The Use of Remote Sensing and Geographic Information Systems in Coastal Zone Management*

KAM SUAN PHENG
School of Biological Sciences
Universiti Sains Malaysia
11800 Penang
Malaysia

JAMES N. PAW
International Center for Living
Aquatic Resources Management
M.C.P.O. Box 2631
0718 Makati, Metro Manila
Philippines

MAYLENE LOO
Department of Zoology
National University of Singapore
10 Kent Ridge Crescent
Singapore 0511

KAM, S.P., J.N. PAW and M. LOO. 1992. The use of remote sensing and geographic information systems in coastal zone management, p. 107-131. *In* T.-E. Chua and L.F. Scura (eds.) Integrative framework and methods for coastal area management. ICLARM Conf. Proc. 37, 169 p.

Abstract

This paper outlines the opportunities and constraints in the use of remote sensing technology and geographic information systems (GIS) for coastal zone management (CZM). Extensive applications of remote sensing under ASEAN/US CRMP were hindered by cost, lack of familiarity with the methodologies, lack of technical expertise and inaccessibility of remotely sensed data. The use of GIS in CRMP was limited to the Malaysian project. Although many of the real-world complexities of the coastal zone cannot be adequately represented in current GIS, it still serves as a useful tool for CZM.

---

*ICLARM Contribution No. 869.

While the advantages of combining remote sensing and GIS technology for studies such as CZM are recognized, some practical difficulties are faced in its actual use in projects like CRMP.

An institutional GIS framework must be established in developing countries to build up the technical capabilities, provide the mechanisms to maintain/update the system and ensure sustained support.

Introduction

For the past 20 years or so, inventory and assessment of the earth's resources and economic activities have been greatly enhanced through the use of remote sensing and GIS, aided in part by innovative developments in computer technology.

Remote Sensing

Acquisition of information about an object with the use of a sensor which is not in physical contact with the object is called remote sensing. Sensor systems (e.g., cameras, radiometers or radar) mounted on elevated platforms (e.g., aircraft or satellites) detect and measure electromagnetic energy reflected or emitted by an object. Such sensor systems may be active, such as radar, or passive. The latter type relies on the radiation naturally emitted or reflected from the target (e.g., terrain, land cover). The data generated may be recorded in either digital or photographic forms. Remotely sensed data which are not camera-based are usually in digital form and typically stored in computer compatible tapes. These are processed through the use of image processing systems (IPS). The IPS consist of hardware (computer) and software which transform the digital data into images. The IPS preprocess the data by making the necessary radiometric (e.g., effect of haze) and geometric (e.g., effect of earth's rotation) corrections. The preprocessed data are displayed in a computer and further processed using enhancement and spectral classification techniques to match the spectral signals with ground information (e.g., vegetation, landforms). The main purpose of image processing and analysis is to extract relevant information, which is then represented in thematic maps and interpreted for various purposes such as environmental assessment, cartography, meteorology, military and management.

Fig. 1 shows an example of a remotely sensed satellite image. As can be seen, it provides a synoptic view of the earth's surface. Supported by ground reconnaissance data, it is one potential source of wide-area coverage data on the earth's surface.

Applications of remote sensing in coastal zone studies

Remote sensing technology has been widely used for meteorological studies and land resource evaluation, especially with the launching of meteorological satellites such as the NOAA series, the GOES series, METEOSAT and GMS; and earth resource satellites such as the LANDSAT series and SPOT. Although the meteorological and earth resource satellites were designed primarily for meteorological and land applications, respectively, remotely sensed data from these satellites have also been employed for studying coastal and ocean phenomena.

For example, the Coastal Zone Color Scanner deployed on the Nimbus-7 satellite had provided valuable data for studying ocean color for over 7 years. Data from the infrared radiometer, AVHRR (A Very High Resolution Radiometer), deployed on the NOAA satellites have also been used to study sea surface temperatures. The suite of microwave sensors on SEASAT, although short-lived, demonstrated the ability of remote sensing surface wind and wave conditions.

The high spatial resolution of multiband radiometers on LANDSAT and SPOT has also proven useful not only for land-based studies but also for research on shallow-water bathymetry of coastal areas. They are a useful source of data for coastal zone studies, which include both the land and coastal waters. Coupled with the use of digital mapping and GIS technology, they offer considerable potential as tools for coastal zone planning and management (Butler et al. 1988; Kam 1989a).

Landsat Thematic Mapper (TM) has a ground resolution[1] of 30 m and uses 7 spectral bands (violet-blue to infrared) with coastal applications as outlined in Table 1 (Conant et al. 1983). In contrast, SPOT has 3 multispectral bands (for color images) with ground resolution of 20 m, and in the panchromatic mode (for black and white images), the resolution is 10 m (Butler et al. 1988). In essence, SPOT has a better spatial resolution, but poorer spectral resolution than Landsat TM. Multispectral data from Landsat TM and SPOT have been used in land use assessment, urban planning and coastal studies, particularly in the intertidal zone (e.g., bottom substrates and algal species differentiation) (e.g., Brachet 1986).

The applications of remote sensing to the marine environment were reviewed in Johnson and Munday (1983). Information on suspended sediment in the water column, topography, bathymetry, sea state, water color, chlorophyll-a, sea surface temperature, fisheries, oil slicks and submerged or emergent vegetation including mangroves, has been provided by available remotely sensed data. Remote sensing has also been used in inventory and assessment of various coastal resources as well as production of maps. In a study done by Hyland et al.

---

[1]Resolution, the minimum distinguishable size of an object or area, is given as an aerial measurement of a square. For example, a resolution of 30 m means that to be distinguishable, an object must cover an area greater than or equal to a square measuring 30 m on a side. The smaller the number, the higher the resolution.

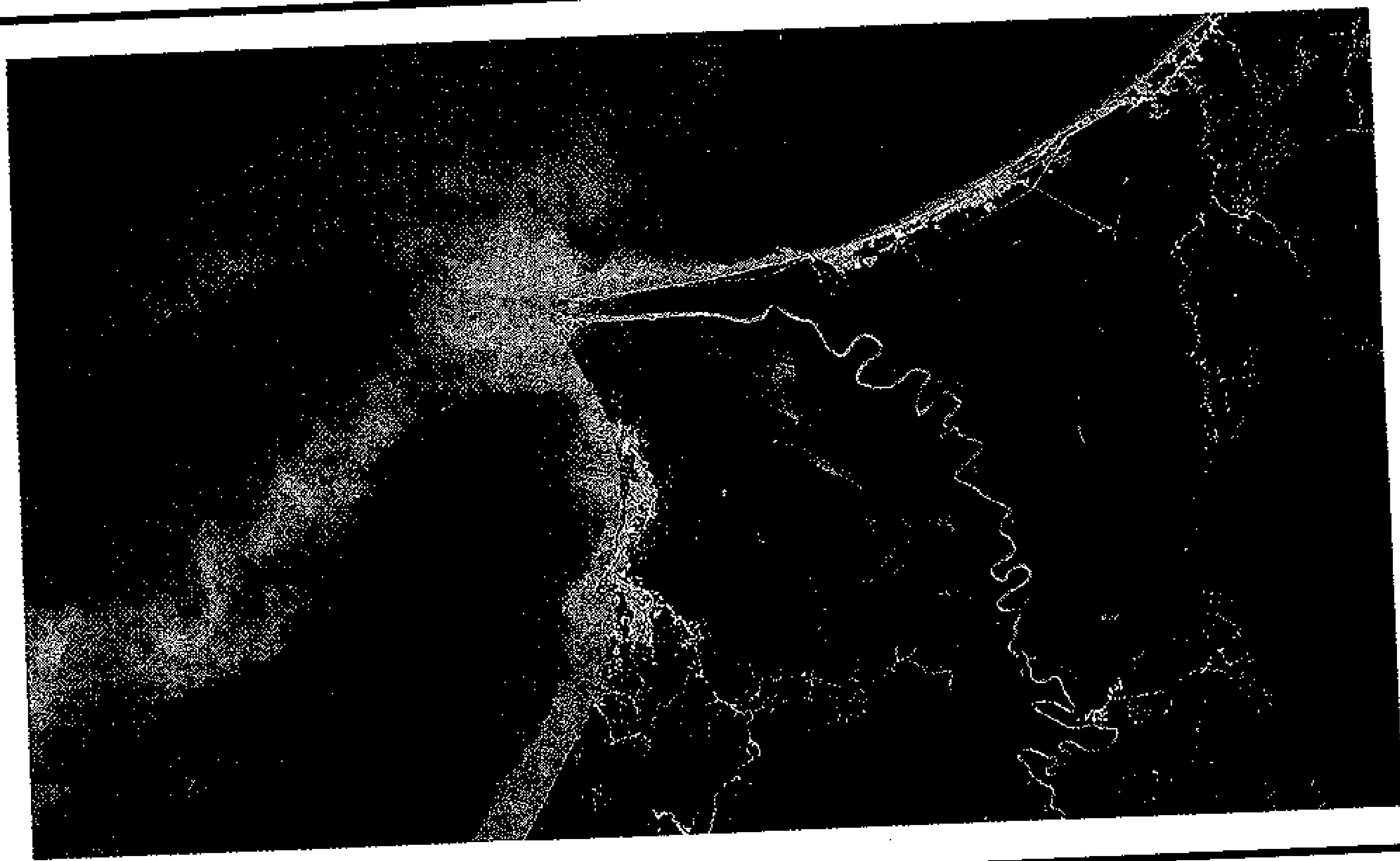

Fig. 1. A remotely sensed image of an area between Brunei Darussalam and Sarawak, Malaysia (Borneo Island) in false color composite taken from Landsat TM.

Table 1. Coastal applications, band designations and spectral ranges of the Landsat TM.

Band	Spectral range (μm)	Color	Application
1	0.45-0.52	violet-blue	For water body penetration, useful for coastal water mapping, also for differentiation of soil from vegetation.
2	0.52-0.60	green	Measures visible green reflectance peak of vegetation for vigor assessment.
3	0.63-0.69	red	A chlorophyll absorption and for vegetation discrimination.
4	0.76-0.90	near infrared	Useful for delineation of water bodies and determining biomass content.
5	1.55-1.75	middle infrared	Indicative of vegetation and soil moisture content; differentiation of snow from clouds.
6	10.40-12.50	thermal infrared	Used in vegetation stress analysis, soil moisture discrimination and thermal mapping.
7	2.08-2.35	middle infrared	Discriminates rock types (geological applications); for hydrothermal mapping.

Source: Conant et al. (1983).

(1989), Landsat TM was used for monitoring seagrasses. The results indicated that TM imagery can be enhanced to highlight dense seagrass either on exposed intertidal banks or in clear, shallow (less than 2 m) water. Seagrasses grow well in the intertidal zone and are susceptible to foreshore modifications. Therefore, TM imagery gives a useful method for monitoring this important coastal habitat. A comparison between traditional mapping methods and satellite-aided mapping for seagrass (Lennon and Luck 1990) showed that over a large area, the latter achieved high accuracy with less cost than traditional methods, which would require extensive and costly field sampling activity.

Remote sensing has been utilized to map atolls, coral reefs and islands (Bainbridge 1988; Hu and Faiz 1990). In using remote sensing (aerial photography and satellite imagery) for reef fisheries planning in the Maldives, Yun and Faiz (1990) were able to correlate water color and other marine environmental factors with the amount of phytoplankton in a reef lagoon to estimate marine primary productivity. They were able to deduce that areas which showed high phytoplankton biomass corresponded to fishing grounds.

More comprehensive information on water quality parameter patterns in bays or estuaries can provide a better understanding of the ecology, biology and dynamics in these ecosystems which are important inputs to management. Coupled with ground measurements such as for turbidity, chlorophyll-a content and transparency, remote sensing leads to better understanding of the hydrodynamic condition of the system, particularly on the productivity of marine waters and indirectly on fisheries biomass (Khorram 1981a and b; Lin et al. 1984; Lathrop and Lillesand 1986; Khorram et al. 1987). The results of a study by Khorram et al. (1991) have been useful for modeling temperature, transparency, turbidity and chlorophyll-a. While the same water quality parameters can be investigated through conventional survey techniques, these are time-consuming and expensive, and fail to represent the distribution of these parameters other than the sample areas. Remotely sensed data provide a synoptic view and thus, may be applicable to modeling, mapping and monitoring of water quality.

With respect to CZM, remote sensing can provide a feasible means for mapping, particularly for insular (archipelagic) countries. For example, in countries with many scattered islands (e.g., Indonesia and the Philippines), land inventory is usually difficult and expensive using conventional survey methods, even with the use of aerial photography. The synoptic coverage of satellite remote sensing makes it less costly in the long run, especially for mapping wide areas of land and vegetation cover.

Problems and constraints

Despite the undoubted potential applications of remote sensing techniques to the study of the coastal zone, there are still limitations and practical problems encountered in their use.

For a dynamic system like the sea, which varies on time scales of seconds, minutes, hours and days, the temporal resolution (i.e., the frequency of data acquisition) of remotely sensed data becomes more important than it would be for land applications. This is particularly so in the case of coastal waters which are tidally dominated, whereby changes occur over short time spans of minutes and hours. Earth resource satellites, with a revisit time interval of 16 to 26 days, cannot provide the temporal resolution to capture the dynamism of coastal waters.

Furthermore, the use of such data of low temporal resolution gives rise to difficulties in interpretation of imagery taken at different tidal times, as encountered in the mapping of reefs in shallow waters, where the spectral response pattern of the same reef can differ vastly depending on the water depth, which fluctuates with the tide (Bainbridge 1988).

Perhaps the most serious constraint faced in the use of satellite data from passive remote sensing systems is cloud cover. It has been estimated that at a latitude of 50° N in Europe, there is only a 5% chance or less of obtaining two consecutive satellite images of the same area containing less than 30% cloud (IOC 1992). The situation can be expected to be far worse in the humid tropics, especially in the coastal zone, where it is not uncommon to find a band of cloud hugging the coastline while the landward interior might be cloud-free. The uncertainty of obtaining cloud-free data makes ground reconnaissance difficult. The use of active remote sensing systems, i.e., microwave sensors, airborne or on satellites (such as those in SEASAT and the new ERS-1), is the only way to overcome cloud cover problems. However, microwave data cannot totally replace passive remotely sensed data for all sea and ocean studies, such as ocean color.

Another problem facing the use of remotely sensed data for the study of waters is the poor penetration of electromagnetic radiation. Thus, most of the coastal and marine phenomena sensed remotely are surface phenomena. While light penetration per se may not be as serious a problem in shallow coastal waters, a different problem is faced in the interpretation of remotely sensed data for coastal waters. This is the confounding factor of suspended and dissolved matter with water depth in the reflectance of electromagnetic radiation by the water body. Moreover, the additional factor of atmospheric interference would also need to be considered. A great deal of effort in image processing of remotely sensed data for water studies has gone into the development of models and algorithms to mask the various confounding effects, many of which are still largely empirical.

Potentially, airborne remote sensing allows for greater flexibility in the deployment of sensor type, time and frequency of data acquisition, and selective areal coverage. However, such facilities are not easily available in this part of the world, and are also very costly. In many countries in this region, CZM studies still resort to the more conventional use of aerial photographs, to which access is generally restricted. The poor light penetration and the absence of spectral resolution in conventional panchromatic aerial photographs render them of little use in coastal water studies.

Notwithstanding these limitations, remote sensing is an appropriate method for addressing information needs in decisionmaking for natural resource development and environmental management. Despite recognition in the Asia-Pacific region of the importance of this technology, its integration into national development planning processes has not been well established. Many users in developing countries face budget constraints in acquiring expensive satellite data. Besides, the promise of obtaining real-time satellite data falls short in reality, especially in this region.

There will be an increasing interest in spatio-temporal studies covering disaster forecasting and monitoring, deforestation, desertification, soil erosion, agriculture, ocean management and coastal zone studies in the Asia-Pacific region. Many of these applications extend across national boundaries and require coordinated efforts among concerned countries. These may take the form of information sharing, technology exchange and collaborative research.

Asia has a sufficient areal coverage of satellite data from the many receiving stations. Ground stations should thus form a coordinated network through cost-sharing schemes which would result in lower operational fees. Countries without ground receiving stations may opt for a batch supply arrangement with existing receiving stations instead of investing in their own infrastructure.

Geographic Information Systems

Geographic information systems (GIS) technology was developed from, and integrate concepts and techniques from various disciplines such as geography, statistics, cartography, computer science, biological sciences, mathematics, economics and geosciences, among others (Maguire 1991). For the purpose of this paper the following definition is adopted:

> GIS are computer-assisted systems that can input, retrieve, analyze and display geographically referenced information useful for decisionmaking.

GIS are sometimes regarded as synonymous with other information acquisition and management systems such as computer-aided design (CAD), computer cartography, database management and remote sensing. On the contrary, while GIS may have certain elements or capabilities in common with these other systems, the functions of the former cannot be wholly met by any one of the latter. At best, the relationship of GIS with these other systems is depicted in Fig. 2. CADs are graphic-based systems with rudimentary links to databases and limited analytical capabilities. Although computer cartography involves digital geographic information (maps), it uses simple data structures that lack topological information. The system emphasizes display of maps rather than retrieval and analysis of spatial information. Database management systems (DBMS) have limited graphical retrieval, display and spatial analytical capabilities but are powerful tools for storage and retrieval of nongraphical attribute data. The DBMS are often linked to GIS to access attribute data. Remote sensing which was discussed at length earlier in this paper, has limited capabilities to handle attribute data and to conduct true spatial analysis (Maguire 1991).

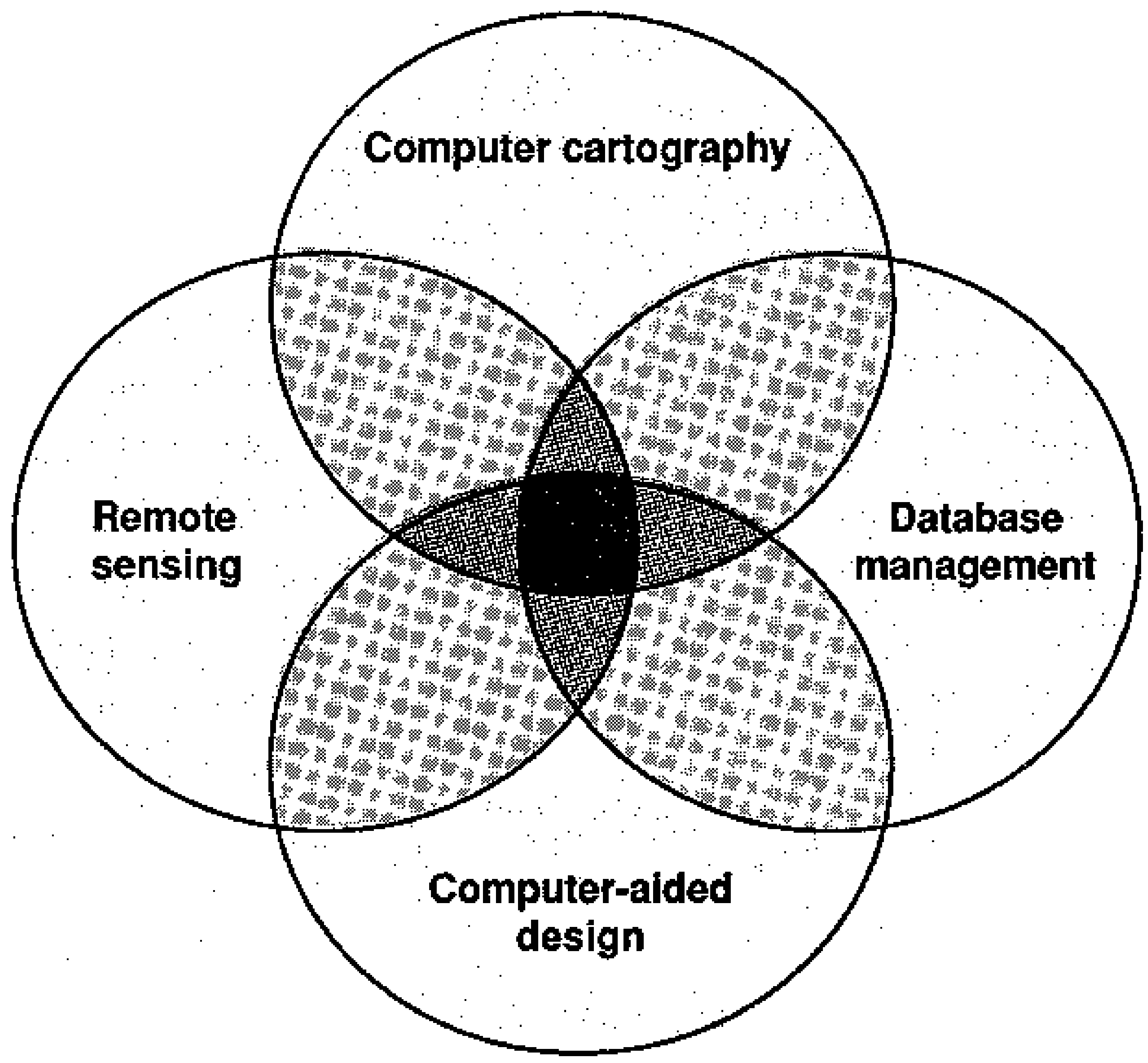

Fig. 2. The relationship of computer-aided design, computer cartography, database management and remote sensing information systems with GIS (Maguire 1991).

From an operational perspective, the four basic components of GIS are computer hardware, computer software, database and manpower (Maguire 1991). The GIS are supported by at least three classes of hardware–mainframes, personal computers and workstations. The widespread use of personal computers has made it possible for relatively small organizations to use GIS. Many GIS software on the market today are designed for different hardware and data structures. The cost of software ranges widely. Generally, the less expensive GIS software run on personal computers, with public domain GIS being the cheapest (Meaden and Kapetsky 1991). Choosing a GIS software will depend largely on the user's need or intended application.

The database is a crucial component of GIS. The effort and costs of establishing and maintaining a proper database should not be underestimated in a GIS project, especially in countries where digital databases are not readily available, and even geographic information is sparse, often outdated or restricted. It has been said that up to 80% of the effort goes into creating the database before GIS can be put into use.

The last and equally important component is people with the necessary training or knowledge in GIS, spatial analysis and related fields. Although training programs are now available (vendor-initiated, short-term courses and degree/diploma programs), there is still a shortage of trained personnel, especially in developing countries. With the interest generated, it is expected that there will be a rapid adoption of GIS technology in these countries. This will outpace human resource development to handle the technology. The potential of GIS for a wide range of applications and ability to integrate data from disparate sectors require users with broad and interdisciplinary perspectives, besides the subject specialists, to make the best use of the technology. Part of this temporary void is being filled by external consultants (Clarke 1991). Nonetheless, it is important that these countries place emphasis on building up local expertise and capability to adapt the technology to their specific needs.

Basic functions of GIS

The capability to perform several basic functions distinguishes GIS from the other information systems mentioned earlier. These functions are data collection, storage, manipulation, analysis and graphical presentation. A model of the real world, referred to as a geographical model, is usually represented by two types of data in GIS--spatial and attribute. Spatial data refer to entities with geographical location (e.g., coordinates in longitude and latitude, identifiable landmarks) while attribute data are characteristics or traits of an entity or location such as object and place names (e.g., water tank, Manila, Kuala Lumpur). Spatial data are generally represented by two types of data structures: vector and raster.

In the vector data structure, geographical entities such as points, lines and areas (polygons) are represented as a series of coordinates in space. This data structure is boundary-oriented, wherein a fuzzy or indistinct boundary (e.g., soil type boundary) is represented as a distinct line, or otherwise as bands of distinct lines.

In a raster (also called grid or tessellation), geographical features are represented as discrete polygonal units which are either regular squares like grids (as pixels in the computer monitor) or irregular triangles and hexagons. It is area-oriented, encoding the content of areas rather than the boundaries between them. Multiple map overlays are more efficiently carried out in the raster than the vector mode.

Most GIS software are either vector- or raster-based, but there is now an increasing trend to utilize both. In general, the raster data structure requires considerable memory for data storage. To overcome this problem, methods of increasing data storage efficiency have been devised. One solution is the use of the quadtree data structure, which is also area-oriented. Quadtrees differ from grids in that in the former there is a hierarchical subdivision or partitioning of space into quadrants and subquadrants only where heterogeneity occurs at the boundaries of polygons. This saves much memory capacity for data storage.

Maguire and Dangermond (1991) identified the functional components of GIS: data capture, data transfer, data validation and editing, data storage and structure, data restructuring, data generalization, data transform, query, analysis and data presentation (Fig. 3). While most of the commercially available GIS have these generic capabilities, they vary in sophistication and ease of use. Some software may be better developed for certain functions, such as cartographic output and presentation, than other functions, like particular kinds of analysis.

Two important functions of GIS are query and analysis. Query can be carried out on the spatial data, or through the link between spatial data and the non-spatial attributes. The two main query functions on the spatial data are spatial search and map overlays. Spatial search is done by specifying a zone of interest, i.e., buffer or corridor, around the feature in question, to ascertain what lies within this zone. Map overlay allows for comparison of features in two or more map layers for any location of interest, e.g., determining elevation, land cover type, soil type, land tenure and ownership of a particular point in question. By establishing logical links between spatial data and their non-spatial attributes, it is also possible to point at a geographical feature and query its associated attributes, e.g., determine the owner's name, type of building, building use at a particular location; or specify a criterion of the non-spatial attribute and determine the spatial entities fulfilling the criterion, e.g., display all factories producing a certain kind of pollutant.

Various kinds of spatial analysis can be carried out in GIS. These include analyzing the areal extent of map classes; "point operation" type analysis through algebraic and topological overlays of multiple map layers; "neighborhood operation" type analysis relating the properties of points on a map surface with their immediate surroundings; and "network operation" type analysis using linkages and flows among linear features. The tools for spatial analysis available in many commercial GIS are varied. It is left to the ingenuity of the user to employ them, alone or in combination, to address specific problems. Many GIS software nowadays come with macroprogramming languages which can be used to string all kinds of GIS operations together; thereby providing a toolkit with which the user can tailor-make application routines to meet specific needs.

The output of GIS could be in the form of maps (colored or in shades of gray; see Fig. 4 for an example), tables, graphs, statistical summaries and reports.

Many applications of GIS have been in the field of land use management–agriculture, forestry and urban development (cadastre, transportation). Only in recent years has there been widespread application in environmental and aquatic sciences, and socioeconomics. GIS have also been used in the military, global climate modeling and geosciences, especially with three-dimensional GIS. Table 2 shows some of the applications of GIS in the coastal zone, especially in fisheries.

The Benefits of GIS in Resource Management and Planning. The benefits of using GIS in resource management are generally recognized, and have been widely documented from applications developed in various countries for different types of natural resources such as conservation area and forestry management. In general, the main benefits include:

1. ability to integrate data of various types (graphic, textual, digital, analog) from a variety of sources;
2. greatly enhanced capacity for data exchange among various disciplines and departments concerned;
3. ability to process and analyze data more efficiently and effectively than can be achieved manually;
4. ability to model, test and compare alternative scenarios before the proposed strategy is imposed on the real-world system;
5. facility for efficient updating of data, especially graphic; and
6. ability to handle large data volumes.

Being an integrative system, GIS can undertake multicriteria modeling which can be useful in coastal zone and resource management where a holistic or integrated approach is required.

The Utility of GIS for Coastal Zone Studies. In evaluating the suitability of GIS for CZM planning purposes, one has to recognize the special features of the coastal zone which might place specific requirements on GIS, in terms of data model, structure and algorithms, and database management techniques (Bartlett 1990).

A complex and dynamic geographic entity, the coastal zone can be perceived as having four main characteristics:

1. *Breadth* refers to the width of the maritime influence on the land, and of the terrestrial influence on the sea.
2. *Depth* relates to the volume of water, with variable vertical distribution of currents and nutrients that influences fish and coral assemblages, and sediment dispersal.
3. Coastal areas have *"fuzzy" boundaries*, i.e., the demarcation line between land and sea, and what is coastal and not at both the sea and land limits, are not well defined.
4. A wide array of spatial scales and resolutions is needed to represent *different processes and phenomena* in coastal areas. These range from the

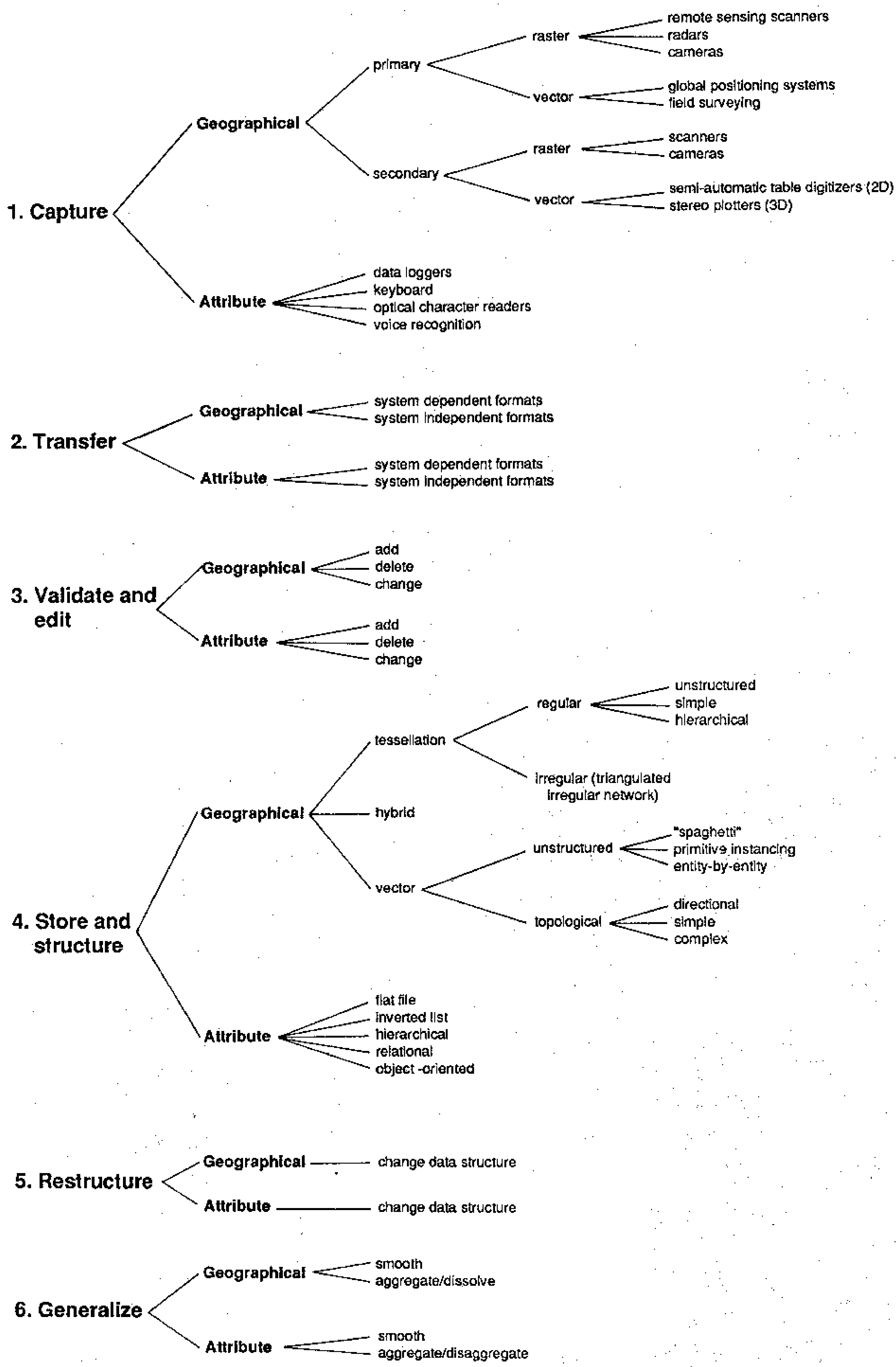

Fig. 3. The functional components of GIS (Maguire and Dangermond 1991).

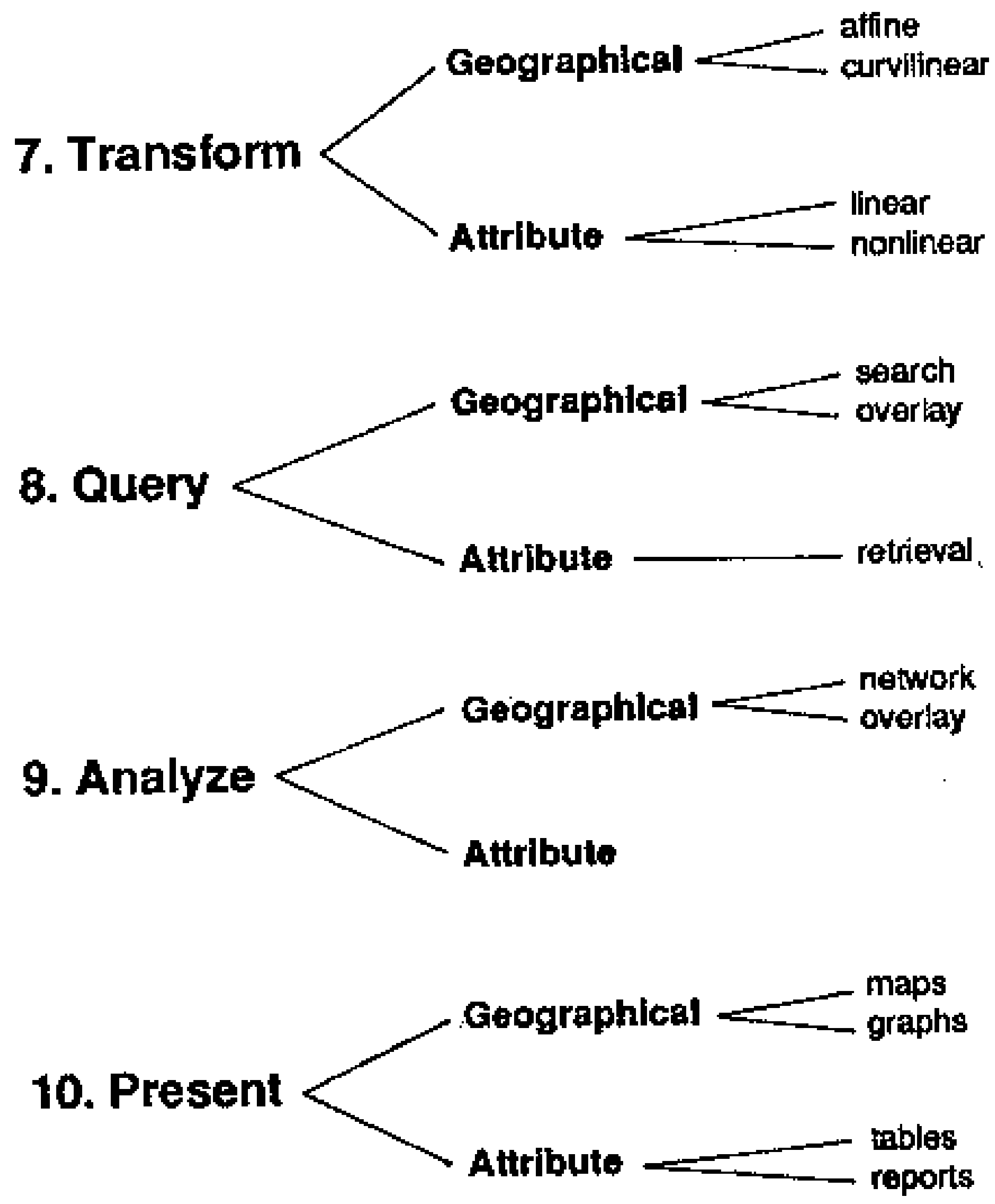

Fig. 3. (continued)

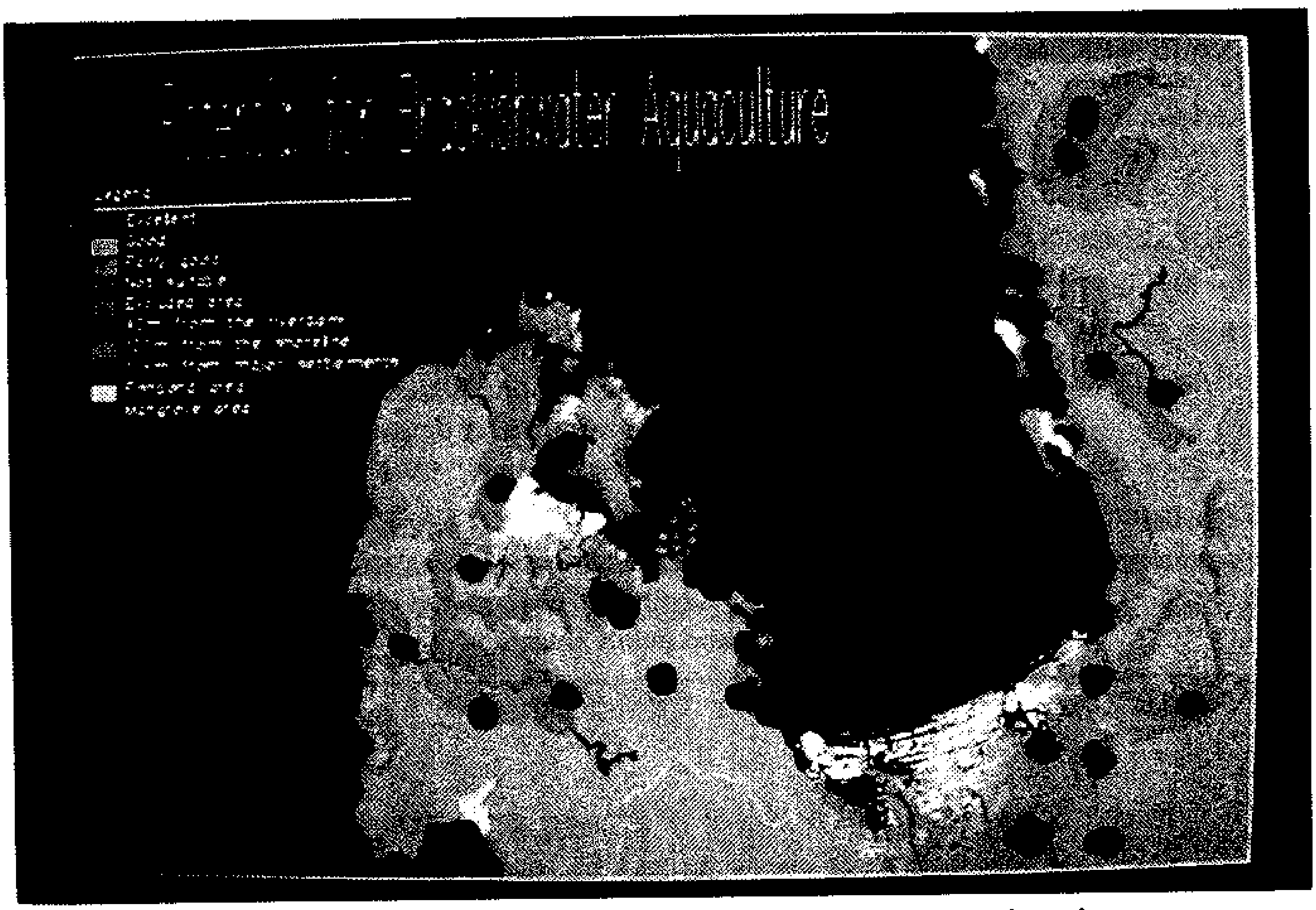

Fig. 4. A GIS-generated map showing potential areas for brackishwater aquaculture farms.

Table 2. Some applications of GIS in the coastal zone.

Field of application	Brief description
Cartography	A study by the United States Geological Survey to produce topographic maps of the nation for use of federal and state agencies, commercial companies and individual citizens at 1:24,000 scale series.
Land management	Profiles developed for each drainage basin based on GIS inventories of the extent of forest lands, cultivated land, urban areas, stream shore, lake shore, silt soil, sand soil areas of 3-6% slope and other parameters for water resource assessment.
Freshwater habitat management	A case study on impact assessment of contaminants. Creates databases for habitat potential, attribute file of habitat condition and stream dimensions, watershed boundaries, point file of contaminant discharge. Describes downstream impact in terms of proportion of fish production loss. Analyzes habitat affected by contaminants and converts habitat areas into fish production.
Marine habitat management	Creates database for various attributes, point data, bathymetry, sediment type. Establishes criteria for suitable habitat model by describing relationship between spatial variables. Overlays maps to produce the desired output.
Potential for aquaculture development	Datasets used are salinity requirements, soil characteristics, rainfall pattern, land use (mangrove vs. nonmangrove area) for determining potential area for shrimp farming.
	Datasets used are environmental parameters, infrastructure, land use, soil types, hydrographic factors, coastal geomorphology and meteorological characteristics for determining potential area for aquaculture development.
	Datasets used are water quality, existing land-use patterns, distance from water source, geomorphological features and distance from existing aquaculture farms for determining potential area for shrimp and fish hatcheries.
Coastal resources study	Identifies socioeconomic variables which might influence developments in a coastal environment. Datasets used are population, employment statistics, income levels, educational background, infrastructure and public amenities.

Sources: Kam (1989b); Hanafi et al. (1991); CISM (1992).

microscopic scale of chemical processes acting on sand and rocks of the intertidal zone, to those measured in tens, hundreds and thousands of kilometers (e.g., fishery licensing zones, shoreline retreat and accretion, areas of operation of fishing gear).

Ideally, selected GIS should be able to deal with these special features and complexities of the coastal zone. True three-dimensional GIS that can handle a third dimension of depth (or height) have yet to emerge. Nevertheless, most GIS available today can represent three dimensions in two-dimensional space. The addition of a fourth dimension, time, to deal with dynamic situations like coastal processes, is beyond the horizon of GIS software development at this stage. While the uncertain boundaries of the coastal zone are now arbitrarily represented as discrete, the introduction of fuzzy logic into GIS algorithms is being researched.

Many of the real-world complexities of the coastal zone cannot be adequately captured and represented, spatially and temporally, in GIS. Future advances may improve its capabilities. However, current GIS, while employing simplifications of the coastal zone models for spatial display and analysis, are still a useful tool for CZM planning.

Criteria for evaluation of GIS for CZM

Selection of GIS for any particular use should basically be needs-driven. Most of the needs for CZM have much in common with those for resource management. A few requirements may be peculiar to the nature of the coastal zone, as described above. The main criteria that might be considered in evaluating the suitability of a particular GIS for CZM include the following:

1. the extent to which the intrinsic data model and data structure used by the system are amenable to the wide-ranging spatial scales and resolutions required of coastal zone studies;
2. the efficiency and effectiveness with which spatial and nonspatial data are captured, edited, stored, retrieved and displayed; and
3. the kinds and capabilities of spatial analysis tools for modeling the coastal zone properties and processes.

The volume and storage capacity of GIS may also be an important consideration for a big project, but this is largely determined by hardware configuration.

As an example, two commercially available software, SPANS and ARC/INFO[2], are evaluated in this paper. They use different data models and structures, which provide an interesting comparison on their handling of coastal resource data. However, this does not preclude the applicability of other GIS software for coastal zone studies.

Spatial Analysis System

The Spatial Analysis System (SPANS) was first released as a microcomputer-based GIS in 1986, using the disk operating system (DOS) and the quadtree. The

[2]SPANS and ARC/INFO are registered trademarks of TYDAC INTERA Technologies of Canada and of Environmental Systems Research Institute, Inc., USA, respectively.

software has since undergone several rapid revisions; the 5.2 version operates on DOS-based IBM-compatible microcomputers, and with OS/2 Presentation Manager on the IBM PS/2. Another version operates with AIX on the IBM RISC System/6000 workstation.

While vector and raster analytical capabilities have been added in the 5.2 version, the analytical core of SPANS is still quadtree-based. For two-dimensional space representing a region, the quadtree structure decomposes the space into rectangular cells of variable size, with the finest pixels at the polygon boundaries. The cell resolution is determined by the quadding level, which is user-defined. Quadtrees are storage-efficient compared with rasters at equivalent resolution, even considering raster structures with data compaction features such as run-length encoding. This storage-efficient feature gives the microcomputer-based SPANS the ability to handle large numbers of data files, such as in the ASEAN/US CRMP study for South Johor (Kam et al. 1990).

This type of data structure allows for selection of resolution of individual map layers, depending on the accuracy of the source data; for example, a fine resolution for more accurate topographic data and a coarser resolution for reconnaisance-level soil maps. By user selection of the quadding level, one can choose a finer decomposition of geographic space at selected (zoomed-in) areas for more detailed study, say at an estuary of interest, or more generalization when the area in question is viewed from the broader perspective of the whole.

More importantly, quadtrees can carry out most of the topological overlays of the "point operation" type (Tomlin 1983) that raster structures can, and even more efficiently. However, the inability of quadtrees to handle the "neighborhood operations," such as visibility analysis, and "draining" and "spreading" over a digital elevation model, has led to the subsequent use of the raster structure for such analyses in SPANS version 5.2. This version also features some limited vector-based analysis, specifically network analysis for optimum routing.

ARC/INFO

One of the earliest GIS products to be marketed, ARC/INFO started as a minicomputer-based GIS, which was subsequently adapted for use on microcomputers. At present, two major products are popularly sold--ARC/INFO operating with UNIX on the workstation (most current release is version 6.1), and pcARC/INFO operating with DOS on IBM-compatible microcomputers (most current is version 3.4D plus). The ARC/INFO is primarily vector-based, although the UNIX-based Release 6.1 now features raster-based analysis. While most of the basic functions of the workstation-based ARC/INFO are available on pcARC/INFO, there are certain file size limitations on the latter. In addition, certain features of the UNIX-based software, such as coordinate geometry, ability to interface with structured query language (SQL)-supported external relational database management software (RDBMS), the Advanced Macro Language (AML), as well as the new raster analytical and linear geoprocessing (or dynamic segmentation) capabilities of Release 6.1 (Perkins 1992), are not available on pcARC/INFO.

Being primarily vector-based GIS, ARC/INFO and pcARC/INFO can represent the coast as a one-dimensional linear entity, as might be done at a small mapping scale of a long coastline. This simple data model of a coast might be sufficient for certain applications, such as mapping its environmental sensitivity at a small mapping scale. In such an application, the dynamic segmentation technique (Doyle 1991) available on ARC/INFO Release 6.1 is suited for documenting and processing the multiple variables of environmental sensitivity which are recorded in linear measures along the coastline.

However, if the coastal zone is primarily studied as an integrated area, the use of a one-dimensional linear model of the coastline can be severely limiting. In this case, there is no clear advantage of the use of dynamic segmentation. The coastal zone is represented as polygons in a vector data structure, and generalizations from a large to a small mapping scale are done through coarsening and collapse of polygons of specified sizes. This procedure requires more input from the user and more processing steps than are needed for quadtrees.

Comparison of SPANS and ARC/INFO-pcARC/INFO

There are two approaches to a comparison of GIS software. One is to compare the total capabilities of the two GIS, which pits the essentially microcomputer-based SPANS against the workstation-based ARC/INFO. This is not fair, however, because of the vast differences in system (hardware and software) costs. The other approach would be to compare the main features of the two GIS at a comparable platform, i.e., the microcomputer, which gives some indication of "value for money" of the GIS implementation for CZM (Table 3). The comparison is primarily between the two microcomputer-based versions; the additional features of the workstation-based ARC/INFO are listed in the third column of Table 3.

On the whole, the cartographic capabilities of the vector-based ARC/INFO are generally more well developed than those of SPANS, with many editing and plotting functions of the former being devoted to high-quality, computer-aided map production. The data management capability, especially query of the nongraphic data through its link to the internal RDBMS, is also better for ARC/INFO, which allows for a one-to-many tabular relationship of nongraphic files.

On the other hand, the spatial analytical capabilities of SPANS, except vector-based analysis such as network analysis, are generally more powerful and efficient than those of ARC/INFO, especially pcARC/INFO. The usual topological

Table 3. Comparison of main features of SPANS and ARC/INFO.

Basic function	SPANS	pcARC/INFO	ARC/INFO
Data capture and conversion			
Digitizing	Arc-node Topology building more cumbersome	Arc-node Topology building more conveniently done after editing	
Conversion of digital graphic data	Accepts vector and raster files from other GIS in various formats Raster files can be converted to quadtree maps to be used in all spatial analytical operations.	Accepts vector and raster files from other GIS in various formats Raster files need to be vectorized.	
	Accepts raster and image files from IPS in various formats. Image would have to be registered prior to import. Version 5 has some image enhancement capabilities.	Does not support image integration	Image integrator module allows for manipulation of images, including rectification to vector maps.
Editing	Editing done in digitizing module; fewer editing features	More editing features	Improved editing features
	No "rubber-sheeting" features Map joining awkward for linear features	Has "rubber-sheeting" features Better map joining features	Additional map rectification features
Database management	Storage of graphical data generally more efficient	Storage efficiency dependent on complexity of arcs	
Query of data base	Real-time multiple map and point queries; weak in query of arcs	Queries generally done in INFO, then subsetted data displayed graphically, not real-time	Additional association of attributes with nodes; dynamic segmentation, which allows for association of attributes with parts of arcs.
	Selective retrieval of attributes done in attribute modeling	Selective retrieval of attributes done in INFO	
Link with RDBMS	Has internal attribute files Version 5 (OS/2) allows for SQL queries using IBM OS/2 Data Base Manager.	Internal RDBMS called INFO Does not support SQL queries to external RDBMS	Supports SQL queries to external RDBMS
Graphic display and plotting	Fewer cartographic tools for output display and pen plotting	Better cartographic tools to create plot files for pen plotting	Improved cartographic tools

Continued

Table 3 (continued)

Basic function	SPANS	pcARC/INFO	ARC/INFO
Analytical tools			
Area analysis	Accuracy of area report dependent on quadding level; no automatic perimeter reporting	Area and perimeter reporting automatic; generally more accurate	
	Real-time single map and two-map cross-tabulation of areas	Two-map cross-tabulation of areas requires actual map intersection.	
Topological overlays	"Point operations" type of overlays, such as matrix and indexing, generally more efficiently carried out	Such overlays done in the vector mode are cumbersome, requiring step-by-step map boolean operations of map intersection, union, identity, etc.	Such overlays can now be more efficiently done in the raster mode
	Spatial modeling gives flexibility in overlays of map layers and modeling of map attributes, using a wide range of map operators. Up to 40 maps can be overlaid simultaneously.	Limited modeling language (SML) available for macroprogramming	AML available, supports both vector and raster-based processing
Neighborhood analysis	Version 5 has raster analytical capabilities, including various filtering algorithms and visibility analysis.	No raster analysis	Raster analytical tools available
Spatial interpolation	Generally more efficient spatial interpolation tools for point data, including chloropleths, voronoi, contouring, potential mapping and point aggregation	No potential mapping and point aggregation	
Vector analysis	Version 5 allows for limited network analysis, mainly routing.	More network analysis functions, including routing, allocation and districting; directional flows and differential resistances allowed	Linear geoprocessing using dynamic segments
Topological analysis	Version 5 allows for modeling of relationships between areas based on adjacency and containment.	Adjacency and containment relationships of polygons inherent in vector data structure	

overlays of the "point operation" type are more efficiently done with raster and quadtree data structures. Both GIS have now incorporated raster-based analytical functions of the "neighborhood operations" and "region operations" nature, but the raster analysis is currently only available in the workstation-based ARC/INFO, not in pcARC/INFO. Besides, SPANS has a wider range of spatial interpolation options, which comes in useful for sampling point data of continuous and semi-discrete variables.

Lastly, the spatial modeling language of SPANS allows for flexibility of writing macros addressing graphic as well as nongraphic data. This facility is useful if a great deal of spatial analysis is required of the study or project. The AML facility for writing macros is present in ARC/INFO, while a simpler version, the Simple Macro Language (SML), is available for pcARC/INFO.

Integration of remote sensing and GIS

There are some clear advantages of using remote sensing and GIS technology in a complementary manner. Fig. 5 shows schematically the role of remote sensing in documenting geographical phenomena of the real world and in providing such information to GIS. Remotely sensed data, and the products of image processing, are already in digital form with more or less standard or known formats. Although raw remotely sensed data are not geographically correct, preprocessing using well-established algorithms in image processing software can bring the data to acceptable levels of geographical accuracy, which can register with other conventional map data. Especially in countries where geographical information obtained through conventional means is difficult to come by, remotely sensed data can fill the gap by providing essentially uniform coverage over large areas at reasonably high positional accuracy, spatial and temporal resolution (Ehlers et al. 1991).

There are several ways to integrate remotely sensed data and GIS (Campbell 1987):

1. Aerial photographs and photographic output of satellite images (subjected to some preprocessing and image enhancement) are manually interpreted, and hand-drawn thematic maps, e.g., vegetation cover, are digitized into GIS.
2. Digital remotely sensed data are analyzed or classified digitally, the outputs are produced in hard copy as conventional maps, which are then digitized into GIS.
3. Digital remotely sensed data are classified or analyzed using automated digital methods, and the output is transferred digitally into GIS.
4. Raw, digital remotely sensed data are entered directly into GIS, where all processing is done.

The best advantage of integration of remote sensing and GIS accrues from digital processing and transfer of data between the two systems (i.e., scenario 3

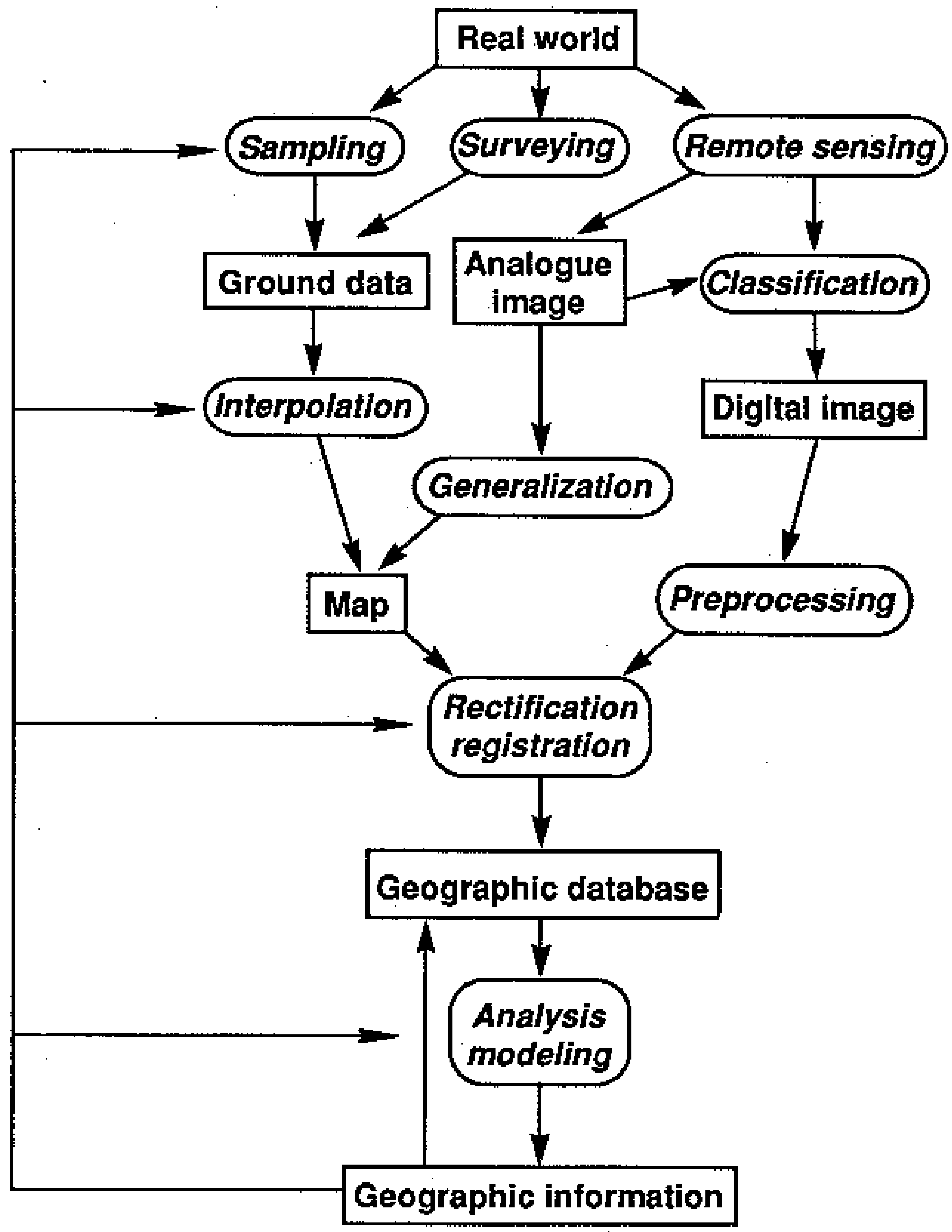

Fig. 5. Remote sensing as source of geographic information (Davis et al. 1991).

above). While much research has gone into digital processing of remotely sensed data, the stage of automated preprocessing, interpretation and analysis of raw digital imagery has not yet reached the level where the accuracy of the products can be routinely accepted into GIS. Much research work is still being focused on aspects of digital processing such as minimizing distortion and errors during data transformation, better automated techniques for interpretation, and improving classification accuracies (Davis and Simonett 1991; Davis et al. 1991).

Digital remotely sensed data are typically of the raster type. Use of remotely sensed data in GIS is better done in the raster mode, partly because vectorization of raster data does give rise to data integrity problems, and also because the raster data structure is more amenable to map overlay techniques, which are commonly employed for analysis of resource data generated from IPS. Hence, integration of remote sensing and GIS tends to favor the use of the raster data structure.

There are several advantages and opportunities in the combination of remote sensing and GIS in handling information for resource studies:

1. Remotely sensed data can be used as a quicker means of updating outdated maps, especially in cases where ground updating is slow or not forthcoming within the duration of the project.
2. The GIS database can provide ancillary data to assist in the classification or analysis of remotely sensed data, thereby improving the accuracy of the map product. For example, ancillary data on topography, geology, soils, etc., can provide vital clues for interpretation of vegetation cover rather than depending only on the spectral response information from remotely sensed satellite data.
3. Remote sensing is not an end in itself, but is the means to an end. Remotely sensed data are most useful in combination, either with geographic information from other sources, or when images of various dates and from different parts of the spectrum are put together. The GIS allows flexibility for such integration. At the same time, many GIS projects require data, especially good spatial, spectral and temporal coverages for analysis and modeling of complex real-world phenomena, and remote sensing sometimes offers a convenient means of obtaining such data.

While the advantages of integrating remote sensing and GIS may be recognized, both from the technical and cost-effective viewpoint, other non-technological considerations need to be addressed. Although the use of remotely sensed data can be cost-effective in the long run for large areal coverage, the technology may not be affordable to individual users or agencies employing them for specific areas and projects. In developing countries, few organizations have access to, or can afford IPS facilities. Those that operate on a commercial basis often charge very high fees for services rendered, whether to classify remotely sensed data or to convert them into GIS-compatible formats. There is a need for some organizational setup within the country or region to provide affordable "clearinghouse" services to small users, before the full potential of integrated remote sensing-GIS as a resource management tool can be realized (Simonett 1988).

Summary and Lessons Learned

With the advancement of computer science and rapid development of GIS technology, the integration of remote sensing and GIS provides a powerful system for resource management which can also be used for coastal zone planning and management.

Although there are two receiving stations for Landsat in ASEAN (Indonesia and Thailand), the use of remote sensing in resource assessment by ASEAN/US CRMP in the six pilot sites (see Chua, this vol.) was very limited. Possible reasons for this were cost, lack of familiarity with the methodologies and lack of technical expertise. In CRMP, only the Malaysian project was able to demonstrate the usefulness of GIS in integrating and analyzing multisectoral data. However, the continual use of the results and the database generated through the

Malaysian GIS study is hampered by the lack of institutional readiness and support to take over and maintain the system (Kam 1992).

Once implemented, a CZM plan is not expected to be static but will continuously evolve and be refined to meet the temporal and spatial changes in the management area. The use of remote sensing and GIS can readily respond to such changes once the database is established. Updating of the database can be accomplished using remotely sensed data while interactions or impact assessment of new changes/developments can be modeled through GIS, given new criteria or determinants.

The choice of suitable GIS for CZM planning depends on the kinds of applications and basic functions that are deemed most important and would be most frequently used. The lack of GIS specialists poses problems for wide adoption of the technology. Most often resource managers have understanding of tools such as GIS and remote sensing, but no working knowledge. The challenge lies with the user to be sufficiently familiar with GIS capabilities and to have a clear notion of the needs of the study.

With respect to applications, spatial analysis using GIS is generally context- and site-specific but the generic functions of GIS software make it possible to modify various criteria or determinants used (i.e., for resource evaluation and monitoring) to respond to the analysis required of a target area, be it land-based or in the coastal zone. In many cases, the constraint to application of GIS is due to data rather than methodology.

There is no doubt that the generic functions of GIS will expand to cover a wider range of applications. Applications for coastal zone studies including evaluation and management are now beginning. Recognizing the relative strengths and weaknesses of vector and raster data structures, most GIS systems are moving towards some form of "hybrid GIS" that offer combinations of vector and raster analytical capabilities. The GIS software development is also taking advantage of the swift progress in hardware technology, especially with respect to memory, storage and graphics capabilities, to offer increasingly user-friendly systems. The GIS market is now very competitive. Reduced cost of computers, particularly personal microcomputers with more powerful computing capabilities, and GIS software will make it possible for even small institutions to acquire such technology. To ensure the adoption of GIS technology, the institutional GIS framework must be established. This will pave the way for setting up mechanisms to maintain/update the system, improve the staff's GIS capability, respond to the corporate need for digital geographic information, and provide the necessary institutional and logistic support.

References

Bainbridge, S. 1988. Remote sensing of coral reefs: problems, methods and some possible solutions, p. 27-32. *In* L.M. Chou and K. Boto (eds.) Living coastal resources data management and analysis. Department of Zoology, National University of Singapore, Singapore.

Bartlett, D.J. 1990. Spatial data structures and coastal information systems. *In* Proceedings of the First European Conference on Geographical Information Systems EGIS '90, 10-13 April 1990. Amsterdam, The Netherlands.

Brachet, G. 1986. SPOT: the first operational remote sensing satellite, p. 59-80. In K.-H. Szekielda (ed.) Satellite remote sensing for resources development.

Butler, M.J.A., M.C. Mouchot, V. Barale and C. LeBlanc. 1988. The application of remote sensing technology to marine fisheries: an introductory manual. FAO Fish. Tech. Pap. No. 295.

Campbell, J.B. 1987. Introduction to remote sensing. Guilford Press, New York.

CISM (The Canadian Institute of Surveying and Mapping). 1992. The Canadian Conference on GIS: proceedings, 24-26 March 1992. Ottawa, Canada. The Canadian Institute of Surveying and Mapping, Ottawa, Canada.

Clarke, A.L. 1991. GIS specification, evaluation and implementation, p. 477-488. *In* D.J. Maguire, M. F. Goodchild and D.W. Rhind (eds.) Geographical information systems. Longman Scientific and Technical and John Wiley, New York.

Conant, F., P. Rogers, M. Baumgardner, C. McKell, R. Dasmann and P. Reining, editors. 1983. Resource inventory & baseline study methods for developing countries. American Association for the Advancement of Science, Washington, D.C.

Davis, F.W. and D.S. Simonett. 1991. GIS and remote sensing, p. 191-213. *In* D.J. Maguire, M. F. Goodchild and D.W. Rhind (eds.) Geographical information systems. Longman Scientific and Technical and John Wiley, New York.

Davis, F.W., D.A. Quattrochi, M.K. Ridd and N.S.-N. Lam. 1991. Research needs in processing and analysis of remote sensing and GIS data. NCGIA Tech. Pap. No. 91-16.

Doyle, A.V. 1991. Cruise control: transportation officials explore new avenues with dynamic segmentation. Comput. Graph. World 14(10): 29-36.

Ehlers, M., D. Greenlee, T. Smith and J. Star. 1991. Data structure and access. NCGIA Tech. Pap. No. 91-16.

Hanafi, H.H., I.A. Hassan, M.M.Y. Nafiah and L.D. Rajamanicham. 1991. Present status of aquaculture practices and potential areas for their development in South Johore, Malaysia, p. 65-73. *In* L.M. Chou, T.-E. Chua, H.W. Khoo, P.E. Lim, J.N. Paw, G.T. Silvestre, M.J. Valencia, A.T. White and P.K. Wong (eds.) Towards an integrated management of tropical coastal resources. ICLARM Conf. Proc. 22, 455 p.

Hu, J. and M. Faiz. 1990. Mapping the central atoll of the Maldives using Landsat TM data. Asian-Pac. Remote Sens. J. 3(1): 97-110.

Hyland, S., P. Lennon and P. Luck. 1989. An assessment of the Landsat Thematic Mapper for monitoring seagrasses in Moreton Bay, Queensland, Australia. Asian-Pac. Remote Sens. J. 2(1): 35-42.

IOC (International Oceanographic Commission). 1992. Guide to satellite remote sensing of the marine environment. International Oceanographic Commission, UNESCO.

Johnson, R.W. and J.C. Munday, Jr. 1983. The marine environment. Manual of remote sensing. Vol. II (2nd ed.), American Society of Photogrammetry, Falls Church, VA, United States.

Kam, S.P. 1989a. Application of remote sensing and geographical information systems in coastal area management, p. 163-171. *In* T.-E. Chua and D. Pauly (eds.) Coastal area management in Southeast Asia: policies, management strategies and case studies. ICLARM Conf. Proc. 19, 254 p.

Kam, S.P. 1989b. The use of GIS for coastal resources study: some case examples. Trop. Coast. Area Manage. 4(2): 6-7.

Kam, S.P., Y.K. Leong, L.K. Foo and S.S. Koay. 1990. The use of GIS in coastal resources management in South Johor. ASEAN/US Coastal Resources Management Project Tech. Rep. (Unpublished).

Kam, S.P. 1992. The use of GIS in coastal zone planning and management in South Johor, Malaysia. Paper presented at the International Seminar on Resource Management and Spatial Planning in Developing Countries: Geo-information Technology Perspective, 22-25 April 1992. Universiti Brunei Darussalam, Bandar Seri Begawan, Brunei Darussalam. United Nations Centre for Regional Development and Department of Geography, Faculty of Arts and Social Sciences, Universiti Brunei Darussalam.

Khorram S. 1981a. Use of ocean color scanner data in water quality mapping. Photogram. Eng. Remote Sens. 47: 667-676.

Khorram, S. 1981b. Water quality mapping from Landsat digital data. Int. J. Remote Sens. 2: 145-153.

Khorram, S., G.P. Catts, J.E. Cloern and A.W. Knight. 1987. Modelling of estuarine chlorophyll-a from an airborne scanner. IEEE Trans. Geosci. Remote Sens. 25: 663-670.

Khorram, S., H. Chesire, A.L. Geraci and G. La Rosa. 1991. Water quality mapping in Augusta Bay, Italy from Landsat-TM data. Int. J. Remote Sens. 12(4): 803-808.

Lathrop, R.G. and T.M. Lillesand. 1986. Use of thematic mapper data to assess water quality in Green Bay and Central Lake Michigan. Photogram. Eng. Remote Sens. 52: 671-680.

Lennon, P. and P. Luck. 1990. Seagrass mapping using Landsat-TM data: a case study in Southern Queensland. Asian-Pac. Remote Sens. J. 2(2): 1-6.

Lin, S., G.A. Borstad and J.F.R. Gower. 1984. Remote sensing of chlorophyll in the red spectral region, p. 317-336. *In* J.C.J. Nihoul (ed.) Remote sensing of shelf sea hydrodynamics. Elsevier, New York.

Maguire, D.J. 1991. An overview and definition of GIS, p. 9-20. *In* D.J. Maguire, M. F. Goodchild and D.W. Rhind (eds.) Geographical information systems. Longman Scientific & Technical and John Wiley, New York.

Maguire, D.J. and J. Dangermond. 1991. The functionality of GIS, p. 319-335. *In* D.J. Maguire, M. F. Goodchild and D.W. Rhind (eds.) Geographical information systems. Longman Scientific & Technical and John Wiley, New York.

Meaden, G.J. and J.M. Kapetsky. 1991. Geographical information systems and remote sensing in inland fisheries and aquaculture. FAO Fish. Tech. Pap. No. 318.

Perkins, G. 1992. ESRI: developments and directions. *In* Proceedings of the Seminar on Advanced Survey Technology - Digital Mapping and GIS, 11-13 February 1992. Kuala Lumpur, Malaysia.

Raper, J.F. and B. Kelk. 1991. Three-dimensional GIS, p. 299-317. *In* D.J. Maguire, M.F. Goodchild and D.W. Rhind (eds.) Geographical information systems. Longman Scientific & Technical, Essex, England.

Simonett, D.S. 1988. Considerations on integrating remote sensing and geographic information systems, p. 105-128. *In* H. Mounsey and R.F. Tomlinson (eds.) Building databases for global science. Proceedings of the First Meeting of the International Geographical Union Global Database Planning Project, Tylney Hall, Hampshire, 9-13 May 1988. United Kingdom. Taylor and Francis, London.

Tomlin, D. 1983. A map algebra. Paper presented at the Harvard Computer Graphics Conference.

Yun, C. and M. Faiz. 1990. Remote sensing applications to reef fisheries planning. Asian-Pac. Remote Sens. J. 3(10): 135-147.