Data Portal.

time.

Development is continuing on the project, with support from the Canadian Space Agency via the Department of Fisheries and Oceans and Environment Canada, and from Borstad Associates Ltd. It is anticipated that the Earth observation data currently available will soon be supplemented with additional oceanographic data, including winds, currents, and possible links to ARGO buoy data or AVHRR imagery. The Image Portal can be accessed at `http://www.borstad.com/grip.html`.

7.2 Network, Capacity Building and Coordination

As discussed in this monograph, satellite data can be an invaluable means of estimating chlorophyll-*a* for monitoring of harmful algal blooms, aiding fishing operations, fisheries management and coastal zone management. However, many potential users, particularly in developing countries, do not have the infrastructure to download and process, or even view, the data. Similarly, in-water sampling of chlorophyll-*a* to validate the satellite images is also very limited. Furthermore, networking and capacity building are needed to share experience on the exploitation of satellite data to support fishing and aquaculture management.

Two main factors influence the extent to which satellite ocean-colour information is used in fisheries studies: the reliability and the availability of these data. To improve the reliability of the satellite chlorophyll (a proxy for phytoplankton abundance), more bio-optical and biological studies are needed in the world's various seas and oceans. This will allow the validation of the satellite products with high quality *in situ* data, and the regional adjustment of the algorithms used to estimate the quantities of interest. This is particularly true for many coastal areas where sparse *in situ* data are available for validation of satellite information. The second factor, the availability of data, has also been mentioned as a limiting factor in the use of remote-sensing data in fisheries oceanography (Podestá, 1997). There have been great advances since the beginning of the ocean-colour era, but despite the free availability of large volumes of data, as noted above, these are often not in a user-friendly format for the non-specialist.

Tools to handle geographical or spatial data have developed rapidly within the last decade and are becoming very useful in the study of marine ecosystems regarding database creation, monitoring, mapping and visualization. For example, GIS enables the integration of data from multiple and disparate sources, and also provides an excellent platform to communicate results of scientific studies to a wider community including the policy makers.

Networks provide an efficient way to tackle both aspects of data distribution. A network with centres performing biological oceanographic studies in different countries, allows *in situ* data to be gathered in a unified database from distant places, and also helps enhance studies carried out at each centre through the commitment of the members to share data, resources and especially expertise. Belonging to a network generates a sense of participating in something larger than one's own individual study at a local site; it also enhances local results by bringing them into a larger regional and ultimately global picture.

7.2.1 Antares network

An example of such a network is the Latin American Antares (Figure7.3), which was fostered by the IOCCG and the Partnership for the Observation of the Global Oceans (POGO). The network was built on ongoing initiatives in different countries in the Americas, including both remote sensing and *in situ* observations. At the moment around 30 researchers from 7 countries, including local scientists from Latin America and consultants from North America, are members of the network. It is proposed to link *in situ* data from the time series stations with remote sensing observations, creating an integrated database for scientific, educational and management purposes. Antares has a website (`http://www.antares.ws`) where satellite information (daily images and ASCII data) of sea surface temperature and chlorophyll (from MODIS obtained from NASA and processed at the Institute of Marine Remote Sensing, University of South Florida) is openly and freely delivered in an easy to use format. Future work should promote the growth of the network, incorporating new centers from different countries in the region, as well as strengthening the *in situ* time

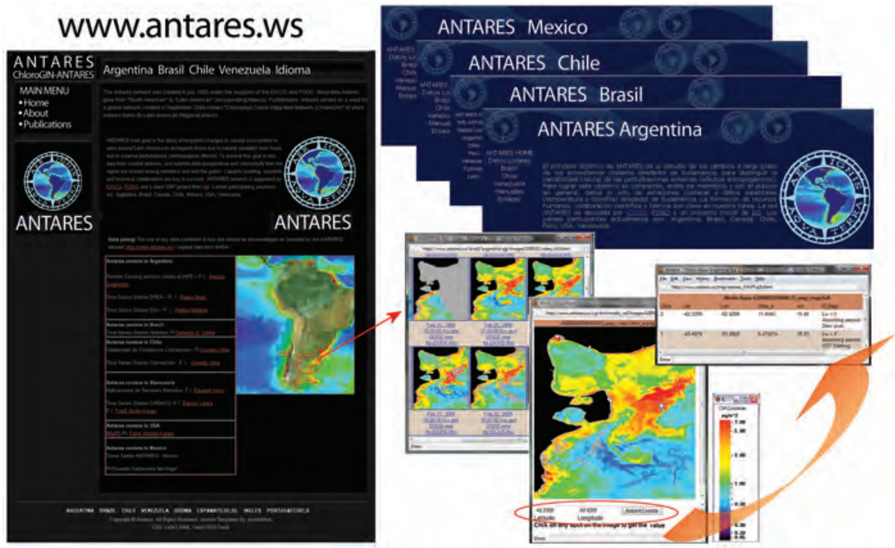

Figure 7.3 Screenshots of the main ANTARES portal (left) and the regional web sites of member countries (upper right) containing local information. Level-2 mapped MODIS chlorophyll-*a* and SST products for selected areas (grey areas in the map) are available in HDF and ASCII format. Images can be downloaded via FTP, and data for individual pixels can be retrieved by specifying the coordinates or clicking on the image via a user-friendly interface (lower right).

series stations, and the facilities offered from satellite information through the website. At the moment at least five research groups in Argentina are starting to use satellite information provided on the Antares website for their research on the distribution and abundance of hake, red Patagonian shrimp, anchovy, king crab, and other coastal commercial fish species.

7.2.2 ChloroGIN network

The Antares network was extended to create the Chlorophyll Global Integrated Network (ChloroGIN) which was established in September 2006. A model for providing remote-sensing data via regional 'centres of excellence' as well as protocols for *in situ* calibration and validation of the satellite products was developed. Satellite data are processed at a number of regional centres and supplied via the internet to a network of end users in developing countries

In South Africa, the ChloroGIN network is used mainly for monitoring harmful algal blooms (HABs) and issuing warnings about potential harmful blooms several days beforehand. This is very helpful for the oyster and mussel mariculture industry and also for rock lobster stock management. In the latter case, the resulting decay of blooms causes a reduction in oxygen concentration of coastal waters which in turn can result in lobster migrations, or even large-scale walkouts onto the shore, with disastrous consequences for the lobster industry.

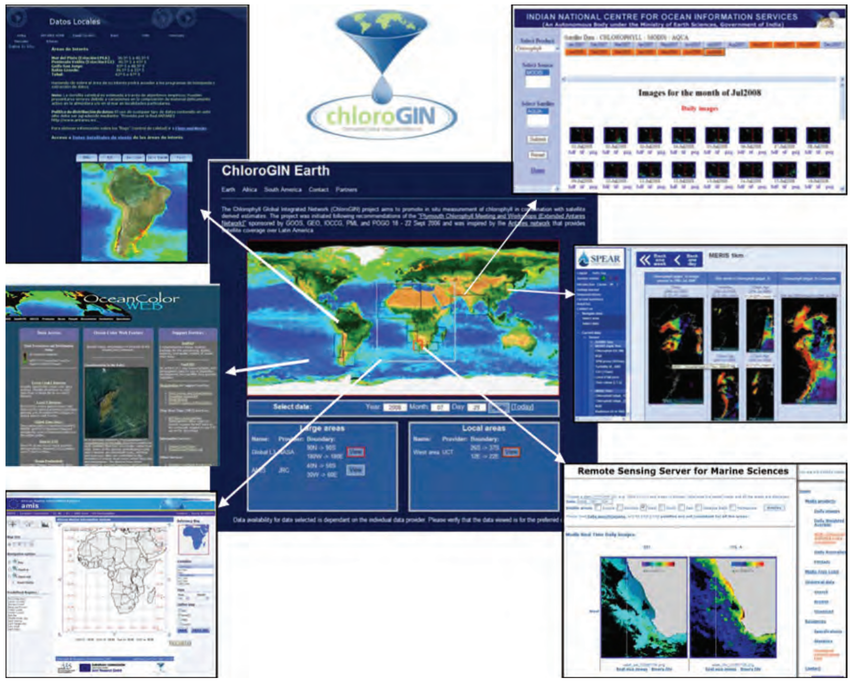

Figure 7.4 ChloroGIN portal (centre) with shots of the websites of various regional and global data providers.

ChloroGIN has created a web-portal (Figure 7.4) that provides links to existing suppliers of regional and global data in South Africa, Latin America, India, the UK, the USA and the EC Joint Research Centre (see `http://www.chlorogin.org/world/`). These provide regular chlorophyll-*a* images and associated products such as SST and other variables (daily, weekly or bi-weekly, depending upon each region's needs and conditions). The web page shows a number of regional areas and mouse clicking within any one will link to the regional data provider's web site. These include, notably, the Indian PFZ information and the South African coastal monitoring for HABs. Clicking outside a regional box provides a link to global chlorophyll-*a* from NASA.

Although still at an early stage, ChloroGIN is already providing a focal point for development of international collaboration, networking and capacity building. As an example, ChloroGIN partners from Africa and Europe are participating in a European Framework project called DevCoCast (GEONETCast applications for and by Developing Countries). GEONETCast is a system whereby environmental data can be distributed at low cost, to and from developing countries with poor internet infrastructure, using satellite based Digital Video Broadcast technology. DevCoCast is using the GEONETCast concept to provide satellite data on chlorophyll-*a*, other ocean-colour products and SST from MODIS, AVHRR and MERIS from regional data providers in South Africa and Europe to countries in Africa (Namibia, Tanzania,

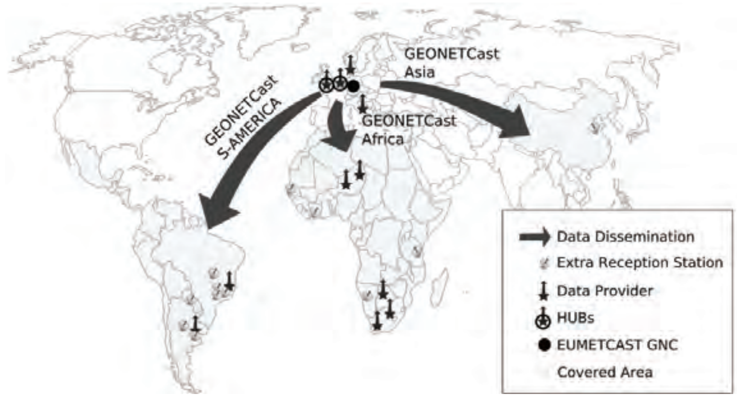

Figure 7.5 DevCoCast data flow diagram

Ghana and Senegal), South America (Brazil) and Asia (China). It will also improve the infrastructure by installing a number of GEONETCast receivers at marine science institutes (see Figure 7.5).

Looking to the future, another aim of ChloroGIN is to develop tools to support fisheries and aquaculture management including the integration, comparison and analysis of satellite data with *in situ* samples and numerical model forecasts as well as derived products such as current or bloom frontal locations, and positions of blooms in relation to territorial or province boundaries. Two systems are the JRC-AMIS system and the InterRisk system.

7.2.3 The African Marine Information System

The African Marine Information System (AMIS, `http://amis.jrc.ec.europa.eu/`) was recently developed as part of the European Commission – Joint Research Centre ‘Observatory for Sustainable Development’ (`http://acpobservatory.jrc.it`). It was established under the EU sustainable development strategy (CEC, 2002) to provide the user community at large with appropriate bio-physical information to conduct water quality assessment, resource monitoring and climate change studies in the coastal and marine waters around Africa.

AMIS is a simple and easy-to-use mapping tool application, developed for the publication and dissemination of African marine information via the web (Figure 7.6). The system relies mostly on Earth observation data from optical and thermal sensors processed according to standard (i.e. space agency-related) and in-house peer-reviewed algorithms. It includes:

- ❖ provision of continuous, detailed and accurate information on relevant marine biophysical parameters as derived from optical, and infrared satellite sensors;
- ❖ generation of indicators for global diagnostics of the coastal state and analyses of changes in marine ecosystems;

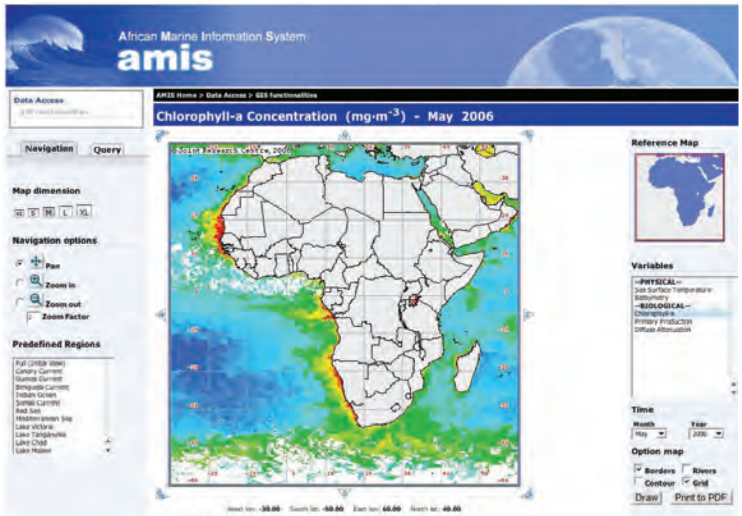

Figure 7.6 Screen shot of the AMIS internet webpage.

- optimization and implementation of an interdisciplinary system of marine resource information and analysis (GIS) to enable decision makers and the public to make full and lasting use of this information.

At present, the user can automatically generate maps, scatter plots, histograms, and time series in a format ready for publication. AMIS applications range from water quality management, monitoring issues that can impact on the ecosystems and resource distribution (e.g. HABs, coastal pollution) to climate studies, examining interactions between marine resources and major forcing variables. The system is extremely fast and simple, resulting in a very practical and useful high level user application.

7.2.4 InterRisk

InterRisk (Interoperable GMES Services for Environmental Risk Management in Marine and Coastal Areas of Europe) is a European Framework project that is building systems to demonstrate web-based integration of various data types from different countries and suppliers in order to better manage coastal pollution events. Since it is web-based, it only requires a browser (such as Internet Explorer) as opposed to specialist and expensive local software. The system includes near-real-time satellite data that can be inspected for high chlorophyll-*a* events (possibly related to eutrophication or HABs) and compared to long-term means and standard deviations from 10 years of SeaWiFS data. The system will also allow, *inter alia*, comparison of satellite data to model forecasts or *in situ* measurements of phytoplankton, overlaying of depth contours, maps of Exclusive Economic Zones, location of bathing beaches, juvenile fish nursery beds, LME boundaries or Longhurst provinces. The

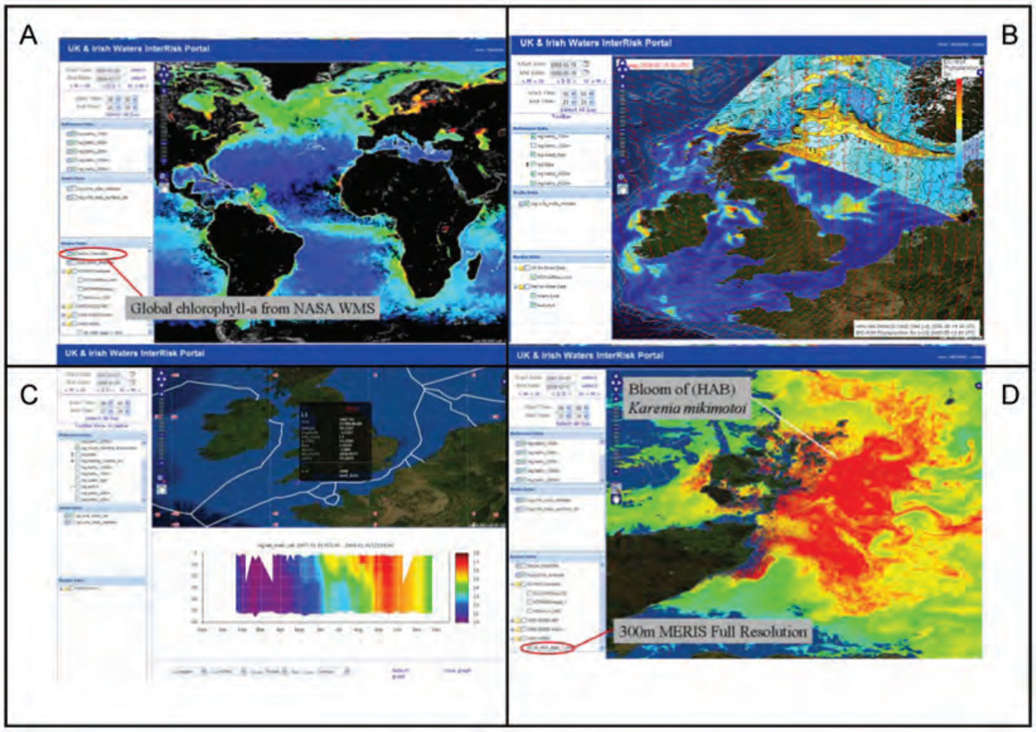

Figure 7.7 Screenshots of the PML InterRisk portal (see `http://www.npm.ac.uk/rsg/projects/interrisk/`). a) global coverage with NASA MODIS chlorophyll-*a* overlaid with bathymetry; b) integration of phytoplankton model output from the UK and Norwegian Met Offices, modelled surface winds, and *in situ* moorings (PML); c) density plot of *in situ* temperature with depth for station L4 south of Plymouth also showing EEZ boundaries; d) MERIS 300 m chlorophyll-*a* image showing a bloom of the harmful *Karenia mikimotoi* around the Orkney Islands July 2006.

system is shown in Figure 7.7 with various screenshots showing data integration, comparison and web-based plotting of *in situ* data sets.

7.3 Looking into the Future

Tremendous strides have been made in satellite remote sensing over the past few decades. What is striking is that the first global ocean-colour image took many months of processing to achieve. Now these are produced routinely, every day. Initially, very different processes were involved in generating ocean colour and sea surface temperature images, but now we have the tools to produce such images, and composite images, on the same scales and integrate them with other remotely-sensed observations (e.g. wind vectors and altimetry). It is becoming relatively easy to incorporate these into models and predict the movement of oceanic features such as fronts, eddies or upwelling that can be used for fish harvesting and management purposes. Remotely-sensed data provides information to calculate objective ecosystem indicators that can be applied in operational mode as an aid to rational management of the oceans (Platt and Sathyendranath, 2008; IOCCG 2008). With the growing time series of data, the information provided by these ecosystem indicators will improve. Thus information and software will become more widely available, user friendly, and accessible to managers rather than just to specialist remote-sensing scientists. This volume contains many examples of applications of remote sensing for the benefit of society, illustrating the advances that have been made. We can expect to project similar rapid developments into the future. This latter point is fundamental since remote sensing provides a global vision in an era of climate change and highly impacted and deteriorating marine ecosystems (Halpern *et al.*, 2008; Bundy *et al.*, 2009; Shin *et al.* 2009). As we move nationally and internationally through agreements such as those forged at the 2002 World Summit on Sustainable Development to anticipate, ameliorate and combat these global impacts, remotely-sensed ecosystem indicators give insight into the state and rate of change of the world's oceans and ocean ecosystems.