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WORLD MARITIME UNIVERSITY
Malmö, Sweden

POTENTIAL OF GIS AS A TOOL FOR INTEGRATING MARITIME ENVIRONMENTAL ISSUES AND COASTAL ZONE MANAGEMENT

By

Fredrik Haag
Sweden

A dissertation submitted to the World Maritime University in partial
fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE
In
MARITIME AFFAIRS

Integrated Coastal and Ocean Management

2006

Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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Abstract

Title of Dissertation: **Potential of GIS as a tool for integrating maritime environmental issues and coastal zone management**

Degree: **MSc**

This dissertation is a study of the possibilities and constraints of Geographic Information Systems (GIS) within the context of ICOM and maritime issues. During the past few decades, GIS has become a widespread tool at different levels of environmental management, planning and research, providing assistance in the management and manipulation of environmental data. However, its application in the marine and coastal context has been considerably slower. Based on a literature review, a survey of available GIS based models and tools; as well a case study from the Bay of Gävle in Sweden, the dissertation examines the fundamentals of geospatial representations and its implications in the coastal context. It further discusses and suggests a conceptual model outline for data of relevance to the maritime and ICOM context. Based on this model outline, a data structure is provided, which is tested in the case study. Using the ModelBuilder function of the ArcGIS software, some of the merits and limitations of the GIS modelling approach are demonstrated. The dissertation highlights the needs of data sharing and to improve data availability in the integrative framework of ICOM. Some of the potentials of GIS are highlighted, such as managing complex and disparate data and the visualisation of intricate structures and relations. Finally, a tiered approach to GIS based modelling within the maritime/ICOM framework is suggested.

KEYWORDS: Integrated Coastal and Ocean Management, Geographic Information System (GIS), maritime environmental impacts, geospatial representation.

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List of Abbreviations

AIS	Automatic Identification System
CORINE	Coordination of information on the environment
CZM	Coastal Zone Management
DSS	Decision Support System
ECTDIS	Electronic Chart Display and Information System
EEA	European Environment Agency
EIA	Environmental Impact Assessment
ENC	Electronic Navigational Chart
ESRI	Environmental Science Research Institute
EU	European Union
EUNIS	European Nature Information System
GIS	Geographic Information System
ICM	Integrated Coastal Management
ICZM	Integrated Coastal Zone Management
ICOM	Integrated Coastal and Ocean Management
IHO	International Hydrographic Office
IMO	International Maritime Organisation
INSPIRE	Infrastructure for Spatial Information in Europe
ITOPF	International Tanker Owners Pollution Federation Limited
MARPOL 73/78	International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978
MRDB	Marine Resources Data Base
SDI	Spatial data Infrastructure
SIKA	Statens Institut för Kommunikationsanalys (Swedish Institute for Transport and Communications Analysis)
SMA	Swedish Maritime Administration

TBT	Tributyltin
UNCTAD	United Nations’ Conference on Trade and Development
VTC	Vessel Trafic Centre
VTS	Vessel Traffic Service

> *"Oceans, seas, islands and coastal areas form an integrated component of the Earth's ecosystem and are critical for global food security and for sustaining economic prosperity and well-being for many national economies, particularly in developing countries".*
>
> World Summit on Sustainable Development, 2002

1. Introduction

1.1. Aim and scope of the dissertation

The relationships between environmental effects induced by the maritime industry and issues pertaining to coastal zone management are many and often apparent. A number of environmental values can be identified that would influence decision-making in the maritime sector, for example deepening of fairways and altered traffic regimes in terms of amount, draught and speed of vessels. On the other hand, environmental values are in turn affected by maritime traffic and installations**.** This is valid both for prevailing traffic and accidents with spills of hazardous material. Contributing to the intricacy of the system are environmental attributes such as shoreline configuration and wave exposure, currents, tidal systems, prevailing winds and waves and weather that may influence navigation as well as potential environmental consequences from shipping.

The coastal zone, being a zone where land and ocean and rivers meet and interact, is thus an environment of great dynamics and complexity. Land uses, such as residential areas, industries, fisheries and aquaculture, trade and shipping, and tourism compete and interact. Some of these land uses are mutually exclusive, e.g. industries. Others cannot coexist with some other kinds of uses. For example, tourism and strip mining of dunes might be quite incompatible. At the same time, the land-ocean interface is defined by the prevailing natural processes as well as impacts from upstream activities (forestry, industries, agriculture and urbanisation).

For successful environmental management and planning of the terrestrial-marine interface, it is vital to understand these relationships, and to make sure that the two viewpoints that by tradition may have been treated separately – the maritime and the coastal zone – are not treated separately. An understanding of the interrelations is important, but it is quite a compound task, which might be facilitated by the use of adequate tools in order to be successful in a planning and management context. The objective of this dissertation is to assess if and how GIS could be used in this process.

1.1.1. What is a Geographic Information System?

A GIS (Geographic Information System) is a computer-based system that is used to collect, store, manipulate, analyse and distribute data with a geographic component (any data with a spatial variation). A GIS is not only the software itself, it is in fact a system made up of software, hardware, routines (approaches), data and the user. During the past decades, GIS has become a tool with applications in most sectors related to planning and management of natural as well as economic resources. In coastal zone management – and especially when it comes to the overarching issues (such as the “I” in Integrated Coastal Zone Management), GIS is however still in its infancy, mainly due to the difficulties presented by this multifaceted and variable environment, with fuzzy borders, complexity of scales and the multitude of stakeholders and interests. This should therefore be an arena where the benefits of GIS could bring in many advantages. In the maritime sector these tools are just currently making its entry, for example in nautical mapping and AIS (Automatic Identification Systems).

1.1.2. Aim

As briefly touched upon in the Introduction, there are pertinent linkages between the environmental issues related to shipping activities and coastal zone management. The aim of this dissertation is to discuss and assess the possibilities and constraints for Geographic Information Systems (GIS) as a decision support tool within this context.

The project can thus be divided into three sub-objectives.

- GIS is already used by both the maritime industry and coastal management initiatives, but it is an immature application in these contexts. The dissertation therefore aims at providing a review and assessment of the current use of GIS through literature studies as well as discussions with relevant experts and contacts (Swedish Maritime Administration, Universities etc), and own experiences from previous research efforts. This review will also identify the critical parameters and relationships in the current context.
- Based on the findings in the review and assessment of current uses – create a GIS-based, conceptual model of the critical parameters identified and their interrelationships.
- The GIS-based approach - through a small case study - will illustrate the possibilities and constraints of a GIS based approach in linking the two fields as mentioned above. Due to the time constraints of the dissertation, the case study will however have more of a demonstration value than an analytical value, focusing on highlighting a relevant structure and approach.

1.1.3. Scope and methodology

The dissertation aims to provide a discussion in an area where there is a gap in the literature, research and implementation. There is a plethora of research and literature on the subject of GIS for Coastal Zone Management (for an exhaustive compilation, see for example Bartlett, n.d.). There is much less done on the application of GIS in the maritime sector, and basically nothing on the integration of these two arenas. However, there is very little to be found in terms of combining these two fields, as this dissertation attempts to do.

As the time allocated for this dissertation is limited, not all aspects of the issues brought up in the thesis can be covered to the fullest extent. The expectations are therefore foremost to provide a discussion and reasoning that answers some of the questions and gives some guidance on future directions of research.

The main part of the dissertation is based on a literature review of coastal and maritime GIS and a survey of available GIS based models for the maritime and ICOM context. These sources of information are essential in the subsequent analysis and discussion. Consequently, there is no distinct methodological chapter.

In order to illustrate the possibilities and constraints of GIS further, the Bay of Gävle, along the Swedish east coast, provides a backdrop to the discussion. Here, the traffic route to the port of Gävle is being re-designed to be able to handle increased transport, as the port is set to become the handling port for the jet fuel at Arlanda Airport, Stockholm. In the case study, data from this region is used to illustrate some of the pitfalls as well as benefits of applying GIS in this context. The data used in the dissertation is solely secondary data, collected and compiled from a variety of sources.

The following chapter will seek to put the constraints and possibilities of these tools into a structured, conceptual context.

2. Background

The maritime sector is a constantly growing industry. In 2004 the world sea-born trade (in tons) grew with some 4.3 percent, the world's merchant fleet increased in deadweight tons with 4.5 percent, and the world container port traffic increased with 9.6 percent compared to 2003 (UNCTAD, 2005). Although large parts of the increase during the last years may be attributed to increasing ship sizes, there is also an increase in the number of calls and the volume of goods handled in Swedish ports (see Table 1).

Table 1. Traffic and volumes of goods in Swedish ports 2003-2005.

	2005	2004	2003
Total goods, 1000 tons	178.1	144.6	137.8
Total foreign traffic. 1000 tons	151.9	144.6	137.8
Domestic traffic, loaded goods, 1000 tons	13.1	11.5	11.8
Total number of vessels entering Swedish ports	106 160	105 066	105 301

Source: SIKA, 2005; 2006.

As transport on our oceans, lakes and other waterways increase, so do the risks for impacts on the environment. Most of the impacts are addressed by international conventions and guidelines, which in turn are translated into national legislation.

The success of these regulations might be hard to quantify. Some impacts are diffuse, intangible and difficult to monitor efficiently, such as operational discharges and illegal spills.

In addition to the increase of shipping activities, other activities in the coastal and ocean environments increase as well. The percentage of the world's population that lives in the coastal areas is very significant. The estimates vary depending on the definition of the coastal zone and the methodology chosen. Cohen, Vitousek and Mooney (1997) argued that most of the estimations that have become standard in international documents are based on guesses and not empirical data. Their calculations indicate that the population percentage is around 37 percent within 100km from the shoreline. Other sources have placed this figure as high as 60%. Whichever figure to believe, large numbers of people live in within a short distance of the coast, and have huge impacts on this environment. The European Environmental Agency (EEA) estimated that the coastal population of Europe to be on average 10% higher than in the inland areas, but in some areas as high as 50% higher (EEA, 2006). In Europe, the coastal population change between 1991 and 2001 was on average 3.44%, but this change has a very variable pattern, with high increases in some areas, and even decreases in others (EEA, 2006).

Growing coastal populations will undoubtedly result in increasing pressures on the environment. Also intensified land uses further inland will contribute, through the catchments draining into the seas. In Europe, the coastal land use saw some major changes between 1990 and 2000. Artificial surfaces increased, pasture and mixed farmland saw a major decrease, and arable lands and permanent crops increased (EEA, 2006).

Further, pressure on coastal resources and environments increase as several countries are moving from a developing nation context into periods of considerable economic growth. The most striking example is probably China, where large parts of the inland population have moved to the economically booming coastal areas within the past decade.

In the immediate Swedish surroundings, potential risks of oil spills are increasing since the oil transport from Russian and Baltic ports is increasing (Swedish Environmental Protection Agency, 2003; Haathi and Kangas, 2006). During the last decade, from 1995 to 2004, the amount of oil transported through the Gulf of Finland has increased from 20 million tonnes per year to 104 million tonnes per year (Haathi and Kangas, 2006, p. 23). New terminals have been built in this region, and transport is expected to increase to 200 million tonnes in the year 2010.

In addition to the growing pressures of existing land use in the coastal zone, new types of activities are appearing. New sectors are emerging, for example the growing industry of wind farming will need to occupy coastal areas or shallow areas in the oceans.

As this brief discussion points out, the maritime sector and shipping activities compete and interfere with other activities in the coastal zone, in many different ways. The potential stresses induced by shipping activities will in many instances sooner or later become a problem at the coast. Air pollution will precipitate over land, noise may disturb coastal populations and fauna, waves generated by ships may lead to increased coastal erosion, and so on. Problems that might have to be dealt with include over-exploitation of fisheries, loss of coastal habitats, deleterious effects of land-based contaminants and eutrophication. Managing these issues thus becomes a matter both of understanding the risks posed by the shipping activities, as well as assessing the opportunities and constraints provided by the environmental setting. Also it is a matter of assessing the impacts separately as well as the synergistic effects of the combination of impacts in an area.

2.1. Defining the coastal zone

With the previous characteristics of the coastal zone in mind, it is no wonder that it is difficult, or rather impossible, to agree on one universal definition. From an academic point of view, some definitions may be attractive, whereas from a policy or planning perspective, there are other criteria that need to be met. Further adding to the complexity are the administrative, legislative and tenure issues that tend to be difficult, especially on the landside.

There are numerous definitions available in the literature. Depending on the aim of a specific activity, some are based on fixed distances from the shoreline; others are variable. The different needs of different actors in the coastal zone were for example acknowledged in the South African Policy for Sustainable Coastal Development (DEAT, 2000), where it is stated that for the purposes of the policy itself, "the boundaries of the coast are seen to extend as far landwards, and as far seawards, as is necessary for effective coastal management" (p. 28). The White Paper goes on to state that governments at different levels will need to – and should – define specific coastal boundaries depending on their areas of jurisdiction and management goals, on an "issue-by-issue" basis.

For the purpose of this dissertation, a more general discussion, the coastal zone is perceived as:

> […] the area, on both sides of the actual land-water interface, where the influences of land and water on each other are still a determining factor - climatically, physiographically, ecologically, or economically.
>
> Fedra and Feoli (1998. p.1)

With such a definition, it is clear that the coastal environment is difficult to manage. It is dynamic and influenced by all other adjacent environments and activities, terrestrial, riverine as well as marine. It will also change over time and with observational scale.

As a point of illustration, a rather narrow definition is presented by the European Environmental Agency, defining the coastal zone as "the resulting environment from the coexistence of two margins: coastal land as defined as the terrestrial edge of continents, and coastal waters defined as the littoral section of shelf seas" (EEA, 2006, p.11). Hence, there is little room for integration between coastal and ocean management and planning with this description.

2.2. Managing the coastal-ocean interface

> All of these activities compete, for space, for resources, and for the waste absorption capacity of the coastal zone. The intensity of activities that characterize the coastal zone implies competition for the use of the available land, in particular, since many activities such as industrial and recreational use are mutually exclusive. […] Somewhere in between are problems related to shipping accidents such as oil spills and not so accidental spills, and losses from off-shore activities, or, on the terrestrial side, classical pollution problems from urban and industrial development, or the socio-economic problems of rapid urban development. All these problems have an obvious and often dominating spatial aspect, which makes coastal zone management a spatial problem.
>
> Fedra and Feoli (1998, p.3)

2.2.1. The emergence of ICOM

The coastal areas have been preferable from a human perspective for man for thousands of years, and consequently attempts have been made to modify and govern nature and its resources. Evidence of this can be found throughout the world, in China, around the Mediterranean and elsewhere. However, before the industrial revolution, these interventions were mainly acts of civil engineering (Kay and Alder, 1999). With the industrial revolution and its technological advances though, man's capability to alter the surrounding environment increased tremendously. At the same time, the view of nature changed to one of regarding the environment as a pool of resources, which was seen as inexhaustible. At the end of the 19th century, there was a realisation that resources were not limitless, but in fact finite. This might be seen as the seeds of modern environmental awareness, and led to the creation of the first national parks.

Trying to summarise the history and emergence of coastal management, focus should be on the last century. During the first half of the 20th century, natural resource management, development and planning, for instance, matured step by step. However, it was not until the 1960s and 1970s that the concept of coastal zone management was born, manifested in the establishment of the first coastal zone management act, in the US (Coastal Zone Management Act 1972). Vallega (1996, p.100) considered the emergence of coastal zone management approaches, to be a "shift from a wild coastal system to a regulated system".

The development and main changes of coastal management and its practice are summarised in Table 2, showing the main events that have shaped this relation, and thereby the state and nature of ICOM. As illustrated in this table, the shifting paradigms of coastal management can best be understood when put in relation to the general turnaround events in man's relation to nature, as manifested by some of the major international conferences held.

The UN Conference on the Human Environment in Stockholm (1972) was the first global conference concerning the environment, and subsequently the declaration was thus the first international document with some regulatory intention that clearly acknowledged the right to a healthy environment. It contained a call to cooperate to reduce marine pollution, and can be seen as the catalyst to many of the following steps towards environmental awareness and international agreements (MARPOL, London Convention on Dumping, UNEP and its Regional Seas Programme). The 1992 Rio Declaration builds on the Stockholm Declaration. It defines the rights of people to development, and the responsibilities of governments to safeguard our common environment. Chapter 17 of Agenda 21 concerning our oceans is probably the most detailed and substantial international commitment to ICOM that exists. However, it is non-binding, and could be seen as a road map.

In contrast to the resulting documents from Stockholm, Rio and Johannesburg, UN Convention on The Law of the Sea (UNCLOS 1982) does not provide exact guidance on how to manage and plan the use of coastal and marine resources in an integrated manner. It does however supply a framework for determining national jurisdiction, and control over the maritime resources, as well as a framework for dealing with marine pollution (Chapter XII). Also, the preamble states that “all problems of ocean space are closely interrelated and need to be addressed as a whole”. Further, UNCLOS formally recognises a common heritage of mankind, and it provides regimes for international environmental law as well as scientific research and technological cooperation (Cicin-Sain and Knecht, 1998).

Table 2. Phases and turnaround event in the development of coastal management.

Phase	Period	Key features in coastal management	Turnaround events
I	1950-1970	• Sectoral approach • Man-against-nature ethos • Limited ecological considerations • Public participation low • Reactive focus	
II	1970-1990	• Increase in environmental assessment • • Greater integration and coordination between sectors • Increased public participation • Heightened ecological awareness • Maintenance of engineering dominance • Combined proactive and reactive focus	1972: UN Conference on the Human Environment (Stockholm) *Main document:* Declaration on the human environment *Main consequences:* Environmental protection claimed as the key issue. Following the USA Coastal Zone Management Act (CZMA, 1972), a wave of national provisions on coastal management arose *Geographical coverage:* Only a strict coastal fringe assumed as the coastal coverage for management plans and actions. Administrative (landwards) and jurisdictional (seawards) criteria, or arbitrary criteria (iso-distance lines from coastlines or baselines) 1982: UN Conference on the Law of the Sea (UNCLOS) *Main document:* UN Convention on the Law of the Sea *Main consequences*: A restriction of the long lasting paradigm of "Freedom of the Seas", by introduction of a

			maritime zonation (EEZ, Territorial Seas, Contiguous Zone) *Geographical coverage:* World-wide acceptance of the national jurisdiction over the 200 nm strip of coastal states.
III	1990-present	• Focus on sustainable development • Increased focus on comprehensive environmental management • Environmental restoration • Emphasis on public participation	<u>1992: UN Conference on Environment and Development (UNCED)</u> *Main documents:* Framework convention on climate change Convention on biological diversity Agenda 21, Chapter 17 *Main consequences:* Contextual pursuit of ecological integrity and economic development adopted Coastal management programs on the national and sub-national scales diffused Focus on climate change as the cardinal issue of the external environment Human pressure considered as a crucial issue The comprehensive consideration of the resource use structure increasingly perceived as essential Coastal management guidelines circulated by the UN organisations and programs *Geographical coverage:* Coverage of management programs widened, particularly seawards, where the jurisdictional zones, including the EEZ, have been progressively regarded as relevant <u>2002: World Summit on Sustainable Development (WSSD)</u>

			Main document: Declaration on Sustainable Development Plan of Implementation *Main consequences:* Climate change, together with subsequent impacts on coastal systems, better monitored and understood. Ecological integrity increasingly regarded as the first essential prerequisite to pursue sustainable development. Coastal areas regarded as key spaces to ensure food security The protection of indigenous techniques on fisheries, and on other coastal uses, regarded as essential to coastal sustainable development *Geographical coverage:* Trends triggered by the UNCED-related materials continued in order to widen the geographical coverage, seawards covering extended jurisdictional zones, and landwards covering the river basins
IV	Future	• Establish coastal area management based on ecological empathy, precautionary management and shared governance	

Source: Modified and adapted from Kay and Alder (1999) and Vallega (2005).

2.2.2. So what is ICOM then?

This brings us to what ICOM is today. Clarke (1997) defines coastal management as a system with two modes; a planning mode and management mode. In terms of planning, ICOM examines consequences of different development actions and suggests ways of dealing with these. In the management mode, ICOM guides development to promote a sustainable resource use. He also highlights the role of *coordination.*

Whichever mode it is, the purpose of ICOM is to be a tool in the pursuit of sustainable resource use. To do this, management and planning cannot be performed in a fragmented or compartmentalised manner. Successful integration of coastal and ocean environments must stem from the integration of:

- Scientific disciplines (natural, social)
- Management and planning levels (global, regional, national, local)
- Stakeholders
- Between land, sea and riverine (catchment) environments of the coastal zone

In conclusion, ICOM is an instrument, or an approach, to integrate the governance, socioeconomic and environmental dimensions of management and planning in the coastal-ocean interface.

2.3. Managing the coastal zone = managing information

> For management of coastal resources to be optimal, it is necessary that policies be based on informed decision-making. This, in turn, requires ready access to appropriate, reliable and timely data and information in a form which is suitable for the task at hand

O’Regan (1996, p.192)

With the previous chapters in mind, it might have become clear that there is a need to manage the information on coastal resources and activities. For successful management and planning, it is needed to be able to visualise, structure, comprehend and analyse how the activities are interlinked and may affect each other. The relationships and interactions in the coastal zone are many, complex and vary over time and space. Hence, it follows that there is a need for data and information from a variety of disciplines and sources, and that this data will be of different formats, e.g. geospatial data (raster or vector format) written reports, orally transferred knowledge, statistics, satellite imagery, aerial photographs. Even if data is in the same format, it may differ in terms of resolution, accuracy, age, up-to-dateness and cartographic format (projection, coordinate system). As an example, a typical coastal zone management database may contain combinations of the data such as listed in Table 3.

The need for tools that help managing these disparate sources of information and make it possible to comprehend the complexity by visualising the elusive relationships is apparent. Often, the tools available tend to grasp the complexity of one single sector only. The tools focusing on a specific scientific problem to solve, but as Olsen, Tobey and Hale (1998) as well as Turner (1999) argue, one of the fundamental challenges for coastal management efforts is not to transfer or refine scientific knowledge; it is to improve and facilitate the objectives, processes and structures of governance. This *compartmentalisation* of knowledge is something is needed to overcome in order to reach the goals of integrated coastal management. What is now urgently needed in the management of coastal information are approaches and tools to assist in the facilitation of *integration* of the knowledge in different sectors, levels and stakeholders. As will be illustrated in coming sections, the tools to handle sector-specific data are already quite matured.

Table 3. Examples of information needs and data sources in coastal management and planning.

Domain	***Data type and source (examples)***
Topography and terrain	Beach surveys, aerial and ortho-photographs, bathymetric charts, soil maps, catchment information
Morphological data	Side-scan sonargraphs, sediment samples, geological bore log data
Major infrastructure	Inventory of shore protection structures, roads, marinas etc.
Forestry and conservation	Forest reserves, forest types, natural vegative species, conservation areas, marine reserves
Coastal fisheries	Licensing zones, pelagic and demersal fish distribution, commercial aquaculture
Oceanography	A variety of physical , chemical and biological oceanographic data
Environment	Point pollution sources, water quality data, industrial site locations, sensitivity analyses
Socio-economic data	Housing location, valuation data, demographic structure, census information
Planning	Cadastral data, past and present land use information, administrative boundaries, coastal hazard zones, development pressure (urban, industrial, aquaculture, tourism and recreation, resource mining etc.), land use capability, environmental constraints

Source: Modified from O'Regan (1996).

Fedra and Feoli (1998) explain how the different paradigms of analysis and decision support are prevalent today. They identify a range of concepts, from purely descriptive systems to descriptive systems with some degree of analytic, query-based systems. Finally, the there are approaches that aim for prescription or optimisation of planning and management.

2.4. Maritime environmental issues and the relation to CZM

Shipping is not an industry totally without environmental impacts. In fact, vessels may affect the environment in many ways, directly or indirectly. The impacts of shipping can basically be divided into three types; accidental, operational and deliberate (dumping). For a long time, the “freedom of the seas” led to the oceans being used as waste dumps. This is in some respects still true, but there have been substantial efforts in this respect, through the work of IMO and other organisations. Overall, the shipping industry is believed to have reduced its pressure on the environment over the past few decades (GESAMP, 2001).

Oil spills is the impact that is receiving most attention, in part due to its dramatic visual impacts. However, there are several other impacts that need to be considered as well.

Oil pollution. Oil reaches the oceans through both accidental spills and operational discharges, from oil carried as cargo and as bunker fuel. The number of accidental oil spills has been reduced over the past decades through initiatives such as traffic separation schemes and higher ship standards. The main part of the oil that reaches the oceans from ships come is of an operational origin (GESAMP, 2001). According to statistics from the ITOPF website (August, 2006), the operationally related oil spills (loading/discharging, bunkering and other operations) account for some 54 per cent. The major causes of oil spills are presented in Figure 1.

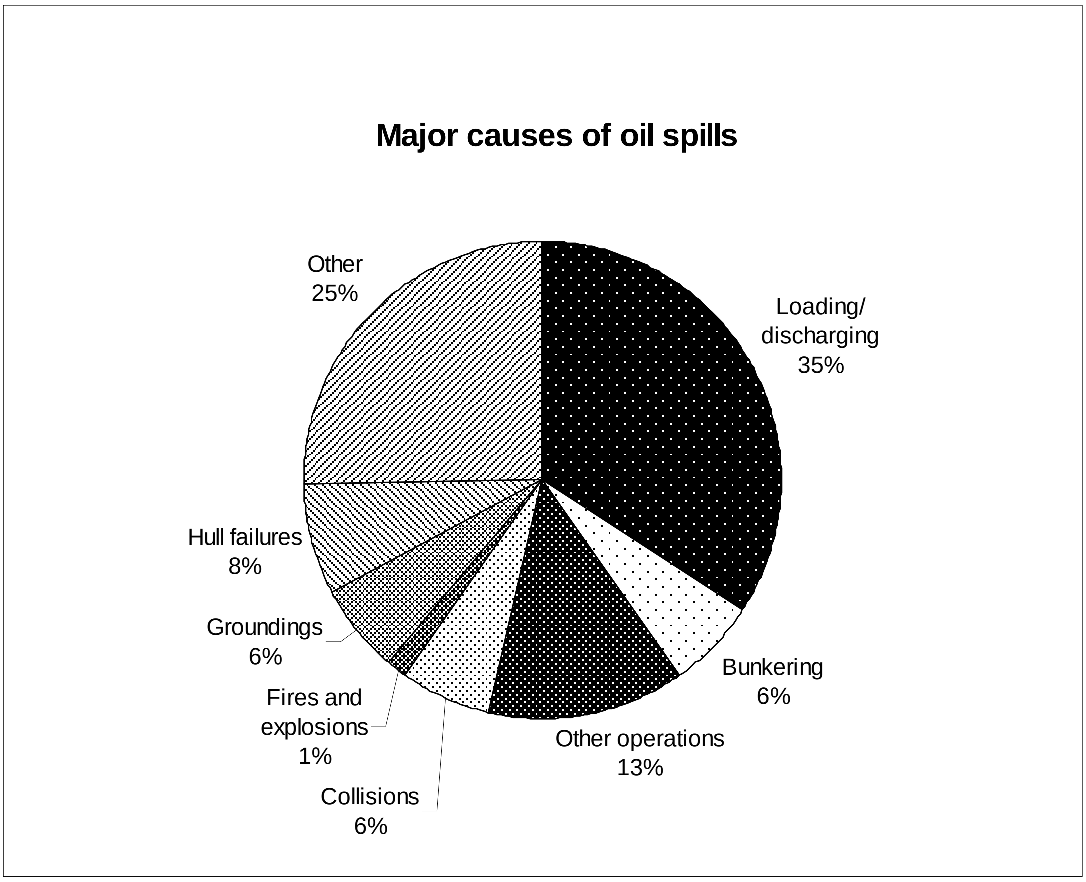


Figure 1. Major causes of oil spills, 1974-2005.

Source: Data from ITOPF, 2006.

Hazardous noxious substances, carried as cargo. Numerous hazardous substances are carried by ships on the oceans. The handling of these is governed through the IMDG code.

Air pollution. Gaseous emissions from ships is a considerable source of pollutants, especially in terms of sulphur and nitrogen (Corbett, 2003). As for SO_2 and NO_x, in some regions the emissions from ships exceed the combined emissions from land-based activities (Saxe and Larsen, 2004; Isakson, Persson and Lindgren, 2003). One of the root causes is that in order to cut the fuel costs, which account for more than 50 per cent of the operating costs, ship-owners tend to use degraded heavy fuel oils that are rich in asphalt, carbon residues, sulphur and metallic compounds (Lin and Lin, 2006).

Ballast water and sediments. Invasive species being transported by ships' ballast water and sediments is one of the major threats to biodiversity. The problem has been given attention by the IMO through the Global Ballast Water Programme (GloBallast), and the International Convention for the Control and Management of Ships Ballast Water and Sediments, which was adopted at IMO in 2004.

Anti-fouling chemicals (e.g. tributyltin, TBT), are used to give a protective layer that hinders the growth of organisms the ships hull. However, its active components such as TBT has been observed leak into the water, resulting in negative impacts on the biology.

*Wave action***.** It is well known that ships can cause substantial wave action by the generation of swell as well as pressure waves, This has been observed along traffic routes in Sweden as well as Finland (Granath, 2004). Different types of vessels will produce different wave effects, and can cause increased shoreline erosion, as well as impacts on flora and fauna.

Noise levels. Issues have been raised concerning the impacts of noise generated by shipping, under water as well as above. The exposure to noise generated by ships is increasing in coastal areas as the number of vessels (both commercial and leisure) increase. Noise pollution can be an issue both above and under water. It is also a major environmental concern at ports (Bailey and Solomon, 2004).

Sewage, Garbage. Ship operations produce sewage and garbage, generating health problems, as well as aesthetic impacts and ecological effects. Sewage and garbage generated from ships are regulated through MARPOL 73/78, Annexes IV and V respectively.

Other major sources of environmental impacts related to shipping come can be identified in relation to ports and surrounding facilities, as well as dredging. The following list is provided by Bailey and Solomon (2004).

- Air pollution from port operations, including smog and particulate pollution
- Loss or degradation of wetlands
- Destruction of fisheries and endangered species
- Wastewater and storm water discharges
- Severe traffic congestion
- Noise and light pollution
- Loss of cultural resources
- Contamination of soil and water from leaking storage tanks
- Air releases from chemical storage or fumigation activities
- Solid and hazardous waste generation
- Soil runoff and erosion

The list reveals that shipping operations, including port operations, present several environmental impacts that impact have effects on or compete with other activities in the coastal zone.

The relation to CZM

As McConnell (2002) argues, shipping is often marginalised or even neglected in ICOM activities. However, shipping activities does compete with other activities in the coastal zone. This interference can be either *spatial* or *functional* (Chircop, 2005). The spatial interference results from the fact that the marine transportation needs space, for all its different types of functions. On the land-side, ports, storage of goods (containers etc) and supporting infrastructure all need large areas of land. Hence, these facilities compete with other economic interest such as industrial developments, residential areas, tourism etc. Some of the competitors have a strong economic interest (e.g.

industry, tourism), while other actors might have less financial means but a strong cultural or emotional interest in the land (e.g. residents). Out in the sea, there is also a spatial competition. The navigational routes of shipping need space, and may interfere with the interests of fisheries, wind farming, aquaculture, oil and gas development, coastal engineering, recreational use etc (Chircop, 2005).

Shipping might also interfere with other coastal and marine activities on a more functional level (Chircop, 2005). That is, not only does shipping compete for space with other activities, it may also have physical (environmental) impacts that interfere with other coastal sectors. The most tangible example is of course an accident, for example oil spills, which may have serious negative effects on other coastal activities such as tourism (oil in water and on beaches) and aquaculture.

But the functional interference may not only have *direct* effects on other sectors, but also secondary psychological effects. For example, when an oil spill occurs, people may stop buying the fish from the region even if there are no toxic levels of pollutants in the fish. Economically, this may harm the fisheries more than the actual oil spill.

The environmental awareness and concern in the shipping industry is however high, according to McConnell (2002), at least at the international regulatory level and at the ship operating levels.

3. GIS and its potential in maritime and coastal issues

GIS has been identified in the past as an essential technology for the dissemination of oceanographic-related data, cataloguing, archiving, display, and mapping (Wright, 1996). Furthermore, Vallega states that:

> Given that approximately 80 percent of human activities in the ecological context are currently concerned with terrestrial or aquatic ecosystems, it follows that Geographical Information Systems (GIS) pertain to a vast proportion of the policy-related knowledge essential to pursuing UNCED and WSSD goals.
>
> Vallega (2005, p. 590)

However, the actual implementation of such systems has been relativity slow. The reason might be found in the fact that GIS technology has traditionally been focusing on data for the terrestrial parts of the environment, and data that is more or less stable over time and objects that are quite static, such as roads and topography. The root causes to this are probably to be found in the theory of representation, the nature of the efforts to measure and represent the surrounding environments, and the character of coastal representations. The explanation may also be found in the way GIS has evolved, which will be dealt with in one of the coming sections.

A GIS should not be considered as merely the software itself. In practice, GIS consists of five interlinked components, namely the user, software, hardware, data and routines (or approaches). Together, these make up a GIS, as illustrated in Figure 2, and work together to contribute to the functions of a GIS; input (collection) of data, storage, analysis and output.

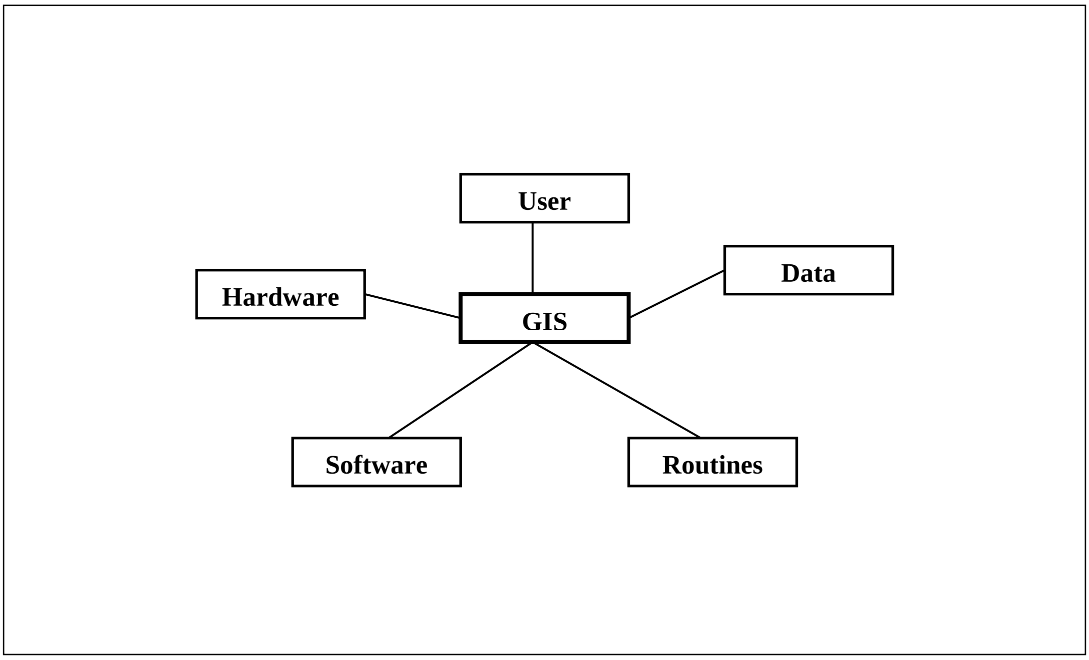


Figure 2. The components of a GIS.

Each of these components and functions are characterised by their strengths and weaknesses, which are covered in great detail by textbooks on the subject. Here, focus will instead be put on the issues of representation.

3.1. Representing coastal realities

This section will briefly touch upon the notion of representation building, and more specifically, the role of GIS in representation building. It is a topic that might help in the coming discussions on the limitations and prospects of GIS, and where it should go from here.

First and foremost, the basic concept of GIS is one of location, of spatial distribution and relationships (Fedra and Feoli, 1998). Consequently, the first tier of understanding GIS is not one of computer science; it is a tier of issues of representation of reality and cause-effect relationships in a spatial context. However, it is also vital to keep in mind that GIS generally deals with changes, over different dimensions (Gold, 2006).

- Attributes change over time (dz/dt)
- Attributes change over space (dz/dx)
- Spatial change over time (dx/dt)
- Inverses of the above

Vallega (2005), using the language of the geographer Gunnar Olsson, identifies three arenas in which coastal GIS can be said to operate. In terms of ontology, GIS concerns changing coastal realities. In the semiotic arena, coastal GIS concerns the role of representation. Finally, in the hermeneutical arena, coastal GIS is a matter of producing signifieds from representations. Therefore, the discourse of coastal GIS is closely related to the development of the ways to measure and represent the reality, to interpret and geographically represent Earth’s space.

This tradition stems from two main inputs. First, the Cartesian rationalism, which deal with cause-effect relationships in a Euclidian space. Secondly, understanding of time and space as arenas where objects are represented either in temporal sequences or in spatial distributions.

When these two basic inputs converged, it resulted in the modern design of representation as is known now (Vallega, 2005), what Olsson (1994) calls the “modern cartographic reason”. Before this convergence, representations of realities were basically mirrors of reality. In the modern mode of representation, this was not enough. Understanding cause-effect relationships became crucial, trying to find an explanation to these relationships, what

Gunnar Olsson (1991; 1994)in the language of Saussure and Lacan calls moving from the signifier (the representation) to the signified (the represented).

So why should this be considered in the context of GIS in the coastal and maritime arena? Well, to understand the possibilities and constraints of representation, it is important to remember that the representation may change due to changes in the state of the object represented (ontological change). But, it may also change when the knowledge or perception of reality changes (epistemological change). Both cases, lead to a change in the signifier, but may not actually represent a change in the signified.

The norm in representations of reality today is the rationalist view, which presumes a univocal relationship between the signifier and the signified (Vallega, 2005). But, as described above, due to the fundamentals of geographic representation and the modern cartographic reason, this is not always the case. The present norm though, might actually act as a barrier in the integration between sciences, disciplines and actors.

Coastal realities

As was discussed already in the chapter on the development of coastal management, land and marine issues were treated separately throughout most of the 20th century. During the past few decades though, Chapter 17 of Agenda 21, an integrated perspective to coastal issues has come into focus. From a coastal GIS perspective, this has becomes a matter of integrating and harmonising two main branches of representations. The first gap to bridge is between those who are set to provide representations on traditional land issues (survey departments) and those who work with representations of marine issues (maritime administrations). This gap is present in most countries, but is in many ways mostly a technical matter. The second bridge to build is between human and natural features, to learn how to represent not only the *use* of resources, but also the *cultural perspectives* of these (imagination, visions, mental maps, cultural values). This is more difficult, as it is in conflict with the prevailing representation paradigms. It is difficult to represent cultural values according to objectivist criteria. Linear, quantitative relations are easier to represent with the tools that have been developed so far, since the tools are developed for these kinds of representations.

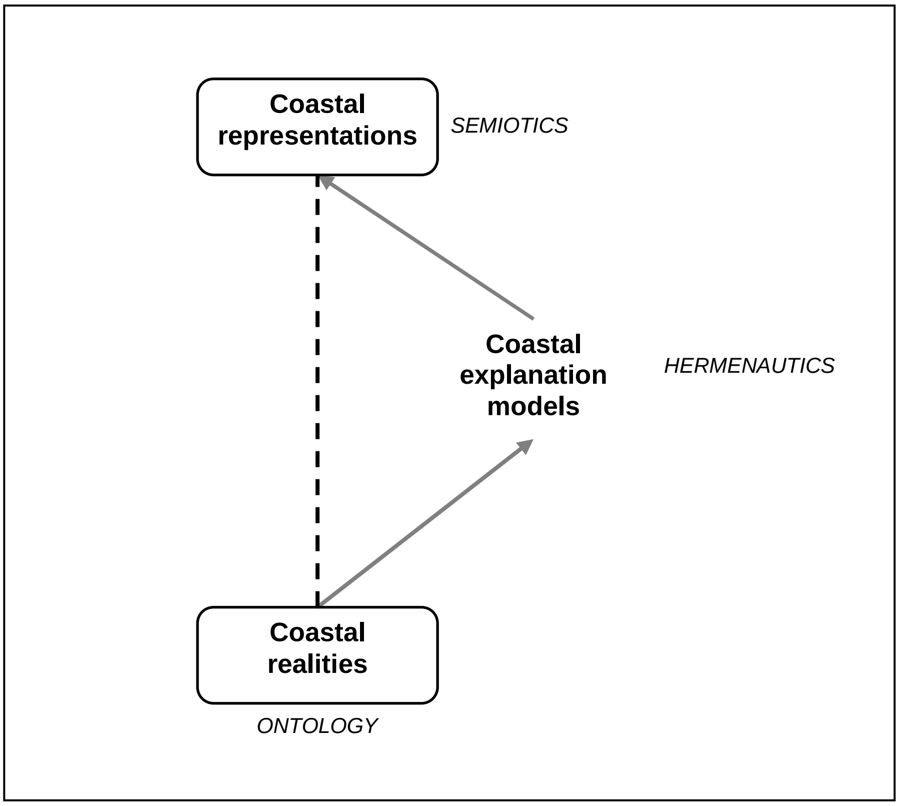


Figure 3. The relationship between the three aspects of representing coastal environments with GIS.

Source: Modified from Vallega (2005).

As Figure 3 attempts to visualise, the key to successful representation, and a huge step towards making GIS a tool in the integration aspect of ICOM, to realise that what should be understood is the coastal reality. However, this can only be done through explanation models. It needs to be clear what is being mapped, the reality or the images of it, and how the explanation models are distorting the reality. The understanding of the coastal realities is based on metaphor building of the same. The biggest challenge of coastal GIS (or any GIS) would thus be to become a successful translator in this process.

Successful representation of coastal realities needs to address both the coastal area itself with its ecosystems, resources and human-nature interactions, as well as external systems that affect the reality of the coastal environment. This could include dimensions of the physical environment, such as climatic patterns and changes that could affect the local ecosystem, but also human dimensions, such as the globalisation process and decision-making frameworks. As Vallega (2005, p.614) summarises:

> As a result, the coastal manager is expected to combine tangible and intangible culture to create strategies and actions. As a result, science is expected to draw on holistic approaches, and GIS theory and techniques are expected to create adequate representation criteria.

3.2. GIS in coastal zone management

> Coastal zone management, by definition, is spatial management. Spatial management means the distribution and allocation of space, ultimately of parcels of land, (with our without water covering it) to alternative uses or activities, or the control of processes that in turn may affect space, such as emissions.
>
> Fedra and Feoli (1998, p.3).

Vallega (2005) describes the evolution of coastal GIS as a convergence of three driving forces; coastal management, GIS and telematic techniques (see Table

4). In the mid 1990s these three converged, resulting in cumulative effects that meant that GIS became readily available outside the scientific domain. It became publicly available, in a more user-friendly format, and understood as a tool that could be successfully used for environmental monitoring and resource use planning. At the same time, coastal management entered a new era, where integration became a key concept, as a result of the general realisation of human impacts to the coastal areas of the world. Adding to this, and probably accelerating the spread and effects of these tools, the rise of Internet and the World Wide Web, accelerated the spread of data as well as software and methodologies to data handling.

Table 4. The four steps in the evolution of coastal GIS.

Step	Characteristic features
1960s Pre-take off stage	Computer aided cartography makes its entrance into geography. The birth of GIS. An embryo to the concept of coastal management emerges. Arpanet network is developed at UCLA (USA).
1970s Take-off stage	Technical improvements (for example database design) give benefits to GIS. World's first coastal management act is adopted in the US (Coastal Zone Management Act, 1972). UN adopts the coastal management concept as a field for international cooperation. Internet Protocol Configuration (IPC) is developed.
1980s Drive to maturity stage	GIS spreads to governmental agencies and public administration. UN Convention on the Law of the Sea (UNCLOS), 1982, encourages governments to widen the management area seawards, and brings attention to the world's oceans. Transmission Control Protocol (TCP) is developed.
1990s Maturity stage	Three modules; coastal management, GIS and telematic techniques converge, giving rise to several cumulative effects.

Source: Vallega (2005).

There is no doubt that the complexity of the coastal zone is reflected in the development of coastal application of GIS. Numerous stakeholders, cultural and socio-economic interactions, and ecological systems and parameters interact. And – these interactions cross over the borders of scientific disciplines and between land, ocean and rivers. How do you represent this complexity without the risk of ending up with a “mirror of reality”? How can an understanding of the signified and not only the sign be achieved?

Another reason for the lack of harmonisation between land and marine data in GIS can be found in the fact that the basic need of having comparable maps of the two environments, i.e. a matter of surveying jurisdictions. Many countries rely on two different surveying departments for maps covering the terrestrial parts of the territories and the ocean parts (Vallega, 2005; Bruce, 2004; Gomm, 2004). An obstacle to harmonisation is thus created that requires time or money to circumvent, as will be discussed in relation to the case study as well.

Chua (1997) identifies the lack of a comprehensive and systematic approach as a common cause to failure in ICOM. Since many, if not most of the interactions, relations and conflicts in the coastal zone can be described as having a spatial component, GIS can be a valuable tool, and could be seen as a type of Decision Support System (DSS). For a DSS to be of value to the decision maker, it must provide information that is (developed from Fedra and Feoli, 1998):

1. **Accurate**. Accuracy in this context can be of different types:
    a. Spatial. The spatial accuracy of data concerns the spatial resolution and the location of objects represented, as well as the completeness of data coverage. Data must be trustworthy in terms of its resolution and location, and it should preferably be based on adequate time series and cover the entire area under management, with an adequate spatial resolution.
    b. Temporal. In addition to being up-to-date, the data also needs to have a temporal accuracy.

    c. Topical. The accuracy also concerns the attributes of the object, i.e. that it is classified as the correct type of object. For example, a well may be classified as a drilled borehole or a dug-out well. The difference may be important for management reasons.

2. **Up-to date**. As data collection is a time-consuming activity, it is difficult to keep all your data up-to-date. For some data, data collection technologies such as remote sensing can be valuable methods for keeping your data as current as possible
3. **Directly understandable and useful.** The problem when it comes to the normative level of coastal GIS may in some cases not be the availability of data, but for the coastal manager to have access to data that is directly understandable as well as useful in the specific context. In many cases, GIS data is produced first and foremost within a specific sector, by a specialist. Hence, the data may not be adapted for being used by a non-specialist.
4. **Easily obtainable.** For the coastal manager, having access to data that fulfils the criteria in point 1 to 3 is essential. However, access can be restricted due to many reasons, one being lack of integration between governmental departments, institutions and other stakeholders. Sharing data, as well as approaches to data collection and handling, might be one of the pivotal approaches to successful integration within ICOM.

These items will be further discussed later, with respect to the case study. As Bruce (2004, p.52) points out, despite the general requirement for well defined and concise boundaries in GIS, most objects in geographic space have unclear, fuzzy and unclear boundaries, which is particularly evident in the coastal and marine environment. Hence, analysis results will undoubtedly be influenced by uncertainties in both the conception and measurement of geographic phenomena (Bruce, 2004, p.53).

Today, GIS is often given the role of a presentation and visualisation tool. In part, this is understandable, as one of the strengths of GIS is the capability to present complexities with a spatial dimension in a comprehensible manner. Often indicators of some kind are used, such as sensitivity indices. Some examples of how GIS is used in the coastal context are listed in Appendix B (discussed below, in section 3.4.1).

One challenge in the strive to use GIS to its fullest extent in the coastal zone, is to increase the prospective and normative contributions (Vallega, 2005). So far, coastal GIS has mostly been a cognitive exercise, based on time series data. However, successful ICOM calls for a GIS use that contributes to the scenario building as well as strategies, planning and management issues.

3.3. GIS and the maritime sector

So far, maritime applications of GIS have mainly been of two kinds; electronic nautical charts and modelling of oil spills. As the nautical charts are transferred from paper charts into digital format, new opportunities and constraints arise. Charts no longer have to be produced according to pre-defined boundaries. With all the data in one, single countrywide database, the customer can decide on the area of interest completely based on the needs and economy. The technology, known as Electronic Navigational Charts (ENC) together with Electronic Chart Display and Information System (ECTDIS), provides a system that is easily updated, both according to new survey data as well as IMO and IHO standards. However, these systems are first and foremost intended for navigational purposes, and are not developed to provide the analytical and modelling possibilities of an ordinary GIS.

Following this development, the Automatic Identification of Ships (AIS) is now developing fast. In some aspects, the AIS display several GIS qualities. It is a system providing real-time data (position and attributes) on objects with a spatial distribution. As Berking (2003, p.61) identifies, the AIS is a tool that can:

- Enhance situational awareness to all users
- Detect potential collisions and groundings
- Allow ships to take proper action
- Enable Vessel Traffic Centres (VTCs) to monitor and optimise traffic flow without significant additional activities
- Enhance scope and quality of information exchange

However, as in the case of ENC/ECTIDS, the primary objective of the AIS is to facilitate navigation and improve safety by transmitting data to other ships and VTS stations. Still, several secondary effects can be identified, that could be useful from an environmental or ICOM perspective, such as better temporal and spatial resolution on statistics regarding traffic. This could be an essential tool in monitoring and modelling diffuse pollution sources such as operational discharges as well as accidental oil spills.

Hence, in conclusion ENCs as well as AIS data are not GIS *per se,* but have the potential to provide crucial data for ICOM, with respect to shipping activities.

Another common application of GIS as pertaining to maritime activities is the modelling of oil spills, their distribution, spreading and related coastal sensitivities. Within the Safety at Sea project (Interreg North Sea Region), one of the sub-projects is the classification of sensitive areas, based on the MOB model (a model for setting environmental priorities with respect to oil spill response preparedness), and the creation of the MRDB, Marine Resources Data Base (Safety at Sea, 2005). Further examples are listed in Appendix B.

These strengths of both these systems are brought together in the Swedish project SJÖBASIS (Maritime Authorities Information System). In this project, a number of Swedish governmental authorities are jointly collecting and coordinating civil maritime information. This includes AIS data, cargo, dangerous goods, different permit registers, weather information, oil spill drift tools, etc. The data will be available to all participating authorities, and the project will lead to a reduction of duplication of data. The data SJÖBASIS system and its data will however not be available outside the participating authorities. It will be implemented gradually and is estimated to be fully functional during 2009 (Swedish Environmental Protection Agency, 2006b).

3.4. GIS modelling for the maritime and coastal context

So what exactly is GIS modelling? In the context presented here, *a GIS model is a string or sequence of processes composed of data and tools.* These will be run in a sequence once the model is started. Several gains can be accomplished. Primarily, a model provides a facilitation and automation of the workflow. In addition, it may provide an improved visual representation of the geospatial relationships and processes, which might be one way of achieving the goal of making coastal GIS directly understandable and useful, as outlined above.

Different models needs to fulfil different criteria. Expert models might need a specialisation and effectiveness within a specific area, resulting in necessary concessions in other areas. However, in the context outlined in this dissertation, a GIS model should function primarily as a DSS, hence the qualities listed in section 3.2 should be prioritised. Consequently, the model should be flexible, adaptable and universally applicable.

Turner, Adger. and Lorenzoni (1998) present an overview and discussion of the principles and practices of modelling in the coastal zone, on the DPSIR-framework (Drivers-Pressure-State-Impact-Response). In this report, a causal diagram, identifying the cause-effect relationship between the system elements of the coastal zone, is presented (Figure 4). The system model presented here focuses on identifying causes, fluxes and effects and economic quantification related to these changes.

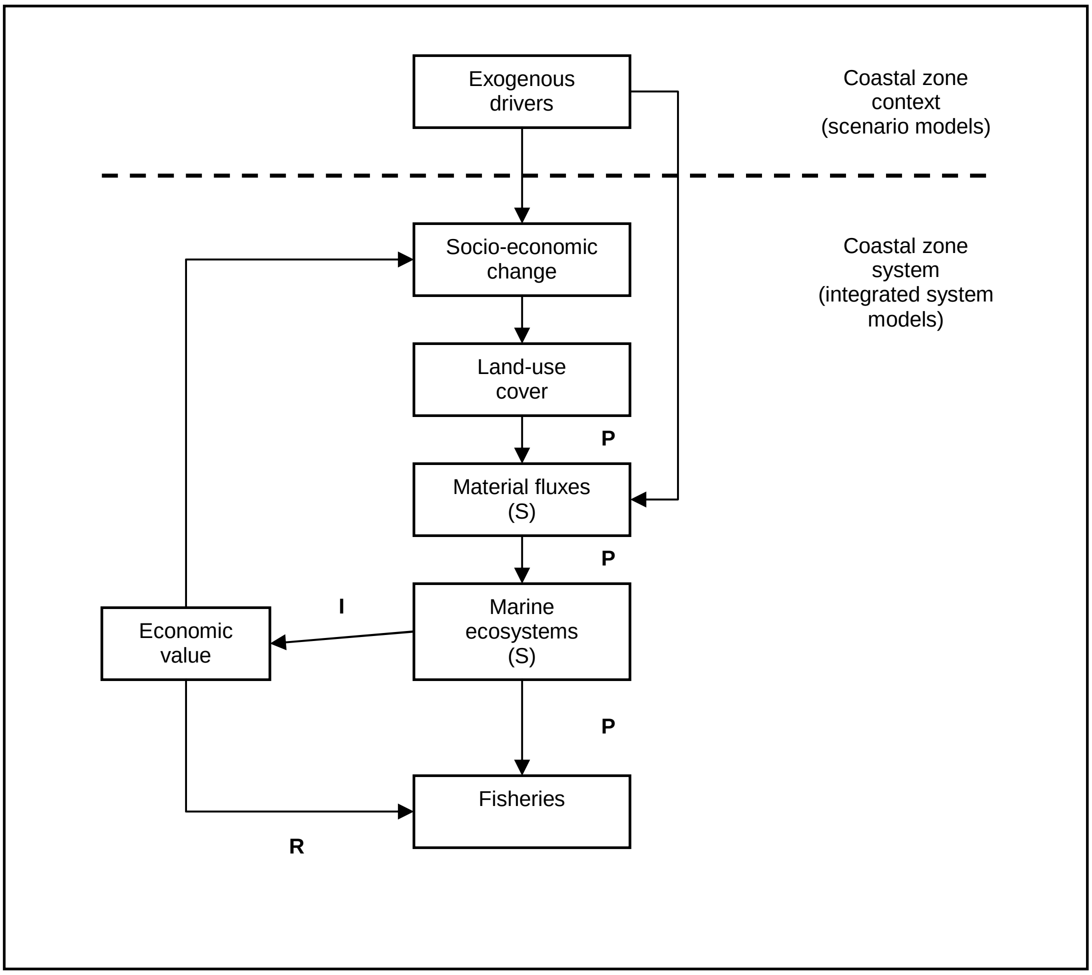


Figure 4. An integrated system model for land-ocean interaction. P=Pressure, S=State, I=Impact, R=Response.

Source: From Turner et al (1998).

So why are one of the models available already used (see Appendix B)? What is the added value of providing yet another attempt at fitting the marine-coastal interactions in a model? The answer, which is in several parts, lies in the needs of a tool for ICOM as well as the deficiencies in the available models.

Clarity and logic

The interactions, relations and potential conflicts represented in the coastal zone are many and transcend the boundaries of scientific disciplines as well as areas of responsibility (governments, agencies, industries). What is needed is thus a model that does not contribute to a further compartmentalisation, but provides an overview and clear, logic structure of the coastal web of information.

Flexibility and adaptability

Data pertaining to the coastal zone will inevitably come from a variety of sources and will be of different scales and formats. The tools employed should thus be flexible. Most of the models available today are not. They are either designed for a specific task, or – if they attempt to grasp a wider arena – merely tools for presentation or visualisation. The discussions in this dissertation thus strive to triangulate the criteria for a model that captures the complexity of the system while it is clear, logic and flexible. It should therefore focus on establishing a framework that is generic, yet comprehensive and expandable.

Availability of software

Based on the criticism brought forward in the preceding paragraphs, it follows that a coastal GIS preferably should be readily available to decision makers. Availability can be achieved in different ways. Either, the tool could be made available as a stand-alone application, downloadable from the Internet. There are several good examples of this solution (e.g. fGIS, Multispec, Macroscope and QGIS). It could also be in the form of commercial, but affordable software. However, unless one possesses the software developing skills necessary to build a tool from scratch, these two solutions demand that there are tools already available that correspond to one's needs. The remaining option is to use a one of the versatile but more costly full-scale GISs that include a scripting or model building function, and at the same time can provide all the necessary tools for data management and analysis.

Availability of Data

Coastal GIS implies handling data of a variety of formats. The model and software should thus be able to handle all different data types that might need to be incorporated. This includes raster as well as vector formats. Today, there is no single standard data format. Still, some data formats associated with the main commercial softwares are dominating the market, such as AutoCAD, DXF, Esri Shapefile and MapInfo formats (Longhorn, 2004).

Availability of data is however first and foremost a matter of routines and possibilities to sharing data. But it also concerns data transfer formats, and data structures. On global, regional and national levels, there are initiatives to set standard for spatial data infrastructure (SDI). Several examples can be found around the world (Longhorn, 2004; Strain, Rajabifard and Williamson, 2006):

- USA: the Coastal SDI (CSDI) under the Coastal Services Centre of NOAA (National Oceanic and Atmospheric Administration
- Canada: the Marine Geospatial Data Infrastructure (MGDI)
- Europe: The Infrastructure for Spatial Information in Europe (INSPIRE), and the European Water Framework Directive
- Global: Global SDI (GSDI), under the Intergovernmental Oceanographic Commission Committee on International Oceanographic Data and Information.

None of these bridges the land-sea divide, which further exemplifies the difficulties of overcoming the inherent compartmentalisation, jurisdiction and data ownership.

3.4.1. Existing models and frameworks

There are numerous of GIS-based models available. Most of these deal with land-based phenomena, and there are also many that focus on the marine environment. However, for the reasons already discussed, the models pertaining to the entire coastal zone are considerably fewer.

In Appendix A, a compilation of models and GIS applications is provided. These have been grouped into three subheadings; pure models, projects that can be described as visualisation of data, and other applications that may be of relevance. A brief survey of these reveals that many of the listed tools are primarily for visualisation of data. Among the applications that have a clear modelling component, most have a specific geographic coverage or focus, and many have a scenario building functionality.

3.4.2. Proposing a framework and relevant parameters

With the preceding discussions in mind, we will now focus on a discussion and a proposal for a potential model structure. In the first section, a general framework of data of interest in such a model will be outlined and described. The following chapters (Chapter 4) will the then elaborate on the relation between the parameters based on a small case study.

What type of data?

The data needed to provide a somewhat comprehensive picture of the relationship between the environmental opportunities and constraints of the coastal zone, and the potential risks posed by shipping activities, can be grouped into four main groups (see Table 5). First, data related to the maritime industry and its shipping activities are needed. The second group of data concerns the marine environment and its characteristics. Third, data pertaining to the terrestrial environment is required. These can be divided into data related to natural phenomena and basic geographic features, and data on human activities. The fourth group relates to planning, i.e. regulatory and legislative issues. Finally, data on impacts are needed.

Table 5. List of parameters and desired data for a ICOM/shipping model.

DATA CATEGORIES	PARAMETERS
1. MARITIME DATA	
a. Traffic	• Routes • Density • Regularity • Cargo
b. Ship	• Type • Size • Age • Speed • Flag
Manning and Crew	• Watch • Crew
2. MARINE DATA	• Depth • Bottom substrates • Circulation patterns • Habitats • Spawning • Tides
3. TERRESTRIAL DATA	
a. Natural	• Basic geographic features • Coastal types (habitats) • Shoreline character • Rivers discharge • Wave exposure • Coastal hazards
b. Human activities	• Cities • Ports • Infrastructure • Industries • Land use • Population
4. PLANNING	• Detailed/regional planning • Development planning/zoning • Maritime zoning • National interests • Protected areas • Cultural values • Economic values
5. IMPACTS	

a. Ship-based	Pollution (noise, air pollution, garbage, sewage, NLS, oil, ballast water) Wave generation
b. Land-based	Point sources Non-point sources

Data sources

The data listed above is not available from one, single source. A number of different sources have to be consulted, such as County Administrative Boards, Maritime Administration, Environmental Protection Agency, The National Survey, municipalities, port authorities etc., which are listed in Appendix B, making it quite a time consuming task. Not only is the data coming from different sources, it is also in different formats (GIS-format, tabular statistics, paper prints etc.). The implications of this will be more thoroughly discussed in Chapter 5.

In this section and its subheadings, data with potential interest to id is discussed. As Chapter 4 will indicate, many of these are not readily available

3.4.1.1. Maritime data

The nature and patterns of the maritime traffic are of course determining if, to what extent, and how the shipping activities may have any potential to pose environmental risks to the coastal zone environment. To characterise the shipping patterns, three different groups of parameters can be distinguished; traffic characteristics, ship characteristics and manning/training.

Traffic characteristics

From a geospatial perspective, the traffic characteristics can be described by its spatial patterns (traffic routes), its density and regularity etc. These data are usually available either from port authorities or maritime administrations. In the case presented in the following chapter, these data were available as tabular data, listing ships, port of call, date and cargo (in tons, type of cargo not indicated).

Ship characteristics

A ships character will determine might be of interest, as it determines what type of cargo, and how much, that can be carried. Consequently, the ship's size and type is of concern (what it transports and how). Also, the ship's speed and age would be valuable information, as these two factors are directly linked to risks in terms of accidents.

Manning, training etc

Additional parameters that could influence directly or indirectly, are the number of crew, the type of watch deployed, and the flag. The ship characteristics can usually be found in the AIS (Automatic Identification System), but is not always readily available, such as in the Swedish case. Data acquisition is not foremost a matter of which data that exist, but which data that is *available*. This will be discussed further in Chapter 5.

3.4.1.2. Marine data

The data concerning the marine parts of the coastal environment are of course of outermost value, and often neglected in terms of geographical cover, temporal and spatial resolution, as well as general attention by decision makers and the public. The desired parameters include information on depth conditions, bottom substrates and types, flora and fauna, slope/gradient, geology as well as circulation patterns.

ArcMarine (2003) is a project aiming to build a comprehensive GIS based model for marine data. In this project, the following layers were identified:

- Basic maps. General background data.
- Marine points, e.g. soundings.
- Marine boundaries.

- Water column data.
- Device measurements.
- Human measurements.
- Bathymetry.
- Substrates.

Mapping of marine habitats and biotopes are for example available for the Stockholm archipelago (Mattison, 2005), which is based on the EUNIS (European Nature Information System) hierarchical classification system.

3.4.1.3. Terrestrial data

The terrestrial data, or rather coastal zone data, since it comprises terrestrial as well as riverine and some marine features, can be divided into natural features and man-made. Among the natural features, a number of parameters can be identified.

Natural and basic layers

- Basic geographic features (land, sea etc.)
- Coastal types (habitats) and shoreline character
- Rivers and their discharge
- Wave exposure
- Coastal hazards
- Tides

Here, one issue to deal with is how to classify coastal types and habitats. Some general classification schemes are available, and it might be valuable to conform to these, as it provides a common platform of sharing data and information. There are several classification schemes available within the European context, one being the EUNIS initiative of the European

Environment Agency (EEA). Land cover data for Europe is available through the Corine database (European Environmental Agency).

On the human or man-made side of the coastal zone parameters, the following can be identified as valuable.

Human related parameters

- Cities
- Ports
- Infrastructure
- Industries
- Land use
- Population
- Off-shore activities (oil, gas, mining, wind-farming…)

3.4.1.4. Planning and management

Issues related to planning and management provides yet another group of parameters to consider. These include zones where restrictions in land use (protected areas) are in place, but also zones outlining the jurisdiction over natural resources, detailed and regional plans for planning etc. In the case study, areas identified by governmental agencies as being of national interest have also been included in this category.

There are also areas with economic or cultural values that do not fall under the previous sub-headings, such as ancient objects, fishing zones etc.

Maritime zones could also be placed in this category (Territorial Sea, Contiguous Zone, EEZ etc.).

3.4.1.5. Impacts

In the final category, data is listed that can be characterised as impacts, be it from shipping or other sea- or land-based activities. Some of this data is available in most areas, other data can be derived from available data layers, and some data is more difficult to find.

The environmental impacts in the coastal zone can broadly be divided into ship-based and land-based. The potential impacts from ships have been discussed in section 2.4. As for land-based sources of impacts, these can be either point sources of pollution (such as industries and river outlets) or non point, diffuse sources (rural or urban areas).

These are important to identify, not only for their individual impacts, but since they may act together to give rise to synergistic effects.

Together, these data, as listed in Table 5 above, provide an open, flexible yet robust structure. It is a design intended to provide a basic framework to build on, and might be suitable for sharing data between users in an ICOM context.

As a comparison, an example of data structure used for local coastal management efforts in Wisconsin is outlined below (Figure 5).

Data used in Wisconsin:

Air and Water quality

- Shoreland zoning - Blue Lake, Onieda County (c)
- Point sources of pollution
    - Non-point sources of pollution
    - Rural, high density: Manitowoc/Sheboygan Counties (u)
    - Rural, low density: Town of Barksdale, Bayfield County (u)
    - Urban: City of Superior, Douglas County (u)
- Sedimentation and polluted sediments (f)
- Atmospheric deposition of pollutants

Special environments

- Dunes, wetlands, islands
- Habitats and natural areas (fish, amphibians, plants, etc.)
- Historic resources (land and water, natural and cultural) (f)
- Apostle Islands National Lakeshore
- Public parks, forests, natural areas, recreation areas
- Habitat of non-indigenous species (zebra mussels, gobies, ruffe, etc.)

Shore development

- Coastal hazards
    - fluctuating water levels/storms, flooding (u)
    - shore erosion: Town of Mosel, Sheboygan County (c)
    - lake bed erosion
- Shore-dependent facilities
- Physical and visual access
- Land and water transportation routes

Figure 5. Data used in coastal management by the local government in Wisconsin.

Source: Hart, Miller, Niemann, and Ventura (2006)

4. The case study

In order to further exemplify some of the arguments and lines of thought presented so far in this dissertation, a small case study will be presented in the following chapter. In this demonstration, the Bay of Gävle will be used, being an area of expansion in terms of shipping traffic. The port of Gävle has been designated to be the main hub for the supply of jet fuel to Stockholm Arlanda Airport for the next 25 years, and is set to build a new container terminal. It is also a region where several ports are located within a relatively small area.

4.1. Outline of the study area

The Bay of Gävle area with the port of Gävle is mainly a hub for the industries in lower Norrland, both the coastal and inland areas, with 80-85 percent of the goods going to or from other areas than Gävle itself. The area is serviced by Holmuddsrännan, which provides access to five main harbour areas (Table 6).

Table 6. The ports/wharfs in the Gävle area.

Harbour	Functions	Owner
Fredrikskans	Main terminal. Oil, bulk, container and forest products.	Gävle Hamn AB
Karskär	Industrial port for Korsnäs paper mill. Pulpwood import.	Korsnäs/Gävle Hamn AB
Granudden	Distribution terminal for forest products (paper pulp).	Gävle Hamn AB
Norrsundet	Pulpwood import and paper pulp export.	Stora Enso AB
Skutskär	Pulpwood import and paper pulp export.	Stora Enso AB

Source: The Swedish Maritime Administration web page.

The main function of the ports is to receive energy and raw materials for the heavy industries in the region. Each year the port of Gävle handles approximately 3.6 million tons of goods (SIKA, 2006). Two thirds of this is incoming goods. The port of Gävle is the third largest container terminal in Sweden and the largest on the east coast, and there are plans to build a new container terminal to expand its capabilities from 75 000 TEU to 150 000 TEU per year (Åkeri & Transport, 2005; Sveriges Hamnar, 2005). The main types of goods are fuel for industries and consumers, jet fuel (starting in 2006), clay for the paper industry, forest products, scrap and steel. The ships that call at the port of Gävle are therefore mostly tankers, bulk carriers, dry cargo carriers or Ro/Ro's. The port of Gävle is the northernmost container terminal on the east coast of Sweden.

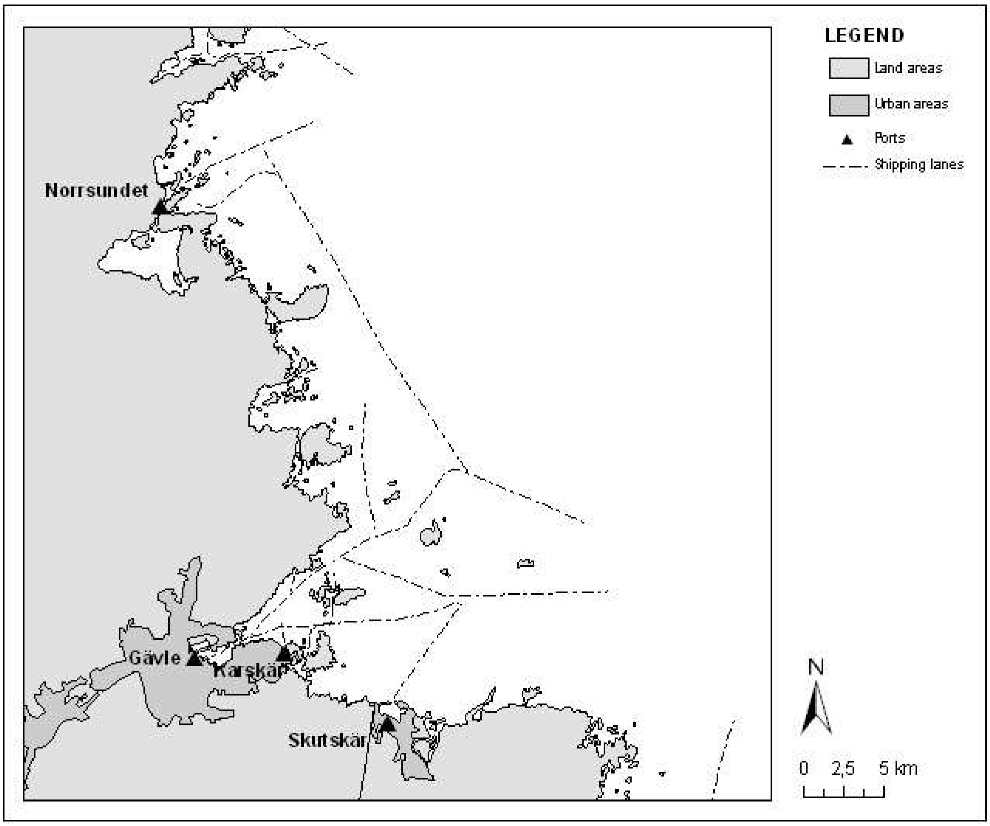


Figure 6. Map of the case study area.

The issue - The new traffic route

Sweden is dependent on transporting goods by sea internationally, regionally and domestically. More than 90 per cent of all export and import is conducted by sea, and the volumes increase every year (Swedish Maritime Administration, 2005).

As a consequence to the general increase of goods shipped by sea, the expected increase in containerised goods and the large volumes of jet fuel to be handled, the port of Gävle is foreseeing a period of expansion. The size of ships calling at the port of Gävle is therefore expected to increase, for all ship types, and hence an extension of the present navigable channels is planned, as outlined in Table 7.

Table 7. Present and proposed restrictions at Gävle Port.

	Length	Bredth	Max. draught	Other
Present, daylight	220m	30/28m	9/10.10m	Pilot required when draught is at 9m or more.
Present, darkness	180m	25m	8.60m	
Proposed	220m	32.25m	12.2m	No restrictions

Present traffic patterns

At present, the traffic patterns (see Appendix D) to the ports in and around the Bay of Gävle indicate that the transport is regularly distributed over the year. Out of the four ports, only the port of Gävle displays a variety of products and carriers. Norrsundet (SENOT) and Skutskär (SESSR) are almost exclusively serviced by dry cargo carriers and bulk carriers, while a limited number of tankers carriers call at the port of Karskär (SEKAS). The ports of the innermost parts of the Bay of Gävle, known as Yttre Fjärden (Fredrikskans/Granudden or Gävle, and Karskär) registered some 778 calls during 2005, while the wharf of Skutskär counted 272 calls and Norrsundet, the northernmost of the ports (not within the Bay of Gävle) recorded 304 calls, according to the records of the Swedish Maritime Administration Appendix D). The traffic patterns show no extreme seasonal variability, but a slight increase in traffic during the spring and early summer months can be detected.

4.2. The coastal zone and its setting

The case study region falls within the County of Gävleborg and the Province of Gästrikland. The landscape is predominately forested, mainly by coniferous forests. The terrain is described as a rift-valley landscape dominated by till soils (Sveriges Nationalatlas, 1996). In terms of population and urbanisation, the area is dominated by Gävle, with a population of approximately 92 000, situated at the mouth of the river Gavleån, and 25 km north of the mouth of the river Dalälven. Several energy and raw material intensive industries are located in the immediate vicinity, such as paper and wood product industries (Korsnäs AB, Stora Enso AB, Kappa-Förenade Well), and many more in the region of lower Norrland.

Protected areas and areas of national interest

Datasets on protected environments as well as areas of national interest are available from the County Administration Board (Internet). There are several areas that fall under some kind of protection in the study area. Areas protected based on cultural values are for example found along the coastline northeast of Gävle, an area of high recreational value (Norrlandet).

There are nature reserves as well as Natura 2000 areas within the area, both on the land and sea side. Two groups of island in the bay are classified as nature reserves; Vitgrund-Norrskär and Eggegrund-Grålsjälsbådan. Off the coast, at Utposten-Västra Banken-Eggegrund, there is an area of national interest with respect to spawning for fish.

A survey of coastal birdlife was performed by the County Adminstrative Board in 1997-1998. It showed that there are several islands along the coast where birds may be seen as in need of protection from disturbances (I. Wänstrand, Country Administrative Board Gävleborg, personal communication, June 12, 2006)

When it comes to mapping of individual parameters of environmental interest, few parameters have been mapped with a complete geographical coverage. Instead, indicators have been monitored at selected sites through inventories and trend analyses. One example is the bladderwrack, *Focus vesiculosus*, an important indicator as it is important for the biological diversity (providing a habitat for the micro fauna as well as food source) and is sensitive to pollutants and eutrophication (Länsstyrelsen Gävleborg, 2004).

4.3. Maritime risk factors in the study area

Accidents are not frequent in the study area. Data from the Swedish Coast Guard (Kustbevakningen, 2006a) indicate that the frequency of accidental and illegal oil spills is low. During 2005, the Swedish Coast Guard registered 313 illegal spills within Swedish waters. Out of these, only six were located in the southern part of the Gulf of Bothnia. The most well-known accident in the area took place in December 1986, when the Swedish owned tanker Thuntank 5 grounded near in the Bay of Gävle. 100-200 tons the 5000 ton cargo (crude oil) entered the sea and caused extensive contamination along the shoreline and islands, affecting five different municipalities (Räddningsverket, 2004).

Oil is not the only substance transported in this part of the Baltic Sea that may give environmental effects if released into the water. According to the Swedish Coast Guard (Kustbevakningen, 2006b), sodium hydroxide, ethanol, sulphuric acid, acetic acid, ethyl alcohol and turpentine are all transported in significant quantities in the southern parts of the Gulf of Bothnia.

The existing shipping lanes in the area are indicated in Figure 6. Several of these run close to or even intersect sensitive or protected areas. Later, this relationship will be used as a small demonstration of the modelling capabilities of ArcGIS.

4.4. A GIS based model of the study area

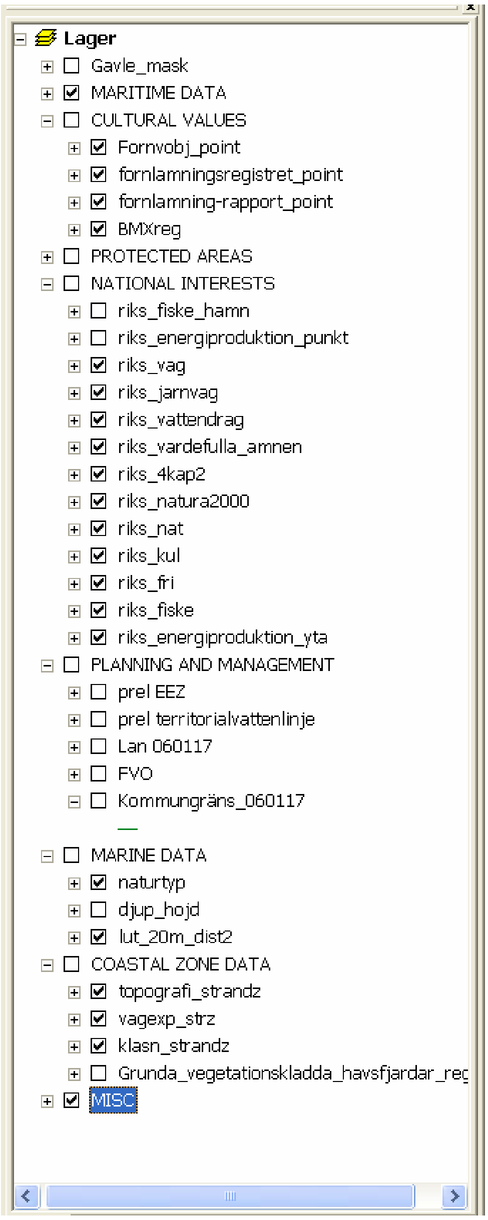
In order to illustrate the possible use of a GIS modelling function within the presented perspective, an attempt was made to structure a basic approach to data management and analysis, including the building of a basic model for data analysis.

This modelling part of the case study consists of three parts that are interlinked.

- Designing a conceptual framework
- Building a database
- Designing and applying a model

The conceptual framework has been described earlier in this dissertation, and can be seen as an illustrative way of explaining and visualising the relation between different parameters and the data structure, thereby setting the basis for the database and model design. It consists of a flowchart where the different parameters are laid out in relation to each other (Appendix B). The structure provided here is very crude and basic, but could be expanded and developed, specifying the relationships in more detail.

The second step was to collect data and create a database. Data was collected from several sources as outlined in Appendix C. These were imported into the ArcGIS software from ESRI (ArcView license), creating a geodatabase (using, ESRI terminology, short for geographic database). In a map document (.mxd), the data was arranged in data frames (groups of data sets), according to the structure in Table 5 (which in turn is based on the framework structure in Appendix B), as is illustrated in Figure 7.



- Lager
  - ☐ Gavle_mask
  - ☑ MARITIME DATA
  - ☐ CULTURAL VALUES
    - ☑ Fornvobj_point
    - ☑ fornlamningsregistret_point
    - ☑ fornlamning-rapport_point
    - ☑ BMXreg
  - ☐ PROTECTED AREAS
  - ☐ NATIONAL INTERESTS
    - ☐ riks_fiske_hamn
    - ☐ riks_energiproduktion_punkt
    - ☑ riks_vag
    - ☑ riks_jarnvag
    - ☑ riks_vattendrag
    - ☑ riks_vardefulla_amnen
    - ☑ riks_4kap2
    - ☑ riks_natura2000
    - ☑ riks_nat
    - ☑ riks_kul
    - ☑ riks_fri
    - ☑ riks_fiske
    - ☑ riks_energiproduktion_yta
  - ☐ PLANNING AND MANAGEMENT
    - ☐ prel EEZ
    - ☐ prel territorialvattenlinje
    - ☐ Lan 060117
    - ☐ FVO
    - ☐ Kommungräns_060117
  - ☐ MARINE DATA
    - ☑ naturtyp
    - ☐ djup_hojd
    - ☑ lut_20m_dist2
  - ☐ COASTAL ZONE DATA
    - ☑ topografi_strandz
    - ☑ vagexp_strz
    - ☑ klasn_strandz
    - ☐ Grunda_vegetationskladda_havsfjardar_re
  - ☑ MISC

Figure 7. Data structure in the Table of Contents of ArcMap.

4.4.1. Example 1: Defining intersecting areas

The ModelBuilder functionality of ArcGIS gives the user the possibility to design and create sequences of processes in a graphically logic manner. In the first example, a small model was created containing the following steps:

- A buffering of the shipping lanes, to create a zone within 500m of the actual lanes. This is an arbitrary value to delineate the immediate areas close to the shipping lanes.

- For each of the files (Natura 2000 areas, Areas of national interest with respect to fishing), the model decides if its features intersect with the buffered shipping lanes.
- Data that covers a larger area than the actual study area is masked, to extract the data that is relevant.
- For each data group (marine data, national interests, protected areas, coastal zone data), the resulting files from the intersection process are merged into one file.

Figure 8 shows the study area with the Natura 2000 areas, the areas of national interests with respect to fish stocks, and the shallow bays and inlets that fall within 500m of the shipping lanes. The model, as presented in ArcGIS's ModelBuilder function, is found in Appendix E.

This is a small but illustrative example of the benefits of the model-building function. Several features could be added, such as a calculation of surface areas or integration of oil-spreading models or other related applications. A geodatabase could contain several predefined models, which can be expandable or editable. This allows for a structured and logic, yet flexible approach to data management and analysis.

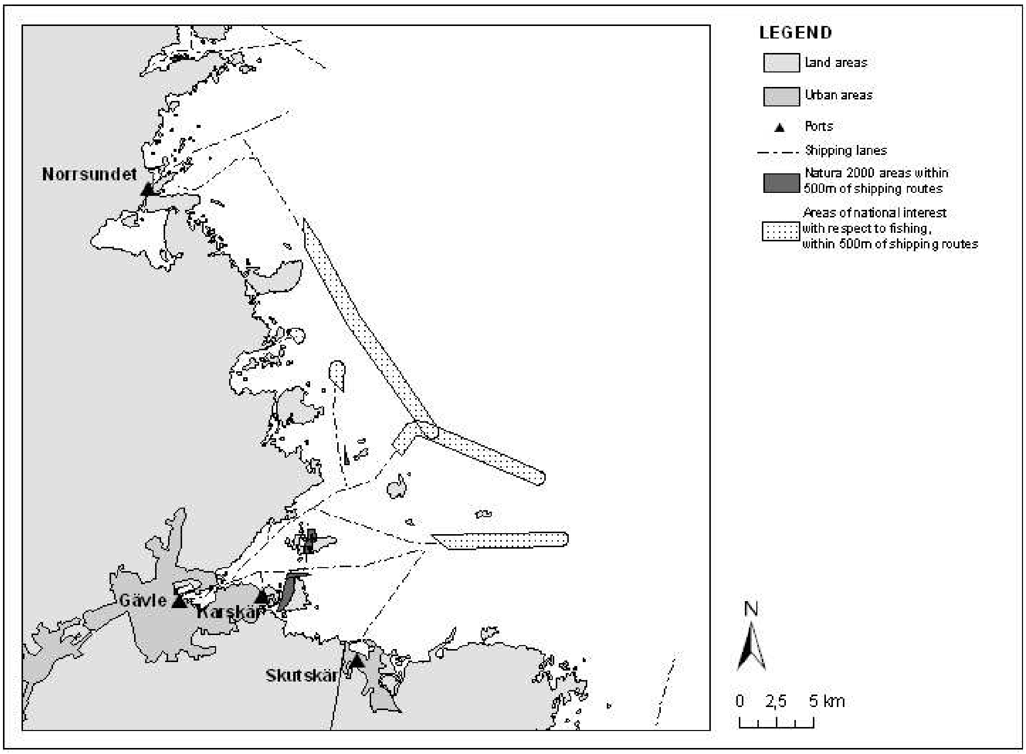


Figure 8. Example of the result from a model execution in ArcGIS (ArcMap) ModelBuilder. The map shows the Natura 2000 areas, the areas of national interests with respect to fish stocks, and the shallow bays and inlets that fall within 500m of the shipping lanes.

This model could easily be expanded. In Appendix F, a schematic illustration of a model is presented, adding some functionality. Data that is available in raster format is converted into vector format, since for most analytical operations data layers need to be of the same format. In the final stage of the model, the resulting data is summarised statistically according to the needs of the user, and presented in map format as well as statistics.

4.4.2. Example 2: Combining data formats and calculating areas

As stated earlier in this dissertation, data in the coastal context is often available from different sources and in a variety of formats. The modelling approach is suitable for facilitating the integration of disparate data, for example by converting data formats, projections or coordinate systems. To illustrate this, an example is provided where the aim is to produce a map of the wave exposure of the coastal areas that are located close to shipping routes within the study area. In addition, the area and percentage of each exposure class is calculated. In short, the different steps involved are (Figure 9):

- Shipping lanes are buffered to create a zone within 500m of the actual lanes, as in the previous example.
- Data that covers a larger area than the actual study area is masked, to cover the study area only.
- Wave exposure data was provided by the SAKU-project (Compilation and analysis of near-shore marine environments) of the Swedish EPA. This is based on wave exposure calculations by Martin Isaeus, using a software called WaveImpact (Isaeus, 2004). Most of the operations in the toolboxes of ArcGIS require that the contributing data is in the same format. Since the data is in raster format, and the shipping lanes are in vector format, the model converts the wave exposure data to vector format.
- The data with the buffer zones of the sipping lanes is combined with the wave exposure data, using the Intersect operation.
- For the resulting data, the area for each class is calculated.

The resulting map is presented in Figure 9, and the calculated areas for each class in Table 8.

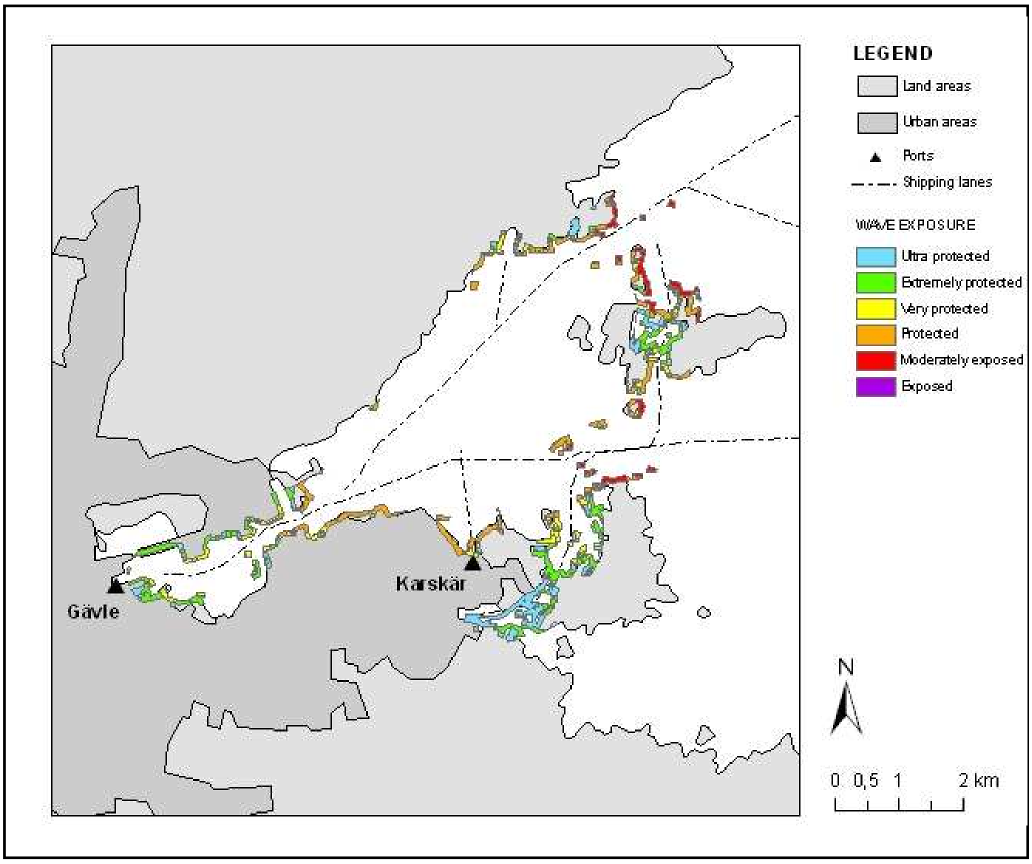


Figure 9. Wave exposure in the Gävle area.

Table 8. Calculated areas (km$^{2)}$ and percentages for each wave exposure class.

Wave exposure class	Calculated area (km^2)	Percent of classified area
Ultra protected	0,84	16,69%
Extremely protected	1,19	23,52%
Very protected	0,68	13,40%
Protected	1,45	28,69%
Moderately exposed	0,85	16,93%
Exposed	0,04	0,76%
Total	5,05	100,00%

5. Discussion

The use of GIS in coastal, marine and maritime application is not as mature and well developed as for terrestrial applications. Several obstacles have impeded the evolution of GIS in the coastal/marine domain; the complexity of relationships, the dynamism of parameters, the consequent difficulties in delineation of borders in this environment and the sharing of jurisdiction over resources as well as responsibilities for mapping and monitoring. Deficiencies in coastal applications of GIS might also stem from the fact that responsible institutions generally tend to do more when it comes to land-based issues, as these receive more attention from the public, politicians and media. As discussed by Smith and Bartlett (2000), coastal GIS and remote sensing applications have developed into a unique discipline, differentiated from marine GIS. According to Smith and Bartlett, this is a consequence of GIS practitioners trying to meet the challenges of coastal management.

Hence, spatial relationships and data structures are still developing, and conceptual models that address these relationships and structures are needed. Naturally, this dissertation does not provide the solutions to all these issues, but might indicate some areas in need of attention.

The structure presented in this dissertation illustrates a tiered approach to organising and using geospatial data in the ICOM context. As demonstrated in Figure 9, one can envision that all three tiers should be part of a successful, integrative database management and modelling for ICOM/maritime issues. Integration starts already at tier 1 and continues to the following levels.

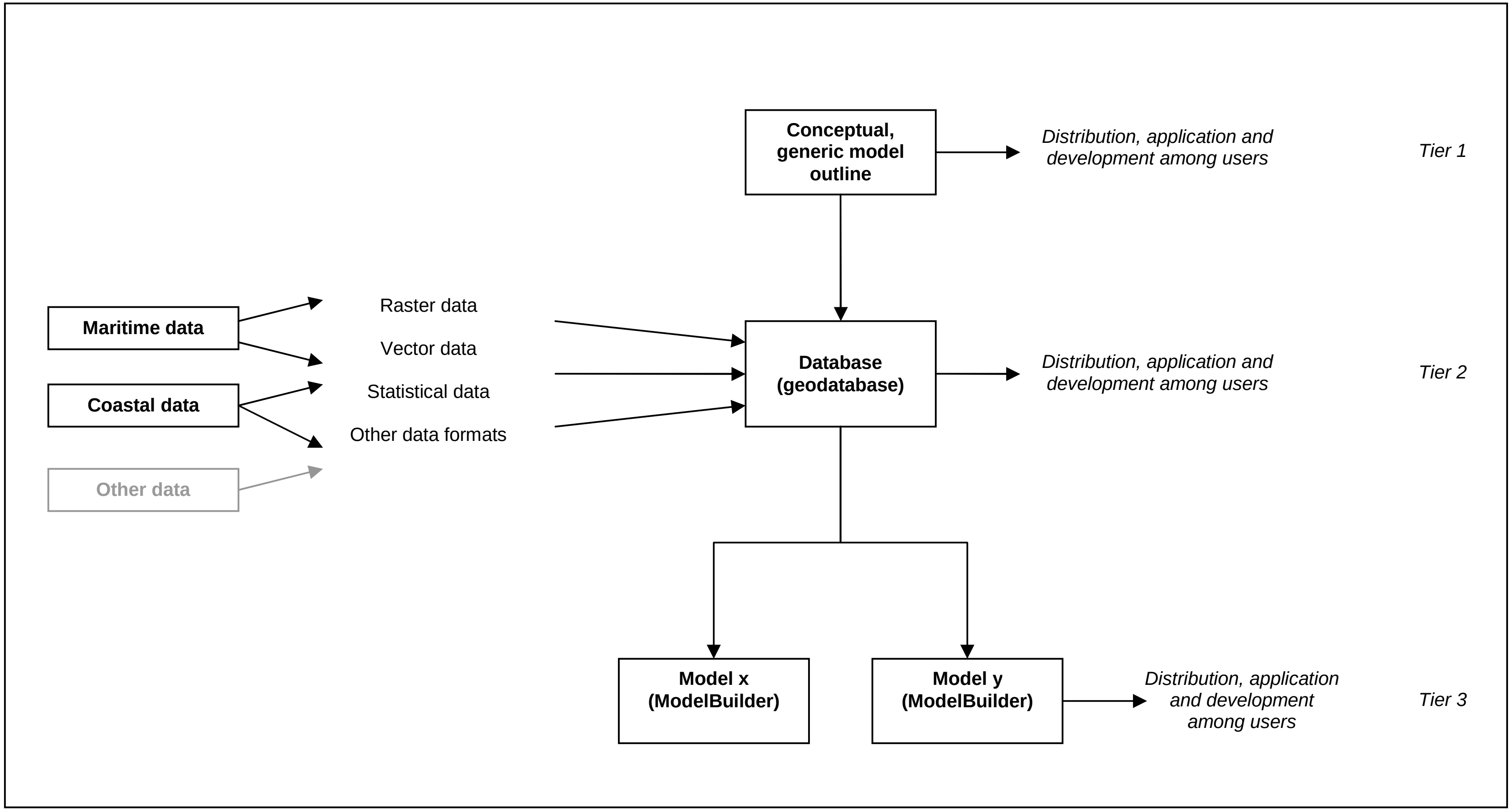


Figure 10. A tiered approach to GIS based modelling for ICOM

The small demonstrational study presented in the preceding chapter illustrates some of the potential benefits of GIS to ICOM. As exemplified in Appendix F, the possibility to provide structured approaches to operations such as data conversion (e.g. raster to vector) is valuable in the coastal context, where data is obtained from a wide range of sources, which was discussed in Chapter 3.

As the two examples hopefully illustrated, the modelling approach can be used to facilitate the flow of data, to manage large quantities of data, and to assist and speed up processes that are repeated for many files. Data format conversions, area calculations and selections based on different criteria are operations that might be time consuming, especially when dealing with large quantities of data. Since models can be shared easily, users can contribute and draw on other user's experiences.

However, GIS is for many users, if not most, mainly a tool for *visualisation* of spatial relations. This quality is essential in the ICOM process, being a vehicle for involvement by the public and other stakeholders (Jude, Jones and Andrews, 2000). The visualisation of spatial interactions in an understandable manner and making intangible relationships tangible are important tools in the process of integration. Traditionally, GIS have had a technical focus, which is unfortunate since this may hamper the true merits of these tools.

Data availability

As pointed out in Chapter 3, the different tasks of a GIS consist of the input, storage, analysis, retrieval and presentation of data. This study illustrates what is already quite well known, but cannot be emphasised too much – that data collection is the most tedious part of a GIS-based approach. However, the data collection and input for a country is not more time consuming than for a limited study area such as in this dissertation; it is the number of files and their origin that determines the time needed. This argument reinforces the important conclusion that follows, i.e. that data sharing becomes even more crucial in a context such as ICOM with such a wide array of data and users.

Given these facts, a natural remedy for this problem would be to create a national database comprising all the data pertaining to the integration of coastal and ocean management and planning. Such a database could be designed and maintained in the ArcGIS environment, using its *multi-user geodatabase* capabilities (ArcSDE is needed). With this function, a database can be stored and maintained on a server, being accessible to multiple users over a network. This database can contain the data itself, metadata as well as models.

This setting has several advantages. First, it allows for a maximisation of data usage, since accessibility is enhanced. It reduces time and efforts in terms of locating data, which is often the most tedious task of all; i.e. trying to establish what data is available and who has it.

One good example of GIS data distribution based on a centralised access service is the County Administrative Board's common web interface (http://gis.lst.se/lstgis/). Here, data from Sweden's 21 CAB's, including metadata, can be accessed through one single web page, containing almost 1500 datasets. What this example (and the discussion itself) points to is the fact that data acquisition is not foremost a matter of which data that *exist*, but which data that is *available*. And availability is in turn depending on several factors, some are technical and some are social or cultural in nature. The technical aspects of data availability are relatively easy to deal with. These mainly include the format of the data and how and where it is stored. The social or cultural aspects are much more difficult, as these include the data owner's willingness and capabilities to share the data. These may be a result of pure politics as well as inherent structures, fields of responsibility and jurisdictions among the potential user of geospatial data within the coastal zone.

A second advantage of a multi-user database is the possibility to avoid duplication of data. Creating data, be it through field work, digitisation of analogue data or any other way, is time consuming and thus costly (often in terms of equipment as well). Reducing duplication of existing through is therefore both a gain in time and money spent, and is arguably a substantial benefit to ICOM activities.

GIS is used by many, at different levels, and thus corresponds to different needs. The bulk part of the users will probably use GIS as a visualisation tool, not focusing on spatial analysis. For example, this group might be interested in showing the distribution of ports along the Swedish coast. In this case, there is no need to be able to use the full analytical power of the high-end GIS solutions. Hence, a web-based client or map viewer software will be sufficient. The next segment of users is those who are interested in geospatial data in the form of databases. Here, the management of large sets of data and the extraction and visualisation of this data is of interest. The last group would include those who use geospatial data and software for more complex analysis, including cartographic conversions, modelling and geoprocessing. This relationship between the analytical power of the GIS and the number of users is visualised in Figure 10. However, today the databases or models for ICOM and maritime related issues are generally restricted to one of these levels. Data may for example be visualised in a web-application (a map interface), but not downloadable.

In the integrative context of ICOM, this might be restrictive. If sharing of data is one of the ways of empowering the ICOM process, data availability should be improved by facilitating the distribution of this data. There are however some potentially negative consequences of sharing data openly, as discussed below.

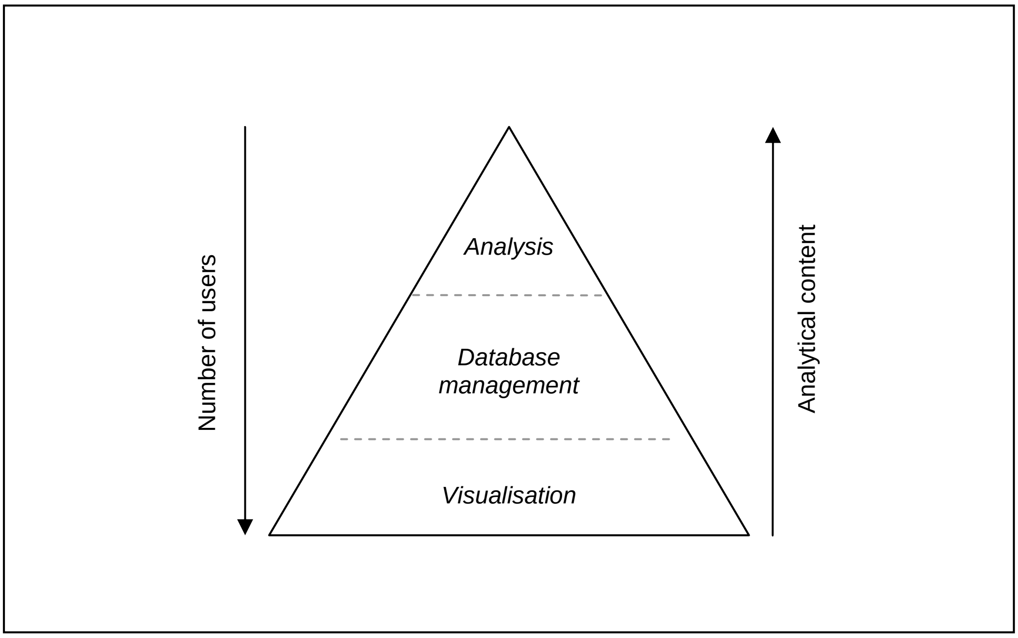


Figure 11. A visualisation of the relationship between analytical content of the GIS application and the number of users.

Data quality

The sharing of data also implies a sharing of metadata to ensure the quality of data. Since ICOM activities are performed at many different scales (regions, catchments, municipalities etc.) data will undoubtedly be of a variety of scales, and from a number of different sources. Historical data is also of interest, and hence data on one parameter might be recorded through different methods over time. Consistent, reliable and understandable metadata is therefore crucial. One of the negative aspects of sharing data openly such as proposed in the previous section relates to data quality. If data is readily shared to whoever wishes to use it, the control of the data decreases. Data can for example be downloaded by a user, manipulated and in worst case corrupted, and then passed on to yet another user who unsuspicious of the deficits uses the data as if it was trustworthy. Issues such as this can however be addressed through multi-user, server-based applications, which gives the administrator a possibility to assign the different users individual rights in terms of data access.

Another benefit of a tiered approach to GIS, multi-user databases and model-building, lies within the domain of repeatability. Further, it allows the users to take advantage of the most advanced manipulation and analysis capabilities of ArcGIS and the support of more complex rules that can be built into the geodatabase (Wright, Halpin, Blongewicz, Grisé, and Breman, 2003).

Apart from the issues above, the success of GIS applications in the coastal and marine field depends on matters that do not pertain to GIS as such. For example, in terms of marine pollution, the hidden statistics are considerable when it comes to operational discharges and deliberate dumping. In such cases, the impacts of under- or over-estimations of certain parameters are of course of uttermost concern.

Consequently, GIS may not be the panacea to the integration of maritime, ocean and coastal management. Other variables are equally important in achieving successful ICOM efforts. Still, as outlined in section 2.3, successful management of the coastal and ocean environment, including maritime issues, will depend on successful management of information. And undoubtedly, GIS has its merits in terms of managing complex and large datasets, visualisation of data and compound relationships, and hopefully in sharing these data.

In the case study in this dissertation, ArcGIS from ESRI (ArcView license) was used. This software has some benefits and some disadvantages. Among its merits is its availability. ArcGIS is a comprehensive but costly software suite. Still, over the years it has attained a leading position among GIS solutions, with its shapefile format becoming somewhat of a world-wide standard. In Sweden as well as many other countries, it is a common alternative among governmental agencies and educational institutions. For this reason, it is often the available software option. Furthermore, the ModelBuilder function of ArcGIS provides a reasonably logic, user-friendly and visually appealing approach to model design and execution.

The drawbacks of ArcGIS are equally evident. It offers complicated data handling strategies, and a somewhat limited export function. The complicated functionalities in combination with the high price may have some implications in terms of accessibility and should be further brought to the fore in the discussion of coastal GIS application in developing country contexts.

5.1. Moving on from here

As has been emphasised throughout the dissertation, this study is not by far a complete analysis of coastal GIS and the integration of maritime environmental issues. Hopefully, some issues are illuminated and some ideas seeded that may be of value. The demonstration study presented is not by any means an exhaustive exposition on the topic. It merely illustrated some of the basic ideas that might be of value within the considered context. Several issues have been left out, that could be adding significant value to the tools, processes and approaches.

The model outline (Annex B and Table 4) could be expanded considerably. The flowchart and list presented are only considering the most basic parameters. To expand these in a structured way all the activities listed by Vallega (1996) could be used. Vallega introduces a systematic classification of coastal zone uses that include: seaports, shipping (carriers, routes, navigational aids), pipeline, cables, air transportation, biological resources, renewable energy, defence, recreation, waste disposal, research, archaeology, environmental preservation and protection. These uses are further subdivided into a total of 250 kinds of uses that compete for space, resources, and the waste absorption capacity of the coastal zone (Fedra and Feoli, 1998).

Other parameters that can be incorporated into a multi-user database are contingency planning, coastal defence plans and sensitivity mapping.

There are also substantial benefits to be made in the inclusion of remote sensing data, such as for land cover and land use changes (O’Regan, 1996). One example of such an application is the Corine (Coordination of information on the environment) land cover data set of the EEA.

Finally, this dissertation has not been able to include a discussion on how to achieve a truly integrated GIS, which incorporates river catchments, marine and terrestrial perspectives (see Figure 12), as is necessary for a comprehensive ICOM. Based on the tiered approach presented here, such an all-embracing perspective should be possible.

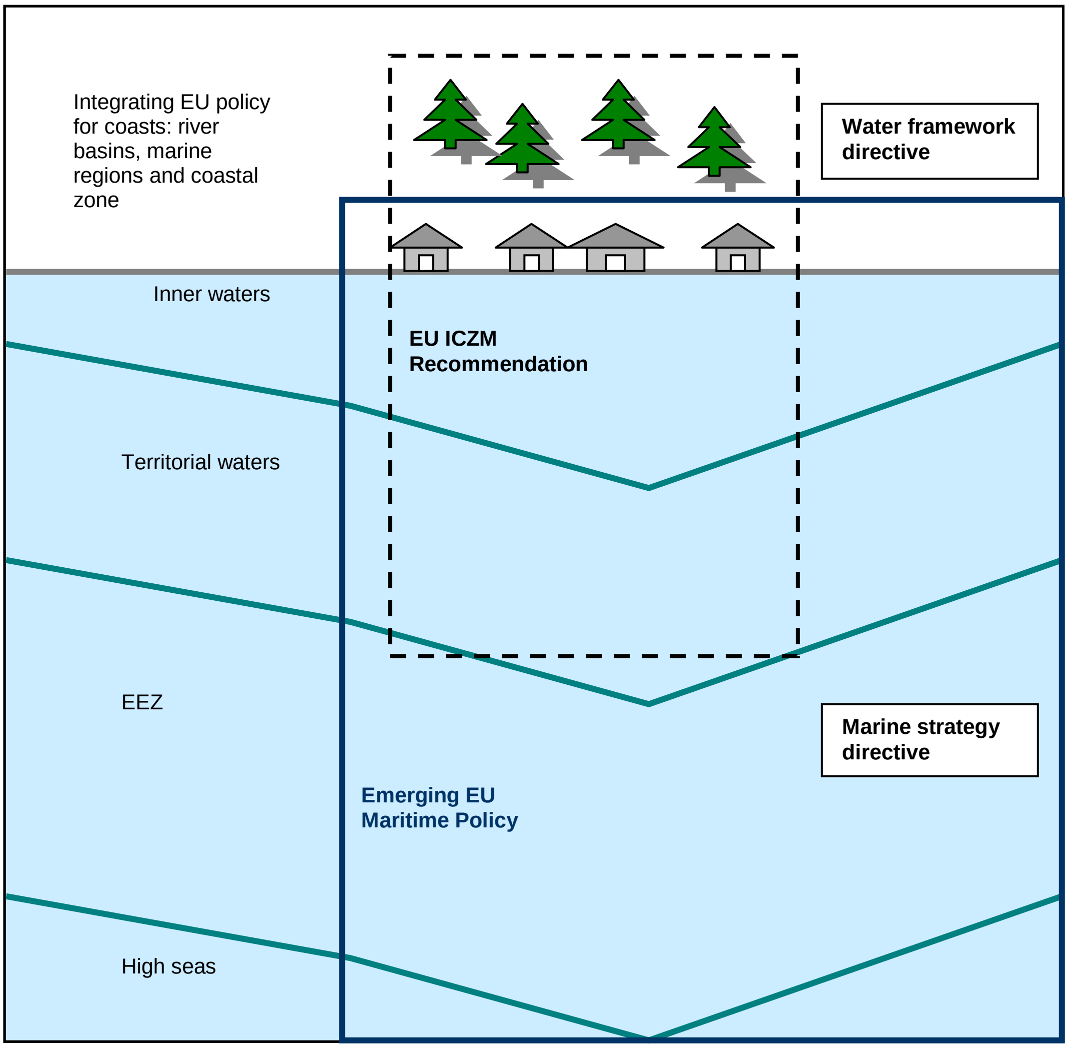


Figure 12. Integration of model of river catchments, marine regions and coastal zones as perceived by the European Environmental Agency

Source: Simplified from EEA, 2006, p.81

6. Conclusions and Recommendations

The main challenge to GIS modelling in the context of maritime environmental issues and integrated coastal and ocean management is not primarily a technological one. It is a challenge of bridging boundaries of existing territories and jurisdictions in terms of geospatial data. It is a matter of braking historical compartmentalisations and facilitating the sharing of data and resources. Many obstacles line the road, technology itself being one. Also, in the ambition to comprehend the specific, the integrated perspective is neglected, which further drives the components apart. Specialised databases within the agencies or departments often never reach outside the walls of that specific institution. From an integrative management and planning perspective, it would be beneficial to provide a basic information database, where data identified as crucial (such as the data listed in this dissertation) is shared without restrictions. Each dataset should be the responsibility of one department or agency, keeping the data and metadata updated.

The dissertation provides arguments for a tiered approach to integrated geospatial data management, analysis and modelling that could bring some benefits to users through visualisation of processes and relations, sharing of data, and facilitation of complex and time consuming data operations.

The use of GIS within the maritime sector has so far mostly been concentrated to cartographic and navigational applications. However, as the survey of available applications revealed, GIS is also a common tool for modelling of oil spreading and mapping of shoreline sensitivity to oil spills. What is yet to be introduced into the geospatial information domain is the practically applicable mapping and modelling of operational discharges. And, in the prolongation, the incorporation of these sector-specific attempts to deploy GIS into an integrative approach where the coastal zone is seen to embrace the riverine, marine and terrestrial environments.

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Appendix A: Relevant and available models and projects

The following table is a list of models and GIS based tools of relevance to Integrated Coastal and Ocean Management and the maritime sector. The list is not complete, but rather comprehensive concerning presently used tools within this field.

Models

Model/Project	Area of interest	Owner or participants	Aim and outline	Parameters	More information
SAMSON (Safety Asssessment Model for Shipping and Offshore Northsea)	Shipping	Netherlands, Ministry of Transport, Public Works and Water Management	Consists of three models and a shell to give users access to the underlying models: 1) shipping model; 2) offshore mining model; 3) oil spreading effect model		http://www.netcoast.nl/tools/rikz/SAMSON.htm
HABMAP	Habitat mapping	Interreg III, Wales and Ireland	To produce seabed habitat maps for the southern Irish Sea, but also to develop a model that will predict seabed habitats and ecosystems from physical data.		http://www.habmap.org/
Safety at Sea	Shipping	Interreg IIIB	To reduce the probability and impact of incidents and accidents in the North Sea. Includes MRDB (Marine Resources Data Base) and MOB-model for classification of sensitive coastal areas.		www.safetyatsea.se
SimCoast (Coastal Zone Management Expert System)	ICOM	UK	Expert system designed to enable researchers, managers and decision-makers to create and evaluate different policy scenarios for coastal zone management. Interdisciplinary and multi-sectoral. The conceptual basis of SimCoast is a two-dimensional multi-zoned map onto which key features such as ports, legal regimes and different habitats and activities such as shipping, tourism, aquaculture are mapped. A commercial software.		http://www.discoverysoftware.co.uk/SimCoast.htm
WadBOS	ICOM	Netherlands	Information system offering support to policy makers involved in the Dutch Waddenzee. Features an integrated model for the ecological and the economic functions of the sea. The constituting sub-models represent processes operating at different time scales, ranging from daily to yearly. They also represent spatial processes operating at three different spatial scales: the whole sea, 12 relatively homogeneous compartments within the sea, and small cellular	The WadBOS system relies on GIS information for its inputs, but its models need economic, demographic and ecological data from other sources as well.	http://www.riks.nl/projects/WadBOS

			units of 25 ha each. Free, downloadable software.		
ArcGIS Marine Data Model	ICOM	US, many participants	Improving the integration of many features of the ocean realm, both natural and manmade. The goal is to provide more accurate representations of location and spatial extent, along with a means for conducting more complex spatial analyses of marine and coastal data by capturing the behaviour of real-world objects in a geodatabase. The model also considers how marine and coastal data might be more effectively integrated in 3-D space and time. Based on ModelBuilder in ArcGIS.		http://dusk2.geo.orst.edu/djl/arcgis/index.html
Anchorage Sensitivity Index Decision Support System (ASIDESS)	ICOM	AeroMap U.S:	Decision Support System (DSS) that enables the user to explore the sensitivity of areas within the Anchorage Bowl Based on ModelBuilder in ArcView	A Sensitivity Index score for each pixel is derived from cumulative results for each of four types of impacts to sensitivity based on 21 datasets. These data sets are grouped into five different topics: Aquatic, Coastal and Public Access, Geotechnical Hazards, Habitat and Human Impacts.	http://munimaps.muni.org/common/coastal_atlas.htm
COSMO (COastal zone Simulation Model	ICOM	Netherlands	A tool to demonstrate the main steps in the preparation, analysis and evaluation of Coastal Zone Management (CZM) plans.		http://www.netcoast.nl/tools/rikz/COSMO.htm

Visualisation or coordination of data

Project	Primary focus	Owner or participants	Aim and outline	Parameters	More information
SJÖBASIS (Maritime Authorities Information System)	Sea surveillance, environmental protection	Swedish Coast Guard	Information system that coordinates maritime monitoring and information while relaying that information to a number of agencies (National Board of Fisheries, National Police Board, Swedish Armed Forces, Swedish Coast Guard , Swedish Customs, Swedish Environmental Protection Agency, Swedish Maritime Administration , Swedish Meteorological and Hydrological Institute , Swedish Rescue Services Agency , The Geological Survey of Sweden).	• Coastal radar stations network • Swedish AIS coast stations network • Helcom AIS • Swedish Coast Guard Air Units • VMS transponders (Vessel Monitoring system) • Cameras • Observations • Satellite Images	http://www.kustbevakningen.se/kbvtemplates/Page.aspx?id=602

Baltic Nutrient GIS	ICOM	HELCOM	An interactive atlas application that can be used to view datasets related to nutrients discharged from point sources and measured at river mouths as well as the area specific loads per sub-region over a common background map. Also includes background datasets (coastlines, sea areas etc.) and documentation for all the datasets.	• Emissions of phosphorus and nitrogen from point sources • Riverine loads of nitrogen and phosphorus • Area specific loads of nitrogen and phosphorus	www.helcom.fi
MARIS - Maritime Accident Response Information System	Shipping, ICOM	HELCOM	Information system focusing on risks of oil spills in the Baltic. Internet interface. Aimed at competent pollution response authorities around the Baltic Sea, the Nordic Council of Ministers and the HELCOM secretariat	• Response and emergency capacity • Accidents • Illegal oil discharges • Maritime traffic • Ports and terminals • Shore sensitivity to oil spills • Protected areas • Marine information • Inland information	www.helcom.fi http://62.236.121.189/website/MARIS1/viewer.htm
Baltic Environmental Atlas		UN Environment Programme, GRID-Arendal	A visualisation tool (online) for land use, land cover and basic geographic information of the Baltic Sea catchment	• Land cover • Population • Arable land • Pasture land • Wetlands • Topography • Rivers, lakes, Drainage-basin, Sub-basins, Countries, Capitals	http://maps.grida.no/baltic/
SensMaps	ICOM, shipping	Netherlands	To identify Marine Sensitive Areas in the Netherlands. Linked to Safety at Sea. The aim is to provide maps that provide operational advice during marine pollution incidents and for use in the evaluation of policies. The maps will support decision making at the national and international level.		
OILECO (Integrating ecological values in the decision making process on oil spill combating in the Gulf of Finland)	Shipping, ICOM	Interreg IIIA, University of Tartu, University of Helsinki	To collect information on the ecological values of the Gulf of Finland. To evaluate the sensitivity of the ecosystem components to oil spills. To produce supportive information for the decision making on oil combating in order to safeguard the most valuable populations in the Gulf of Finland in case of oil spill. To evaluate the justifications for the investments on preventive measures.		http://hykotka.helsinki.fi/oileco/index.html
MESH – Mapping European Seabed Habitats	Habitat mapping	Interreg IIIB North West Europe (Ireland,	Collate and harmonise existing habitat maps Develop and test standards and protocols Develop predictive mapping tools, undertake case	The project includes an online metadata catalogue for the five countries involved.	www.searchmesh.net

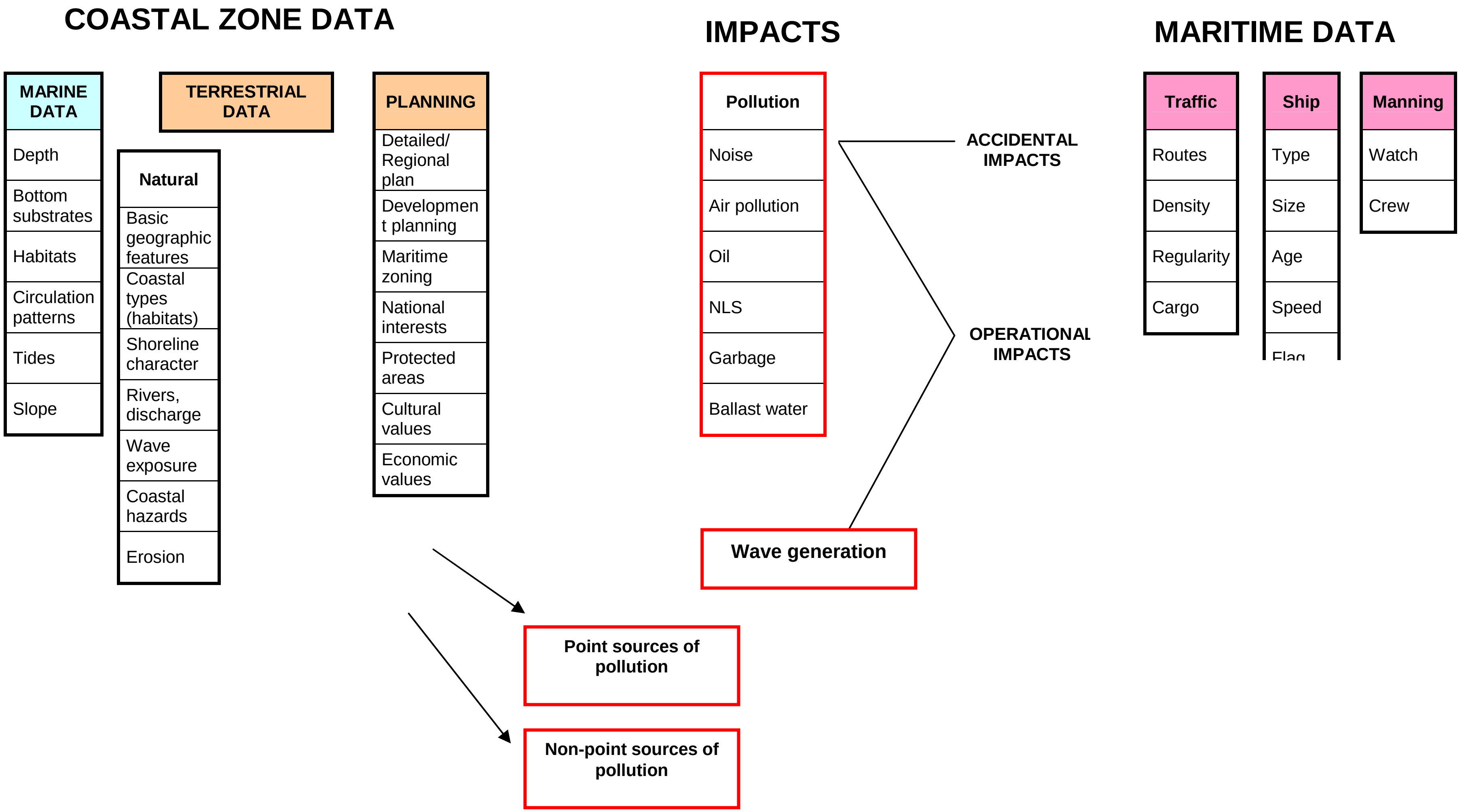
		UK, Belgium, Netherlands and France)	studies on use of maps Communicate and disseminate information.		
ComCoast (Combined Functions in Coastal Zones)	ICOM, coastal defence	Interreg IIIB North Sea Programme (Belgium, Denmark, Germany, Netherlands and UK)	Focuses on coastal defence and the concept of Multifunctional Coastal Defence Zones (MCDZ). Looks at sensitive areas and activities for use in actions such as identification of suitable off-shore wind energy areas and marine pollution contingency plans. GIS is used to provide a database of geographical sensitivities and activities.	The GIS is linked to the NOKIS national meta-data network for the North and Baltic Sea Coastal Information System	http://www.comcoast.org/
EROCIPS (Emergency Response to Coastal Oil, Chemical and Inert Pollution from Ships)	Shipping	Interreg IIIB Project within the Atlantic Area Programme	Developing sensitivity mapping for areas of the coasts of France, Spain, Portugal and UK. The maps will advise decision makers during maritime pollution incidents.		http://www.erocips.org/
GEONAMICA	ICOM	Netherlands, RIKZ	A modelling and simulation toolbox for the development of dynamic land use models and spatial decision support systems		http://www.riks.nl/products/GEONAMICA
COZMIS (Coastal Zone Management Information System)	ICOM	Netherlands (RIKZ) and WL Delft Hydraulics	A tool where GIS based information can be combined with documents and images. Information can be retrieved from the database by spatial and criteria queries.		http://www.netcoast.nl/projects/netcoast/tools/cozmis.htm
INSROP (International Northern Sea Route Programme)	Shipping, ICOM	Canada, Denmark, Finland, Italy, Japan, Norway, Russian Federation, Sweden, Netherlands, UK, US	Consists of several hundreds of datasets. It also contains tools for carrying out Environmental Impact Assessment of NSR activities An ArcView 3.0a Extension. .	Includes datasets on ice conditions, meteorological conditions, ship transit simulations, ecological data, port data, infrastructure, administrative borders and much more.	http://www.fni.no/insrop/defaultINSROP.html
Oil Spill Response Atlas (OSRA)	ICOM, shipping	Australia	Aims to systematically compile all relevant geographic and textual data into a standard GIS format for the majority of Australia’s maritime and coastal environments. The OSRA GIS includes maps, charts, satellite imagery, point, line and polygon digital data as well as databases and textual information in a user-friendly point/click format.	National OSRA data sets include: • biological, environmental, wildlife and man-made resources present, Australiawide, • geomorphological mapping and shoreline sensitivity to oil spills, • human-use resource considerations, • logistical and infrastructure information to supporta spill response.	http://www.amsa.gov.au/Marine_Environment_Protection/National_Plan/General_Information/Oil_Spill_Response_Atlas/OSRA_Information.asp

DESIMA (DEcision Support for Integrated Coastal Zone Management)	ICOM	Strategy and Systems for Space Applications Unit (SSSA) Pilot project EU funded project	The Project aims to support Coastal Zone Management applications through an improved integration and use of various information sources and information providing tools. In this context the project intends to increase and broaden the use of existing and future Earth observation data.		http://marine.jrc.cec.eu.int/
ICZMap	ICOM	UK. British Geological Survey, Ordnance Survey and the UK Hydrographic Office		• Offshore solid geology • Offshore Quaternary sediments • Offshore seabed sediments • Offshore seabed facies • Onshore solid geology • Onshore Quaternary (drift) sediments	http://www.iczmap.com/

Other

Model/Project	Area of interest	Owner or participants	Aim and outline	Parameters	More information
COASTBASE CoPraNet (Coastal Practice Network)	ICOM	EU	The European virtual coastal and marine data warehouse for integrated, distributed information search, access and feedback.		http://www.coastalpractice.net/

Appendix B: A model framework



Appendix C: Data sources and file information

DATA	EXPLANATION	FILE NAME (shp-files)	SOURCE
MARINE DATA			
Depth	Depth and elevation	Djup_hojd	Swedish EPA
Bottom substrates	Bottom types	naturtyp	Swedish EPA/ Swedish Geological Survey
Slope	Slope in degrees, calculated from depth/elevation	lut_20m_dist2	Swedish EPA
TERRESTRIAL DATA			
Natural			
Basic geographic features	Coastline (land, sea) Coastline (land, sea) Small islands	SJK landomr Hav_land_sv gavleborg_oar_skar	Derived from nautical charts, SMA Swedish EPA
Coastal types (habitats)	Shallow, vegetated bays/inlets Coastal lagoons Estuaries	Grunda_vegetationskladda_havsfjardar riksintresse kustlaguner_gsd_marktackedata estuarier_sverige	CAB Gävleborg
Shoreline character	Beach type and character Topography of beach	klassn_strandz topografi_strandz	Swedish EPA Swedish EPA
Wave exposure	Wave exposure, according to model by Isaeus	Vagexp_namn	Swedish EPA
Human			
Urban areas		stads-yta	SMA
Ports	Ports and their classification	Hamnar	SMA
Infrastructure	Roads, railway	vägar, järnvägar	SMA
Land use		clc00_se_eu	CORRINE/EEA

Population	From Corine data		CORINE/EEA
PLANNING			
National interests	Areas of interest for leisure Areas with special requirements (Env. Act Ch. 4 §2) Areas identified by the national energy department Areas identified for wind energy production National interests for professional fishing Fishing harbours Areas identified by National Rail Administration Areas of cultural value Areas identified by the National Road Administration Areas Identified by the Swedish Geological Survey Watercourses in need of protection according to Environmental Act, Ch. 4, §6	riks_fri riks-nat riks_4kap2 riks_energiproduktion_punkt riks_energiproduktion_yta riks_fiske riks_fiske_hamn riks_jarnvag riks_kul riks_vag riks_vardefulla_amnen riks_vattendrag	CAB Gävleborg
Protected areas	Natura 2000 areas Ramsar areas National parks Nature reserves Natural monuments Areas requiring consultation Areas in need of protection Animal protection areas	riks_natura2000 ramsar_Dalalven natpark nat_res naturminne samradsomraden_region skyddsva djur_vaxt	CAB Gävleborg
Cultural values	Ancient remains, points Ancient remains, polygons Historic buildings	fornlamningsregistret_point fornlamningsregistret_rapport BMX	CAB Gävleborg
Economic values	Fishing zones (fiskevårdsområden)	FVO	CAB Gävleborg

MARITIME DATA			
Traffic			
Routes	Shipping routes	Farled allmän o övrig	SMA
Density	Statistics, tabular	Excel file	SMA
Regularity	Statistics, tabular	Excel file	SMA
Cargo	Statistics, tabular	Excel file	SMA
Ship			
Type	Statistics, tabular		
Size	Statistics, tabular		

Abbreviations

SMA: Swedish Maritime Administration
CAB: County Administrative Board
EPA: Environmental Protection Agency

Appendix D: Traffic patterns at the ports in the Bay of Gävle

Data on the number of calls at the ports in the Bay of Gävle in 2005. Based on data from the Swedish Maritime Administration.

Gävle SEGVX										
	Other tankers	**Oil tankers**	**Chem. tankers**	**Bulk carriers**	**Container**	**Ro-Ro**	**Dry cargo**	**Barges**	**Other**	**TOT**
Jan	7	1	1	4	4	5	29	1	0	52
Feb	4	0	0	2	6	8	23	1	0	44
Mar	1	1	1	1	10	9	16	1	0	40
Apr	5	0	0	1	10	5	15	0	0	36
May	6	1	1	2	10	7	16	0	1	44
Jun	6	2	2	2	9	8	13	0	0	42
Jul	2	1	1	3	9	7	12	0	0	35
Aug	6	1	1	1	9	9	13	0	2	42
Sep	6	2	2	1	9	7	14	0	1	42
Oct	8	2	2	1	8	7	16	1	1	46
Nov	3	1	1	2	10	10	15	0	0	42
Dec	3	3	3	1	10	9	22	1	2	54
TOTAL	57	15	15	21	104	91	204	5	7	**519**

Karskär SEKAS										
	Other tankers	**Oil tankers**	**Chem. tankers**	**Bulk carriers**	**Container**	**Ro-Ro**	**Dry cargo**	**Barges**	**Other**	**TOT**
Jan	0	0	0	0	0	0	10	0	0	**10**
Feb	0	1	0	0	0	0	17	0	0	**18**
Mar	1	0	0	1	0	0	20	0	0	**22**
Apr	0	0	0	0	0	0	21	0	0	**21**
May	0	0	0	0	0	0	28	0	0	**28**
Jun	1	0	0	0	0	0	23	0	0	**24**
Jul	0	1	0	0	0	0	24	0	0	**25**
Aug	3	0	0	0	0	0	26	0	0	**29**
Sep	1	1	0	0	0	0	24	0	0	**26**
Oct	0	0	0	0	0	0	20	0	0	**20**
Nov	0	0	0	0	0	0	18	0	0	**18**
Dec	0	0	0	1	0	0	17	0	0	**18**
TOTAL	6	3	0	2	0	0	248	0	0	**259**

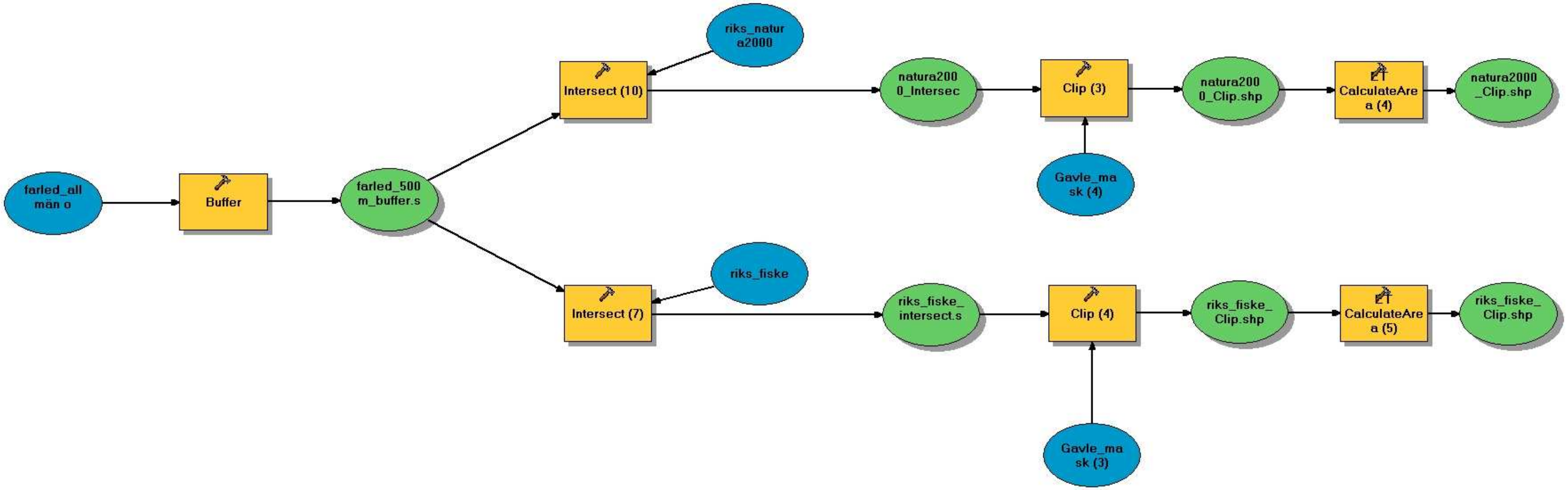
Skutskär SESSR

	Other tankers	Oil tankers	Chem. tankers	Bulk carriers	Container	Ro-Ro	Dry cargo	Barges	Other	TOT
Jan	0	0	0	0	0	0	17	0	0	**17**
Feb	0	0	0	0	0	0	20	2	0	**22**
Mar	0	0	0	0	0	0	24	1	0	**25**
Apr	0	0	0	0	0	0	30	4	0	**34**
May	0	0	0	0	0	0	30	3	0	**33**
Jun	0	0	0	1	0	0	21	7	1	**30**
Jul	0	0	0	1	0	0	20	5	0	**26**
Aug	0	0	0	0	0	0	14	1	1	**16**
Sep	0	0	0	0	0	0	14	2	0	**16**
Oct	0	0	0	0	0	0	17	2	0	**19**
Nov	0	0	0	0	0	0	14	1	1	**16**
Dec	0	0	0	0	0	0	16	2	0	**18**
TOTAL	0	0	0	2	0	0	237	30	3	**272**

Norrsundet SENOT

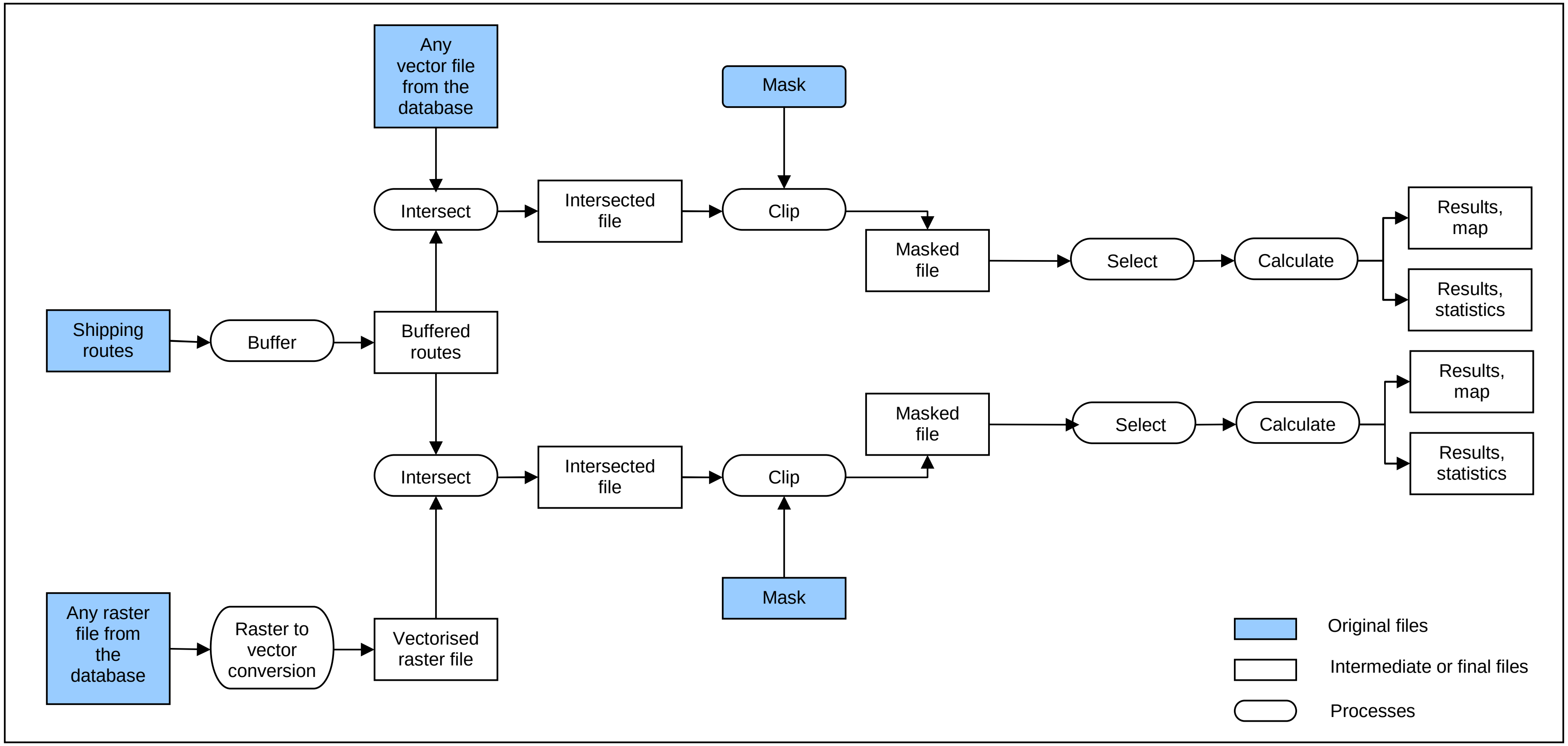
	Other tankers	Oil tankers	Chem. tankers	Bulk carriers	Container	Ro-Ro	Dry cargo	Barges	Other	TOT
Jan	0	0	0	0	0	0	15	0	1	**16**
Feb	0	0	0	1	0	0	21	0	0	**22**
Mar	0	0	0	0	0	0	13	0	0	**13**
Apr	0	0	0	1	0	0	28	0	0	**29**
May	0	0	0	2	0	0	41	0	1	**44**
Jun	0	0	0	1	0	0	40	0	0	**41**
Jul	0	0	0	3	0	0	37	0	0	**40**
Aug	0	0	0	2	0	0	30	0	0	**32**
Sep	0	0	0	0	0	0	16	1	1	**18**
Oct	0	0	0	2	0	0	13	0	1	**16**
Nov	0	0	0	3	0	0	14	0	0	**17**
Dec	0	0	0	1	0	0	14	0	1	**16**
TOTAL	0	0	0	**16**	0	0	**282**	**1**	**5**	**304**

Appendix E: Model for Example 1: Defining intersecting areas

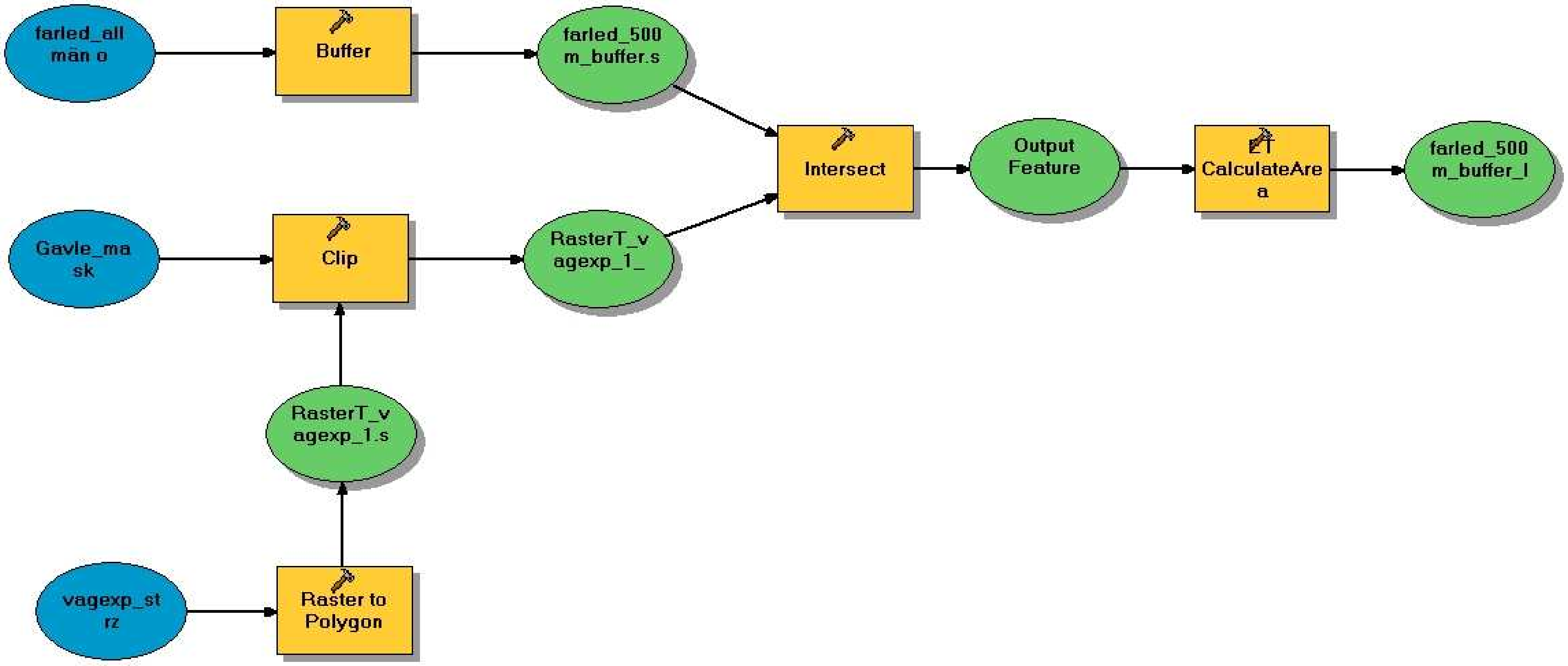


Model outline as represented in ModelBuilder in ArcGIS. Blue ovals represent original data, yellow squares correspond to processes, and green ovals represent resulting data.

Appendix F: Schematic model outline



Appendix G: Model for Example 2: Combining data formats and calculating areas



Model outline as represented in ModelBuilder in ArcGIS. Blue ovals represent original data, yellow squares correspond to processes, and green ovals represent a data.