Chapter 5
Spatial Data Infrastructures for Coastal Environments

Dawn J. Wright

Central to this chapter is a review and discussion of the "data portal" as the primary means for search, discovery and download of spatial data. Discussed are some of the most pressing challenges to effective implementation of portals within the broader context of a spatial data infrastructure or SDI. Potential solutions are featured via two major case studies of interest to practitioners in coastal ecosystem assessment and management. While there are numerous projects that can be pointed to as successful case studies to emulate, the projects highlighted, along with related efforts and initiatives, are significant demonstrations of innovation, implementation, and practice, from which lessons can be learned. And finally, as critical as a data portal may be to successful SDI implementation, so too are the partnerships behind the portals, which are discussed at chapter's end with a consideration of virtual communities as an emerging necessity.

5.1 Introduction: The Continuing Challenge of Data

This chapter is about the effective sharing of digital data sets for practitioners in coastal and estuarine ecosystem assessment and management. Digital data sets continue to grow exponentially worldwide, especially with recent launches of high-resolution satellite systems (e.g., Carlson and Patel 1997, UÇa et al. 2006, Zibordi et al. 2006) and the increasing ease with which digital imagery, video, and sound are delivered over the Internet. Digital libraries have largely achieved the initial vision of enabling 24-h access to digital papers, journals, books, and data (Buttenfield and Goodchild 1996, Buttenfield 1998, Beard 2007). And with the steady rise in the adoption and use of remote sensing and geographic information systems (GIS), there continues to be a proliferation of digital geospatial data available, along with a considerable increase in the number of users and producers of these data, making access and effective integration a very difficult challenge (e.g., Nedovic-Budic 2002).

D.J. Wright (✉)
Department of Geosciences, Oregon State University, Corvallis, OR 97331, USA
e-mail: dawn@dusk.geo.orst.edu

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Indeed, our entire society has changed from being data-poor to data-rich, but our ability to derive knowledge and management decisions from all of these data in an analytical context remains poor. This is especially problematic in the dynamic zones of coasts and estuaries where it can be difficult to capture features accurately in both space and time or to adequately monitor and manage resources (Kracker 1998, Cimino et al. 2000, Wright and Bartlett 2000, Valavanis 2002, Paul et al. 2003). Government agencies, businesses, academic institutions, and even non-profit organizations all have a tremendous stake in the development and management of geospatial data resources, especially in the coastal zone where, worldwide, 20% of humanity lives less than 25 km away from the coast, and 39%, or 2.2 billion people, live within 100 km of the coast (World Resources Institute 2000). Any problems that remain in finding data are now compounded by the additional challenge of effectively filtering through large volumes of them in order to find meaningful knowledge. From an organizational perspective, although geospatial data sets are legion, there has been a general inability and often unwillingness to exchange data across boundaries, exacerbated by low levels of coordination (Mapping Science Committee 2001, Nedovic-Budic 2002, de Man 2007).

Several nationwide partnerships have been launched in order to build a spatial data infrastructure or SDI, defined in U.S. Presidential Executive Order 12906 as, "the technologies, policies, and people necessary to promote sharing of geospatial data throughout all levels of government, the private and non-profit sectors, and the academic community" (www.archives.gov/federal-register/executive-orders/pdf/12906.pdf). A similar definition may be found in Masser (2007) or Craglia and Annoni (2007) on behalf of the Infrastructure for Spatial Information in Europe (INSPIRE): "both technical and non-technical issues, ranging from technical standards and protocols, organizational issues, data policy issues including data access policy and the creation and maintenance of geographical information for a wide range of themes"; or in Nebert (2000) on behalf of the Global Spatial Data Infrastructure (GSDI): "the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data" (www.gsdi.org/pubs/cookbook/).

In the U.S., federal and state governments, commercial entities, universities, and non-governmental organizations have all worked to create searchable metadata catalogs that enable users to search descriptions of geospatial datasets as contained in web-based clearinghouses. Notable efforts in the U.S. include the Federal Geographic Data Committee (FGDC, www.fgdc.gov), the Geospatial One-Stop (GOS) Initiative (gos2.geodata.gov), and The National Map (nationalmap.gov), all of which share the goal of building the U.S. National Spatial Data Infrastructure (NSDI) (Mapping Science Committee 2001, Nedovic-Budic 2002, DeMulder et al. 2004, Crompvoets and Bregt 2007). Other large initiatives include the National Biological Information Infrastructure (NBII, nbii.gov), a coastal NSDI coordinated largely by the NOAA Coastal Services Center (www.csc.noaa.gov/shoreline/cnsdi.html), and the Geography Network of the Environmental Systems Research Institute (ESRI, geographynetwork.com). In Canada, there is a Canadian Geospatial Data Infrastructure (CGDI, cgdi.gc.ca), and in Europe past notable efforts include CORINE

(Coordination of Information on the Environment), NATURA 2000 (in support of natural habitat conservation) (see more descriptions in Masser 1998). The European Commission of the European Union has recently established the ambitious INSPIRE (eu-geoportal.jrc.it). And further international cooperation is now being facilitated by the GSDI (gsdi.org), particularly where the developing world is concerned. Both INSPIRE and the GSDI will be revisited near the end of the chapter.

Coastal and marine data have many unique requirements that warrant special consideration within an SDI (e.g., the dynamic complexity of this geography as an interface between land and ocean, the multiple jurisdictional issues, the cultural nuance of coastal space, etc.). The reader is referred to the very complete reviews by Lockwood and Fowler (2000), Bartlett et al. (2004) and Canessa et al. (2007), which define and discuss all the essential components of coastal SDIs for the U.S., Europe, and Canada respectively (e.g., framework and specialized datasets of coasts and estuaries, metadata, clearinghouses, standards, policies, partnerships at all levels, cultural issues, etc.). This chapter does not attempt to revisit the excellent background already covered by these works, but rather focuses on one of the most important and intuitive aspects of an SDI: the search, discovery and download of spatial data via a clearinghouse (also known as and hereafter referred to as "data portal"). Here I define a data portal as an Internet environment (large web site or content management system) that features some kind of metadata catalogue with descriptions of available data sets and imagery. The portal may be rich in content itself, but more often than not serves as a focal point linking many networked servers distributed over a large geographic area (these being invisible to the user if need be). In addition to spatial data, content available to the user also includes documents, web sites addresses, and even software applications. In addition, registered map services allow users to build online maps using data within the portal. Another critical ingredient is Internet map service technology allow users to visually browse and query individual or multiple data sets in order to determine whether a download is necessary. Once downloaded, the data may then be viewed in other software or analyzed using a GIS or image processing package. Canessa et al. (2007) describes the evolution of coastal and marine infrastructure in Canada as a progression from hardcopy atlases in the 1970s and 1980s to information systems in the 1980s, to integrated, distributed networks and portals that emerged in the 1990s. A modern, present-day data portal may encompass digital versions of all of these.

5.1.1 Limitations of Past Approaches

The national efforts mentioned in the previous section, including a National Academy of Science study (Mayer et al. 2004), have all called for or involved the development of data portals (often with the inclusion of an Internet map service) in order to connect the variety of spatial data producers with their users. Again, this has normally involved government at all levels, the private sector, and academic institutions. However, as reported by Sarkar (2003), despite the expense and energy devoted to information sharing initiatives, governments at all three levels (local, state, and federal) are left to wonder if it really knows how to implement them successfully. The pieces are out there, but they still haven't been applied well to large-scale efforts (e.g., nationwide scale). Communication about the availability or the need for data is also lacking (caused usually by the lack of proper metadata in order to properly assess geographic coverage, quality, accuracy, point of contact for access, etc.), and thus the duplication of data sets is still a huge problem.

In the state of Oregon for example, even experienced users of geospatial data with some GIS sophistication working in state agencies and local governments continue to have a serious problem finding natural resources data. They can locate bits and pieces here and there via portals but, over time as they locate a data type (e.g., a digital elevation model for a landslide susceptibility study along the Oregon coast or stream data for evaluating sediment load delivered to estuaries from surrounding watersheds), they end up finding several different versions of the same in varying degrees of completeness or update, and some or most of which may be poorly documented. If they do find a completed data set, how do they know it is the best or most up-to-date data set available? Are there any policy restrictions or proprietary holds that would prevent access? What if they decide to create a data set and then later find out that another agency has already created such a data set? And as a related issue, what if they find an ecosystem assessment tool developed by a university scientist to work with the data but it only runs with software X and their agency uses software Y? How easy will it be to integrate these newly obtained data with existing data? Workers in different agencies and regions around the state experience these problems, where different data sets are obtained in order to solve the same natural resource problems, but integration or analyses may yield different answers.

5.2 Successful Partnerships and Portals

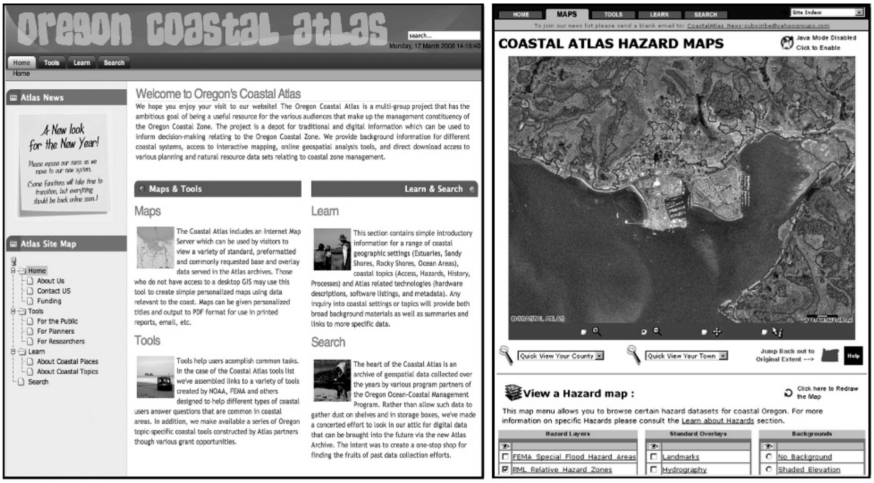
Fortunately, there are efforts underway that are addressing problems with sharing and finding geospatial data and are thus contributing greatly to the development of coastal SDIs (important background discussions can be found in Katz et al. 1991, Masser 1998, Lockwood and Fowler 2000, Gärtner et al. 2001, Miller and Han 2001, Bartlett et al. 2004, Canessa et al. 2007). Toward this end, there has been a steady advancement over the last decade in the design and effective implementation of data portals specifically for coastal data. The key to this success has been comprehensive partnerships that ascribe to the vision and principles of an SDI. Without these partnerships, the proliferation of data portals can become as problematic as the duplication of individual data sets (i.e., the duplication of portals adding to the confusion – which portal to use and why). Regional partnerships that seek to guide and/or influence coastal resource planning and management for example, have been identified as critical not only for data solutions but for enabling creative solutions to broader environmental and socio-economic problems, for economic development, community service, and even emergency and disaster response (Nedovic-Budic 2002, Eleveld et al. 2003, Sietzen 2003, Asante et al. 2007). While there are numerous projects that can be pointed to as successful case studies to emulate, three projects are highlighted here as significant demonstrations of innovation, implementation, and practice. These are projects that are within the realm of the author's experience and participation.

5.2.1 The Oregon Coastal Atlas

In coastal and estuarine ecosystem assessment and management, computer applications are often developed expressly for the benefit of decision-makers, at all levels of government and in various non-governmental organizations. As alluded to already, there are still many challenges faced by these practitioners, including gaps in data, effective data integration, data presentation, how to turn existing data products and information management tools into useful information products, and how to use or create appropriate indicators of varying types (e.g., hazard, health, suitability, etc.). In Oregon, effective coastal management relies largely on the outcome of resource decisions made at the local level, by local officials and ordinary citizens (e.g., Smith 2002, Wood and Good 2004).

Resource decisions are problematic, however, because they implicitly require that accurate and appropriate resource status information be available in a usable form and manner that are timely to the decision process. In the absence of such information, the possibility exists that resource decisions may not adequately or efficiently protect systems of value to the community. In answer to these needs, a partnership was formed between the Oregon Coastal Management Program (OCMP, state government), the Davey Jones Locker Seafloor Mapping/Marine GIS Laboratory at Oregon State University (OSU, academic), and Ecotrust (one of the largest non-profit environmental conservation organizations in the Pacific Northwest and headquartered in Portland, Oregon). These organizations came together in order to allocate resources, conduct individual work programs, and share the effort needed to design, build, test and deploy a new portal to support data sharing, spatial analysis for statewide coastal management, and resource decision making.

A primary driver for the portal effort was the need to integrate the data distribution efforts of the OCMP with complementary data emerging from federal agencies, academic research institutions, and local government/volunteer organizations. The OCMP is a state-networked program whose data products are distributed free of charge to the public and local governments. The primary user group for OCMP data products are agency program partners (e.g., the Oregon Division of State Lands, Oregon Department of Fish and Wildlife, Oregon Department of Environmental Quality, Oregon Department of Geology and Mineral Industries), academic partners (e.g., OSU Geosciences, OSU College of Oceanic and Atmospheric Science, Oregon Sea Grant, the University of Oregon's Institute of Marine Biology), and coastal county and city planners. The intent is that easy access to up-to-date information about coastal resources will lead to improved resource management decisions in the coastal zone.



(a) (b)

Fig. 5.1 (**a**) Opening page of the Oregon Coastal Atlas (OCA), with tabbed navigation at the top (circled in red) guiding users to the four main sections of the atlas, "Maps", geospatial "Tools", "Learn", and "Search" (for GIS data and remotely-sensed images archived in the atlas). There is also a wealth of background information on the project, and related links; (**b**) Hazard mapping portion of the OCA, resulting from a user navigating to the "Hazards" coastal topic within the "Learn" section of the atlas, and then choosing a coastal site and hazards data layers from that section to map out in the Maps section

The portal itself is called the Oregon Coastal Atlas (OCA; www.coastalatlas.net; Fig. 5.1a). Powered by the open source Minnesota MapServer (mapserver.gis.umn.edu) and hypertext processor (PHP) scripting, it provides background information on different coastal systems, access to interactive mapping, online geospatial analysis tools, and direct download access to an array of natural resource data sets with associated metadata related to Oregon coastal zone management. The Oregon coastal zone is loosely defined as extending from the crest of the Oregon Coast Range to its territorial sea boundary 3 nautical miles offshore. Embedded in the OCA is the Oregon Coast Geospatial Clearinghouse, a node of the NSDI that aids in advertising OCA metadata well beyond Oregon by way of the Geospatial One-Stop. A typical session within the OCA includes (Fig. 5.1b):

- selecting a region of interest from a map of the Oregon coastal zone;
- enlarging the selected region and specifying an environment such as rocky or sandy shore;
- exercising an option to display one or more layers (e.g., swash zones, land use zones, recreational areas, watershed boundaries, rivers, etc.);
- viewing and printing more detailed data related to specific layers;
- linking to an OCA metadata table, glossary definition, scientific document, or additional resources located elsewhere on the web; and
- downloading simple, generic spatial tools based on the user's selections and/or criteria, in order to solve a coastal management or scientific problem.

The OCA is indeed somewhat unique in that it couples up-to-date, interdisciplinary resource data along with several online tools for coastal decision-making. These include a coastal erosion suite that calculates dune overtopping, dune undercutting or bluff recession based on the foredune erosion models of Marra (1998) and Ruggiero et al. (2001), as well as traditional ground survey beach elevation data (Haddad et al. 2005). A watershed assessment tool provides the necessary GIS data, instructions, and an Internet map service to facilitate watershed assessment and mitigation according to the Oregon Watershed Enhancement Board (OWEB) assessment manual (Haddad et al. 2005). A coastal inundation tool uses an Internet map services to help users visualize near real-time coastal storm flooding near Tillamook, Oregon and project potential wave inundation for that region. Emergency response agencies and coastal planners can then establish appropriate setback distances along the coast in order to protect the built environment.

The OCA has grown to a catalogue of over 3380 data layers, having served over 3 million hits in the last 2 years to over 35,000 unique visitors (it "went public" in December 2002). In the last year, average daily visits have grown from ~100 to ~200. January 2005 was the all-time highest traffic volume month ever, attributable (based on items downloaded) to users seeking maps and information about the potential effects of a tsunami on coastal communities, after hearing about the December 2004 Sumatra earthquake. It has received considerable interest and advocacy by the Oregon Ocean Policy Advisory Council (an advisory board appointed by the Governor of Oregon), the Oregon Department of Geology and Mineral Industries, the Oregon Geospatial Enterprise Office, the Oregon Coastal Program Network of Local Planners, the Oregon Shores Conservation Coalition, and the Oregon Land Conservation & Development Commission, as well as feature coverage in Oregon's top newspaper, The Oregonian. Beyond Oregon, it has received advocacy from the NOAA Coastal Services Center (South Carolina), the NOAA Pacific Services Center (Hawaii), and the Federal Geographic Data Committee.

5.2.1.1 Next Stage: Improving the Search for Data

The OCA is established, well used, and decision-makers and general citizenry are accessing the data and metadata. It is now at the stage where the coordinating partners seek to better understand how decision makers use its data. In order to do that, the partners seek to improve the use of the metadata, and to understand how the quality of both the metadata and data should evolve over time, even after initial publication. While much of the information technology and social science research needed to solve these kinds of problems is similar to ongoing research in other domains, there are some issues unique to SDI research (e.g., Dawes and Pardo 2002, de Man 2007). For instance, in addressing the needs of government decision-makers, there must be a recognition of the need to combine quantitative information with qualitative, the social and economic value associated with these decisions, and the risk involved in using information technology to make resource management and environmental decisions that could have significant impacts on public health or must stand up in a court of law (Cushing et al. 2005).

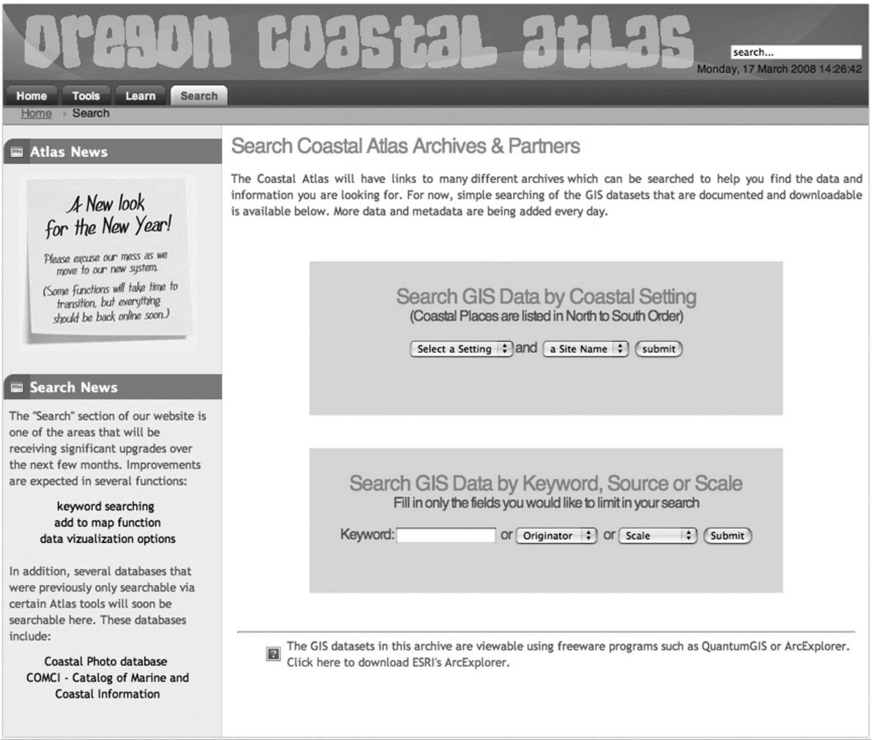


Fig. 5.2 Current search interface for the Oregon Coastal Atlas (OCA), incorporating text menu choices or entry of text keywords

Metadata is at the heart of any search for data within a portal, and searching is the critical first step in the ultimate completion of a task or the making of a decision. Such improvements are also needed in the search mechanism of the OCA (Fig. 5.2). For example, a keyword search in the OCA for "shoreline" returns 197 data sets, but a search for "coastline" returns no data sets. In order to more effectively search among the existing 3380+ data sets in the OCA, we need to incorporate innovative changes to our metadata catalogs. Needed also are updates and additions to the existing toolset, as it does not cover the full range of functions needed by coastal decision-makers. Specific research questions to be addressed in the next phase of work to devise an improved search mechanism include:

- The OCA was designed as a scalable system, and given the usage to this point, as well as anticipated future use, how should we scale in terms of additional data, tools, and educational modules?
- The text-based (keyword) search and downloadable data approach has been successful but is still limited. What are the best ways of improving searches within a portal, and in presenting the results of those improved searches to the user (beyond just a laundry list)?

- As improved search must start with existing metadata (e.g., Wright et al. 2003), what are the practical advantages of having a controlled vocabulary in an ontology (i.e., a dictionary of categories and properties arising from a systematic study of how knowledge is structured), in addition to a database of existing metadata records? What are the best ways to structure a coastal resource decision-making portal, in terms of descriptive elements in text, data properties in numbers, and relationship properties (data derived from? entered by whom? best combined with?).
- Are existing ontologies, such as SWEET (Semantic Web for Earth and Environmental Terminology; http://sweet.jpl.nasa.gov) sufficient for research that uniquely combines physical science with social science and decision-making?

By way of further clarification, it is useful here to include more formal definitions of the terms ontology and controlled vocabulary (after the Marine Metadata Interoperability (MMI) project, marinemetadata.org/guides):

An ontology may include a catalog (list of terms), glossary (list of terms with definitions), thesaurus (list of terms with definitions and synonyms), and a more formal ontology (list of terms with definitions, synonyms, and other relationships between terms). An ontology therefore provides the structure of the controlled vocabulary similar to a dictionary or a thesaurus (i.e., an ontology could be construed as including the entire spectrum of controlled vocabularies). A controlled vocabulary can be defined as a set of restricted words, used by an information community when describing resources or discovering data. The controlled vocabulary prevents misspellings and avoids the use of arbitrary, duplicative, or confusing words that cause inconsistencies when cataloging data. The vocabulary agreed to by a community is the expression of concepts (i.e. mental abstractions) of their domain. Since a concept can be expressed in different ways and differ in meaning from one person to another, the controlled vocabulary helps to solve semantic incompatibilities.

Data portals have been criticized as providing data descriptions only at the most basic level, making it difficult for both users and providers to interpret or represent the applicable constraints of data, including the related inputs and outputs of analyses or decisions (e.g., Cabral et al. 2004). A semantic approach has been shown to provide higher quality and more relevant information for improved decision-making (Helly et al. 1999, Sheth 1999, Cabral et al. 2004). Associating formal terms and descriptions captures semantics (e.g., “shoreline” vs. “coastline”), thereby making cross-disciplinary connections between them, in order to attach well-defined meaning to data and to other web resources. In this way, the quality of data retrieval or integration are greatly increased, based on meaning, instead of on mere keywords (Berners-Lee et al. 2001). Basic semantic web research has only recently started to address the support for spatial data and information (Fonseca and Sheth 2002 and references therein, Shi 2005), which is a clear focus of the OCA archive, composed primarily of GIS shapefiles, coverages, raster grids, and images. In order to improve the results of queries for information stored in geographic databases it is necessary to support better definition for spatial concepts and terms used within a discipline such as ocean and coastal management (Eleveld et al. 2003). Equally important is the development of multiple spatial and terminological ontologies to define and operationalize meanings and formal descriptions (Egenhofer 2002, Goodchild 2003). Building the necessary tools to define, verify and deliver these ontologies is a significant research challenge, as well as understanding the gaps and inconsistencies in ontologies, trust and verification of the content of ontologies, and understanding and handling changes in the material represented by ontologies, all in ways that go beyond simple versioning (e.g., Cushing et al. 2005).

To implement an effective semantic web resource, a data set's ontology should include a controlled vocabulary, ultimately revealing which data sets are interoperable and how. Ontologies can act both as registration mechanisms for vocabularies, and as a means of mapping vocabularies to each other using defined relations. For example, if relations such as "shoreline same as coastline" or "SST same as sea surface temperature" or "seafloor same as seabed" are used to map vocabularies, the results (which can be stored in a collected ontology) can be translated between co-vocabularies, and can also generate other inferences about the relationships between the different vocabularies and their terms. This is the approach that the OCA is building upon, with the expected benefits of:

- better/more complete discovery and filtering of data;
- clearer, more precise, more computable characterization of data;
- contextualization of information, so that it is provided in the right format, place, and language;
- semantic value, where human users but also computerized inference engines and harvesters can make better use of information;
- better display of search results, where terms can be substituted if they are equivalent; and
- integration into additional tools for the OCA, which will then immediately be working with more appropriate data sets.

5.2.1.2 A Solution Via Controlled Vocabularies and Ontologies

The diversity of data sources and data types resident within the OCA are reminiscent of the situation faced at the advent of the SIOExplorer project a few years ago. SIOExplorer is a digital library project of the Scripps Institution of Oceanography (SIO; Miller et al. 2001, Helly et al. 2003, SIOExplorer.ucsd.edu). It sprung from an initial effort to open access to more than 700 SIO expeditions for both research and education. The effort was then formalized by a group of investigators at SIO, the San Diego Supercomputer Center and the University of California-San Diego Libraries as a fully searchable digital library within the National Science Digital Library (NSDL; www.nsdl.org). The collection is rich in complexity with data, images and documents in a wide variety of formats, drawn from 100 years of documents and 50 years of data. General-purpose tools automate collection development, including the harvesting of data and metadata from highly diverse disciplines and three separate data publishing organizations. This collection with approximately 150,000 items, requires 1 Tb of storage, and is growing at about 200 Gb per year. It now consists of five federated collections, and new collections from various disciplines are added each year as other funded projects commence.

The technology underlying SIOExplorer has recently been leveraged to create a comprehensive information system for several other communities, thus demonstrating that a similar transformation can be accomplished for portals such as the OCA. For example, SIOExplorer has been implemented at the National Institute of Water and Atmospheric Research (NIWA) in New Zealand. This includes a portable stand-alone version of SIOExplorer, called "Digital Library in a Box," which operates in real-time aboard the R/V Tangaroa. It is based entirely on public domain code, e.g., using PostgreSQL instead of Oracle. SIOExplorer technology is also being used for managing multibeam holdings at the Center for Ocean and Coastal Mapping (CCOM) at the University of New Hampshire, and plans are underway to implement it at the Monterey Bay Aquarium Research Institute (MBARI). SIOExplorer components are being re-used for hydrological community information within the Hydrologic Information System (cuahsi.sdsc.edu), part of the Consortium of Universities for the Advancement of Hydrological Sciences, Inc. (CUAHSI; www.cuahsi.org) initiative. CUAHSI is planning a distributed data network over 24 hydrological observatories across the country with real-time radar feeds, as well as stream and precipitation gauges, remote sensing images, and access to USGS and NOAA archives. Collaborators at University of Texas, Drexel and Virginia Tech are building user-oriented tools based on the flexible SIOExplorer metadata architecture. A number of convenient tools for mapping to FGDC and ISO standards, and for working with controlled vocabularies, will soon be available for download.

By drawing upon the expertise and facilities of the SIOExplorer Digital Library, the OCA partners are moving toward the implementation of a similar, semantically interoperable data archive. The key to the SIOExplorer success was the definition of a Canonical Cruise Data Structure (CCDS), encompassing the scope of all the various data types, valid over the 50 years of the collection. The structure was implemented as a set of nine data directories, plus a few sub-directories. The flexibility and scalability were derived from a template-driven, rules approach that allowed a processing script to harvest data and metadata from arbitrary original data structures in a staging area, and store them in a simple CCDS. A similar approach for the OCA would be to define a Canonical Coastal Atlas Data Structure (CCADS) with a hierarchy of data objects appropriate for the existing OCA data archive, including vector files, digital orthophotoquads, digital raster graphics, and new satellite grids and images. A CCADS also translates the CCDS structure into an XML, OWL-based ontology (OWL Web Ontology Language), thus exposing relationships and dependencies between data sets, science themes, decision-making themes, and geographic locations. OWL is a powerful language that allows the user to encode vocabularies in a way that web browsers and software packages can understand (www.w3.org/TR/owl-features). OWL also supports the creation of relationships among vocabularies more easily than most other formats.

In order to arrive at the final ontology, it will be important to follow the recommendations of the international Marine Metadata Interoperability initiative (MMI;

www.marinemetadata.org) in order to create initial markup vocabularies that specify the content of OCA data sets and records (i.e., by reading in the current metadata). MMI is a virtual community of marine scientists and engineers led by the Monterey Bay Aquarium Research Institute (MBARI, www.mbari.org), and with a host of U.S. and international partners that provide the coastal/marine community with guidance, background information, tools, standards, cookbooks, vocabulary and ontology tool development (Fig. 5.3), as well as working examples of marine metadata. This is also done in consultation with the ocean observatory community (e.g., the Integrated Ocean Observing System or IOOS at www.ocean.us, and the Ocean Research Interactive Observatory Networks or ORION at www.orionprogram.org). Existing data markup vocabularies (such as the British Oceanographic Data Centre vocabulary for marine applications, www.bodc.ac.uk/data/codes_and_formats) provide a means for replacing the cryptic and often meaningless strings used for spreadsheet column headings and data channel labels with clearly defined terms that have the potential to carry metadata rich enough to support true data interoperability

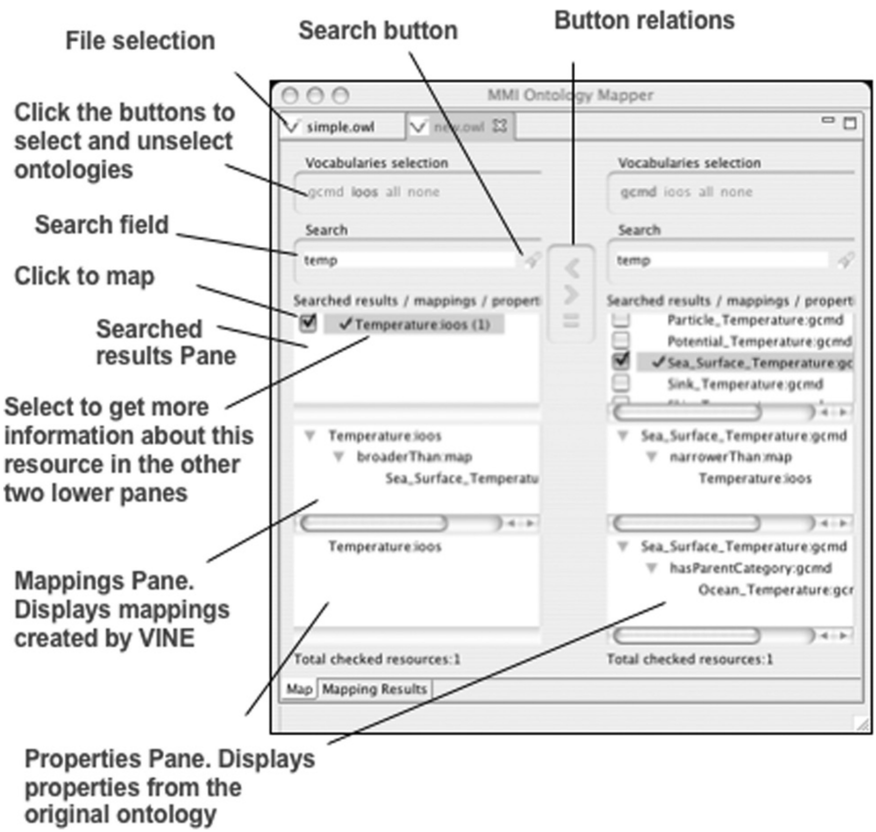


Fig. 5.3 Example screenshot from the Vocabulary Integration Environment (VINE) Tool developed by MMI to map terms from vocabularies that are represented in ontologies, in the Web Ontology language (OWL) format (from marinemetadata.org/fordevelopers)

(www.marinemetadata.org/vocabularies, O'Neill et al. 2003). This allows for the automatic generation of a discovery vocabulary, which then leads to improved data search, discovery, documentation, and accessibility.

5.2.1.3 The Final Ingredient: Style Sheets

A successful search would display all the viewable data types listed in the OCA, along with the underlying, well-defined vocabularies powering the searches. However, that successful search might return twice the number records to a user than before, a case of "too much of a good thing." A style sheet must be developed to sort search results for the user, broken out by data set type (e.g., vectors, grids, or satellite images from the existing GIS archive, photos from the new photobase in development or documents/journal references), and by category (e.g., biological, environmental quality, infrastructure, geomorphology). Sorting of records in various ways must be experimented with, based on user feedback (i.e., which categories are most useful?), and input must be sought from state government agencies such as Geospatial Enterprise Office (Oregon's statewide service center for GIS) or the Oregon Watershed Enhancement Board.

5.2.2 DISMAR/DISPRO

Another example of a successful SDI implementation is the web-based component of the Data Integration System for Marine Pollution and Water Quality (DISMAR). DISMAR was initiated through a partnership of seventeen organizations from six countries (Norway, Germany, Italy, France, the United Kingdom, and Ireland) and is focused on improving the management of pollution crises in the coastal and ocean regions of Europe. DISMAR supports public administration and emergency services responsible for prevention, mitigation and recovery of crises such as oil spill pollution and harmful algal blooms (HAB). A prototype decision-support system component of DISMAR (named DISPRO) was developed for the integration and distribution of multi-source data, as well as results from ocean numerical models (Hamre et al. 2005). DISPRO is a product of the Coastal and Marine Resources Centre in Cork, Ireland (http://dispro.ucc.ie/apps/dismar), and serves as a portal to distributed marine pollution data servers across Europe. Its architecture is therefore consistent with INSPIRE's general model of an SDI (Hamre et al. 2005).

Similar to the OCA, DISPRO uses the open source web mapping code of Minnesota MapServer. However, additional map services of the Open Geospatial Consortium (OGC, www.opengeospatial.org) are more at the heart of its approach. A web mapping service (WMS) produces a digital raster image of a geospatial data set (not the dataset itself), and is thus quickly transferable and readable in a web browser. In addition, maps may be requested from different servers, enabling the creation of a network of distributed map servers from which users may build customized maps (www.opengeospatial.org/standards/wms). Users do not necessarily need specialized software on their desktop, only a web browser. However, if they are in fact users of powerful desktop software such as ArcGIS, they can easily connect to a WMS from right within ArcGIS and load data on the fly. In addition, web feature services (WFS) enable the transfer of actual vector data sets, along with attribute and topology information, and a web coverage service (WCS) will enable the transfer of the actual raster data. By establishing these implementation specifications, the OGC has removed barriers to sharing/exchanging data related to proprietary data formats and communication protocols.

DISPRO is very effective because, by using a WMS, users are able to build a single map from multiple servers (Fig. 5.4) so that they are not restricted to using data from a single server (as is the case with the OCA). As long as the requested map images are in the same projection and cover the same geospatial extent, DISPRO can overlay the images to make a synthetic map using data from many different sites (Fig. 5.5). There are many advantages to this approach, including:

- much easier search and retrieval of data across a distributed network. Instead of a data set being hidden on someone's computer, it is selectable via WMS/WFS/ WCS. These services combine the ease of file transfer protocol (FTP) with the

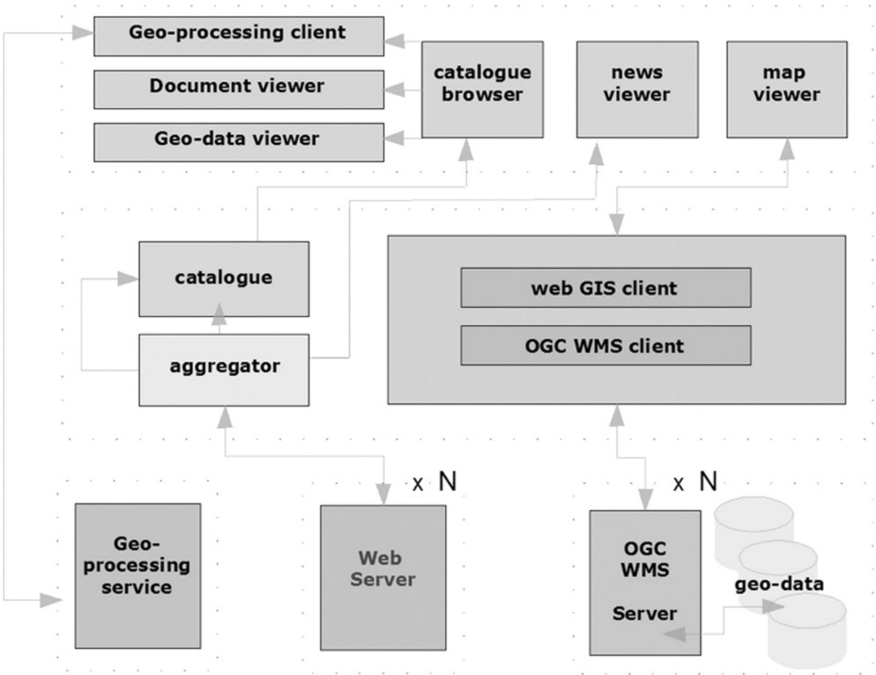


Fig. 5.4 Architecture diagram for DISPRO showing the centrality of OGC web mapping services and web servers (note that the "xN" signifies that any number of these servers and services may be employed across Europe), as well as the configuration of related catalogues, geoprocessing services, and viewers for maps, data, documents, and news items. Diagram by E. Ó Tuama and reproduced by permission of the Coastal and Marine Resources Centre, University College Cork, Ireland

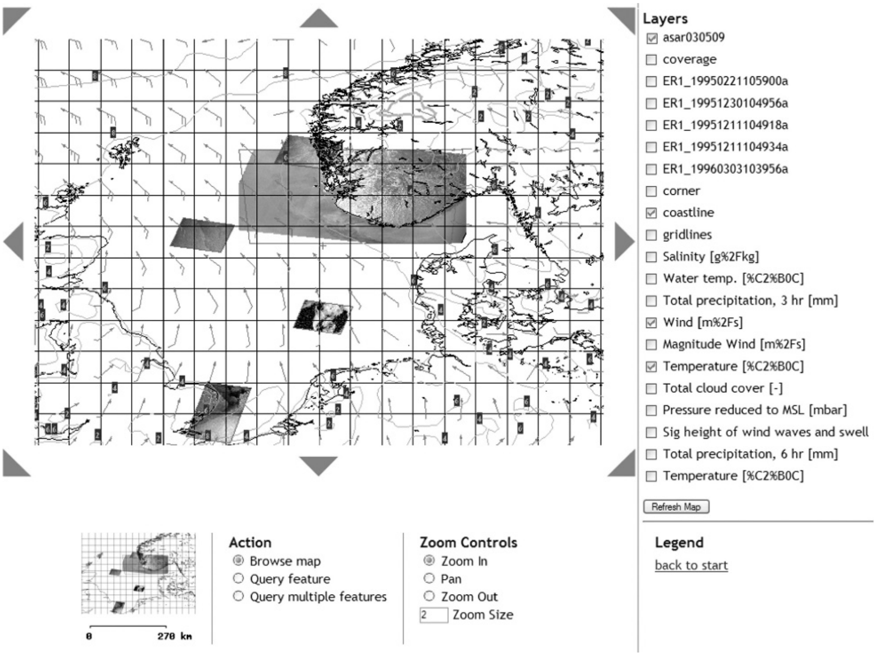


Fig. 5.5 Screen snapshot of a typical session in DISPRO showing the map viewer controls and the many layers available for browsing and query from INSPIRE datasets. Shown are coastlines, wind vectors, satellite overlays, and temperature data for monitoring harmful algae blooms along northern European coasts. Screen snapshot by E. Ó Tuama and reproduced by permission of the Coastal and Marine Resources Centre, University College Cork, Ireland

added ability to actually see what the data will look like in mapped form. It is also possible to transfer whole directories of data, which is not easy with FTP.

- advantages for datasets that are frequently updated or edited (as opposed to static files). The current practice of mapping a drive allows read-only access, which is fine for a situation where a dataset does not change very often. But if a dataset is consistently updated, a WMS solution is much more efficient.
- With existing data scattered across servers in different counties, states or countries, this approach takes advantage of a distributed network rather than having to have copies of datasets all in one place or having people download duplicate copies from many different places excessively.

5.2.3 *Other Portals*

In addition to the "case studies" discussed above, there are a number of other coastal data portals that have reached a mature or near complete stage, including the Marine Irish Digital Atlas or MIDA (mida.ucc.ie), funded by Ireland's Higher Education Authority under the Irish National Development Plan, and in Northern Ireland by the Department of the Environment's Environment and Heritage Service. MIDA has recently emerged as the one of the most comprehensive portals to the coastal and marine regions of Ireland. It is currently the only data portal in Ireland that brings together data from many organizations, and it has thus been identified a key part of Ireland's SDI (Strain et al. 2006, O'Dea et al. 2007). Other examples include the North Coast Explorer of the Oregon Institute for Natural Resources (northcoastexplorer.info), and the Pacific Coastal Resources Atlas of Canada (www.shim.bc.ca). Similar efforts were discussed at length during the CoastGIS '05, the 6th International Symposium on Computer Mapping and GIS for Coastal Zone Management, where the theme was "Defining and Building a Marine and Coastal Spatial Data Infrastructure (www.abdn.ac.uk/∼geo466). All of the aforementioned portals have been built and maintained as a result of significant financial and human resource investment as a result of very strong regional partnerships between universities and government agencies. Many technological challenges have been met along the way to provide web-based mapping solutions that meet with end user requirements.

A series of recent workshops (Trans-Atlantic Workshops in Coastal Mapping and Informatics, workshop1.science.oregonstate.edu) has examined some of the significant developments in the emergence of these web-based coastal data portals, as well as related issues in coastal/ocean informatics (the general study of the application of computer and statistical techniques to the management of coastal and ocean data and information, including data/metadata vocabularies and ontologies, metadata creation/extraction/cross-walking tools, geographic and information management systems, grid computing) (Wright et al. 2007). Funding was obtained from the National Science Foundation (NSF) to support U.S. participation at two joint workshops designed to identify common research priorities, and focused on specific areas of research collaboration. European efforts were funded in part by the Marine Institute of Ireland's Marine Research, Technology, Development and Innovation (RTDI) Networking and Technology Transfer Initiative under Ireland's National Development Plan. The main objectives of these workshops were to:

- quantify and qualify the strengths and weaknesses of coastal data portals as decision support systems for the integrated coastal zone management process;
- further refine a geo-spatial framework for the coastal zone;
- describe novel and innovative activities in the uptake of geo-spatial tools by coastal managers;
- develop and publish guidelines to the coastal/marine research community and resource decision makers on the development of coastal data portals (including usability of coastal web atlas interfaces, map design, data content and display, attribute tables, and metadata formats, soliciting user feedback, etc.); and
- develop common vocabularies and ontologies to facilitate database searches with coastal data portals of Europe and North America.

The first workshop was held in Cork, Ireland in the summer of 2006, under the theme of "potentials and limitations of coastal web atlases" (O'Dea et al. 2007), and the second was held in Corvallis, Oregon in the summer of 2007, under the theme of "coastal atlas interoperability" (i.e., building a common approach to managing and disseminating coastal data, maps and information). Both workshops brought together key experts from Europe, both coasts of the United States, and Canada to examine state-of-the-art developments in web-based coastal mapping and informatics, along with future needs in mapping and informatics for the coastal practitioner community. These workshops were intended to advance research in the field by providing recommendations for best practices in coastal web mapping (including the effective translation of science to coastal decision-making). Another goal is to develop a cadre of scientists who will play a leadership role in forging international collaborations of value to the participating nations, especially within the context of the U.S. Coastal SDI and the European INSPIRE.

Another outcome of the workshop series is the formation of the International Coastal Atlas Network (ICAN), a new virtual community of over thirty organizations from ten nations, and growing. The strategic aim of ICAN is to share experiences and to find common solutions to coastal web atlas development (where a coastal web atlas is a special kind of data portal focused solely on the coast), while ensuring maximum relevance and added value for the end users. An initial project of ICAN is the development of a prototype (Wright et al. 2008 and ican.ucc.ie) to demonstrate initial interoperability between the OCA and MIDA, with plans to expand the interoperability among all the organizations of ICAN, thereby providing a common point for access and exchange of data instead of having to search aimlessly through each individual portal. The prototype employs a semantic mediation approach (where ontology relationship rules are used order to rewrite the user's query into queries over several distributed information systems, all of which will return more meaningful results), within the interface framework of an OGC catalogue services for the Web (CSW). ICAN activities will be ongoing and progress may be followed at workshop1.science.oregonstate.edu/join.

5.3 Conclusion

One may look at an SDI in many different ways and try to separate it into components, but a portal actually integrates many of those separate components (metadata based on standards, data, clearinghouse, all results from good partnerships). This chapter has focused on the portal as the primary means for search, discovery and download of spatial data. It has attempted to lay out some of the most pressing challenges to effective implementation, and then to describe the case studies of interest to practitioners in coastal and estuarine ecosystem assessment and management (i.e., the OCA and DISMAR/DISPRO), along with related efforts and initiatives, all of which might emulated.

It has been argued here that partnerships are absolutely critical for success ("success" being defined, in one sense, as users being able to find what they are searching for – in the form of original data and derived products–to judge the quality of what they have acquired, and what limitations apply to its use). As evidenced by the case studies, successful partnerships involve a variety of players (e.g., government with academia with non-profit), all of whom ascribe to the vision and principles of an SDI (e.g., use of standards and protocols, allocation of resources to fulfill responsibilities of metadata and data stewardship, development of strategies for advancing geospatial information activities at all levels, etc.). Partnerships also help to reduce the duplication of data through communication and collaboration. And they always bring to bear considerable resources, while still efficiently dividing the labour, and sharing the efforts needed to perform the complex series of tasks required to design, build, test and operate a portal. But one issue for further thought is, if a partnership makes a portal successful, what can help to make a partnership more successful?

In a recent vision document on the closely-related issue of cyberinfrastructure (NSF 2007), the National Science Foundation highlighted what it calls "virtual organizations" for distributed virtual communities, which help to step scientists and social scientists through the nuts-and-bolts of participating in a cyberinfrastructure. The virtual community can show users why their participation is worth the effort, and how it will, in the end, optimize their ability to do their research effectively, to answer scientific questions, or to make decision. I suggest here that virtual communities can have the same positive effect on the partnerships behind the portals. The communities may not be the actual builders of a data portal, but provide the building materials and the know-how. The MMI is one such virtual community as it "promotes the exchange, integration and use of marine data through enhanced data publishing, discovery, documentation and accessibility" (from www.marinemetadata.org) for a distributed community of coastal and ocean scientists, to enable them to recognize the benefits of a marine SDI, and to actually use an SDI. This virtual community provides guides, cookbooks, tools, case studies, and online discussion forums, but perhaps more importantly, hands-on workshops that feature web applications and stand-alone tools that partners can immediate build upon in their own work. It currently enjoys the support and endorsement of the NOAA Coastal Services Center, which shepherds the U.S. Coastal SDI (www.csc.noaa.gov/shoreline/cnsdi.html). The MMI is one virtual community that practitioners in coastal and estuarine ecosystem assessment and management should keep abreast of or consider joining. ICAN, though just beginning, will likely develop along a similar trajectory, though with a more specific focus on coastal web atlases and a more targeted audience of coastal zone managers. The International Hydrographic Organization (IHO, www.iho.int) may be considering a similar effort (Maratos 2007).

Given the emphasis in this chapter on domain-specific SDIs for the coastal zone, one must also recognize a shift from SDIs for these specific areas (vertical) to more integrated horizontal approaches. Bartlett et al. (2004) have already argued convincingly that it is not possible to develop a coastal SDI in isolation from broader regional, national, and global initiatives. These broader initiatives may connect the coast to the deep ocean, connect science to resource management and policy, bring in the consideration of communities and infrastructures of the built environment, or makes connections between all aspects of the global natural environmental (land, sea, and air). As such, we need to keep looking at efforts within the coastal realm, but most certainly outside of it as well. In this vein it will be important to keep abreast of the NSDI in the U.S., INSPIRE in Europe, and the GSDI Association. The reader is also directed to the new International Journal of Spatial Data Infrastructures Research (IJSDIR, ijsdir.jrc.it), which covers the full range of research experiences that advance the theory and practice of SDI development.

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Canadian Geospatial Data Infrastructure (CGDI) – cgdi.gc.ca
Coastal National Spatial Data Infrastructure – www.csc.noaa.gov/shoreline/cnsdi.html
CoastGIS '05, 6th International Symposium with theme of "Defining and Building a Marine and Coastal Spatial Data Infrastructure" – www.abdn.ac.uk/∼geo466
Consortium of Universities for the Advancement of Hydrological Sciences, Inc. (CUAHSI) – www.cuahsi.org
CUASI Hydrologic Information System – cuahsi.sdsc.edu
Data Integration System for Marine Pollution and Water Quality (DISMAR) DISPRO – dispro.ucc.ie/apps/dismar
Executive Order 12906 (establishing the U.S. National Spatial Data Infrastructure, NSDI) – www.archives.gov/federal-register/executive-orders/pdf/12906.pdf
Federal Geographic Data Committee (FGDC) – www.fgdc.gov
Geospatial One-Stop (GOS) initiative – gos2.geodata.gov
Geography Network – geographynetwork.com
Infrastructure for Spatial Information in Europe (INSPIRE) Directive and Documents – inspire.jrc.it
INSPIRE GeoPortal – eu-geoportal.jrc.it
Integrated Ocean Observing System (IOOS) – www.ocean.us
International Coastal Atlas Network (ICAN) – workshop1.science.oregonstate.edu/join, ican.ucc.ie
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National Biological Information Infrastructure (NBII) – nbii.gov
National Science Digital Library (NSDL) – www.nsdl.org
The National Map – nationalmap.gov
North Coast Explorer – northcoastexplorer.info
Ocean Research Interactive Observatory Networks (ORION) – www.orionprogram.org
Oregon Coastal Atlas (OCA) – www.coastalatlas.net
Open Geospatial Consortium (OGC) – www.opengeospatial.org
OWL Web Ontology Language – www.w3.org/TR/owl-features
Pacific Coastal Resources Atlas of Canada – www.shim.bc.ca
SIOExplorer (of the Scripps Institution of Oceanography and San Diego Supercomputer Center) – SIOExplorer.ucsd.edu
Trans-Atlantic Workshops in Coastal Mapping and Informatics – workshop1.science.oregonstate.edu
Web Mapping Service (WMS) – www.opengeospatial.org/standards/wms

Also web feature services (WFS) and web coverage services (WCS)