

Geographic Information Systems: A Tool for Integrated Coastal Zone Management in Belize

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The planning process for marine protected areas in Belize Central America, adopts geographic information system (GIS) technology to integrate data from a variety of sources. This article describes the importance of GIS in assisting institutional co-operation and illustrates the many advantages of GIS over conventional approaches to mapping and data management. GIS is a powerful analytical tool that has allowed the improvement of inadequate ground control and base mapping through the incorporation of differential global positioning systems technology. Subsequent resource mapping has been carried out through the application of SPOT Panchromatic and other remotely sensed imagery, field survey, and existing GIS data. In Belize, GIS products are increasingly being used as the primary source for management plans. The technology will play a key role in the future development of management initiatives for the country's coastal zone.

Keywords coral reef, geographic information system, integrated coastal zone management, remote sensing, resource mapping

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The Central American nation of Belize has territorial ownership of the largest barrier reef in the

western hemisphere. Although the reefs are reported to have suffered little human disturbance (Smith & Ogden, 1993), the past decade has been marked by a dramatic rise in development activity associated with commercial agriculture, tourism, and fisheries exploitation. As such, the coastal zone of Belize has become an area of intense physical, ecological, and social interaction and faces an increasing number of potentially detrimental activities. Rightly, the Government of Belize and a number of international and national organisations view the management of Belize's marine resources to be of prime importance.

Traditional sectoral approaches to resource management are generally being replaced by more holistic, integrated strategies (Hildebrand & Norrena, 1992). Integrated coastal zone management has been formally defined as a "dynamic process in which a coordinated strategy is developed and implemented for the allocation of environmental, socio-cultural, and institutional resources to achieve the conservation and sustainable multiple use of the coastal zone" (Coastal Area Management and Planning Network, 1989). The need for institutional collaboration is implicit in this definition; successful management planning relies, to a great extent, on co-operation among government institutions, non-governmental organisations (NGOs), and local interests (Ricketts, 1992).

In Belize, institutional co-operation is achieved through a Coastal Zone Management Technical Committee, whose members represent government departments, NGOs, the University College of Belize, and the Chamber of Commerce. The committee is co-ordinated by the Department of Fisheries' Coastal Zone Management Unit (CZMU), which was established in 1990 to develop a country-wide management strategy for Belize's coastal zone. In 1993, the CZMU received financial support from the Global Environment Facility/United Nations Development Programme.

Although institutional co-operation is undoubtedly key to the success of an integrated approach to coastal zone management, it is clear that the emergence of rational policy relies on accessibility to data drawn from a wide range of sectors and based on a variety of collection techniques. Given the spatial nature of these planning data and the (often understated) importance of assembling them into coherent and accessible map products (Kelly et al., 1987; Ricketts et al., 1989; Tortell, 1992), the adoption of geographic information system (GIS) technology is not only appropriate but perhaps essential. A GIS is a computer-based system for storing, querying, analysing, and displaying geographically referenced information (Smith, 1991). The technology is well established as a management tool for terrestrial systems and its popularity is rising among marine managers, especially given the increase of digital data sources (Ricketts, 1992) and improvements to the software.

Both the introduction of GIS to Belize and the development of an appropriate institutional framework have coincided with the data gathering/analysis phase of the CZMU's management strategy. In practice, this has allowed the approach for resource mapping, biological surveys, and data analysis to evolve in line with the capabilities of GIS.

Several NGOs and research institutes are actively involved in data collection and resource surveys of Belize's coastal zone. These activities are coordinated by the CZMU and are targeted to areas that either experience some degree of human disturbance or possess intrinsic qualities that are regarded as warranting special conservation measures (e.g., sites of atypical biodiversity). For example, the volunteer-based British organisation, Coral Cay Conservation (CCC), at the request of the CZMU, has undertaken an intensive ecological assessment of the marine resources of the proposed South Water Cay Marine Reserve (Raines et al., 1992), which was identified as a critical habitat in 1990 (Belize Centre for Environmental Studies, 1990).

The availability of accurate base maps (showing, for example, coastline, cays, reef) is a prerequisite for the ecological assessment of marine resources. Unfortunately, in many regions base maps are inadequate, often requiring updating or improvement from aerial photography (Clark & Rohmann, 1994). However, the common underlying problem of the original maps, namely the difficulty of georeferencing aerial imagery in marine areas, may still persist (Ferguson et al., 1993; Friel & Haddad, 1992). In practical terms, two approaches to georeferencing aerial photographs of marine

areas exist. First, if the photographs incorporate areas of land and adequate topographic or navigation charts exist, sufficient ground control may be obtained for the entire photograph without having to seek off-shore ground control points. If however, land is not available, the aerial photography is usually georeferenced by placing large markers on the water surface during the fly-over. The co-ordinates of the markers are then used to provide ground control (Fuller et al., 1994). Unfortunately, neither technique is particularly practical for many areas of the Belize barrier reef, which lies approximately 15 km from the mainland, and cost constraints currently rule out the commissioning of new aerial photography incorporating surface markers. As a consequence, existing maps and navigation charts of the area are poor both in terms of locational accuracy and spatial detail.

An alternative source of remotely sensed information is that obtained from satellites. Landsat TM and SPOT HRV data are routinely incorporated into GIS for land-use mapping in Belize (Land Information Centre, 1994), and satellite remote sensing is widely considered to provide a cost-effective and useful means of mapping tropical marine ecosystems (Loubersac et al., 1988; Luczkovich et al., 1993; Zainal et al., 1993), although the cost-effectiveness has never been clearly demonstrated in economic terms. The principal advantage of satellite remote sensing over aerial photography, ground surveys, and nautical charts is that information can be collected uniformly in both time and space (de Vel & Bour, 1990). It also offers a non-intrusive, repeatable solution to mapping large areas of marine features, given suitably clear water and little atmospheric interference. With the current spectral and spatial resolution of satellite sensors, the major limitation of remote sensing is perhaps the difficulty of spectrally separating biological communities rather than geomorphological zones (Bainbridge & Reichelt, 1988). However, results obtained in Belize demonstrate that satellite remote sensing can offer valuable information on reef structure, particularly if used as a means of directing ground truthing (Mumby et al., 1994).

This article has three principal aims:

- (1) To describe the development of methodologies for assessing marine resources based on the capabilities of GIS and, in doing so, illustrate several advantages of GIS over conventional approaches to mapping and data management. The proposed South Water Cay Marine Reserve and Turneffe Atoll provide examples.
- (2) To describe the use of integrating remotely sensed data with GIS applications.
- (3) To outline the approach being taken toward institutional co-operation and the development of an ongoing and mutually beneficial data gathering and management infrastructure in the context of integrated coastal zone management in Belize.

GIS as a Marine Resource Mapping Tool

Mapping the Proposed South Water Cay Marine Reserve

The proposed South Water Cay Marine Reserve (Figure 1) is particularly difficult to map because of the paucity of land throughout much of the area. Two initial attempts were made by CCC, both of which were inadequate for resource management purposes. The first attempt, in 1992, was simply a broad baseline map of the whole reserve, which was generated by transposing the outlines of cays from 1:35,000 monochrome aerial photographs. At this stage, the high-accuracy satellite-based differential global positioning system (DGPS) was not available in Belize and therefore cays and reef crest were positioned using ground co-ordinates obtained from a standard GPS unit, which lacked a differential facility (see August et al., 1994, for a discussion on the use and accuracy of GPS). This base map was digitised into the GIS, ARC/INFO, at the Land Information Centre (LIC) and referenced to the Universal Transverse Mercator.

In the second attempt, the aerial photographs were re-photographed to accommodate for image

distortion created by rolling movements of the aircraft during flight. The extent of this aircraft induced distortion varied from flight line to flight line and the reef section was found to be the least distorted. Enlarged copies of these corrected photo-graphs were used to create a mosaic with each of the principal geomorphological zones digitised (Natural Resources Institute and Coral Cay Conservation, unpublished). However, this second map did not encompass the entire reserve and several of the lagoon polygons were inaccurately delineated.

To produce a satisfactory coverage of the whole area, it was necessary to superimpose the reef section of the second map onto the outline coverage produced earlier. This composite included all cays and a detailed reef section but revealed little of the geomorphological properties of the lagoon. The addition and classification of new lagoon polygons was carried out by CCC using aerial photography and baseline environmental data collected by CCC volunteers. DGPS was routinely used to georeferenced biological survey data, and a dedicated database was developed and refined to ensure direct compatibility with ARC/INFO. At a later stage, the locational accuracy of the map was further enhanced by deploying a GPS unit to measure the perimeter of the cays, and rubber sheeting techniques were applied to fit the polygons to the improved ground control. The circle error probable (median) accuracy of co-ordinates derived from DGPS is between 2 and 5 m (Trimble Navigation Ltd., 1993).

Despite the problems encountered in mapping the proposed South Water Cay Marine Reserve (Figure 2), this example does serve to illustrate how GIS offers the flexibility to solve fairly complex problems.

Mapping tile Turneffe Atoll

Lying outside the Belize barrier reef the Turneffe Atoll (Figure 1) encompasses a wide variety of habitats including an intricate network of mangrove islands, a shallow lagoon, and topographically complex fringing reefs. With an area exceeding 500 km², this is the largest atoll in Belize and is an extremely important commercial fishing ground. It may also support one of the largest populations of American crocodiles (*Crocodylus acutus*) in the Caribbean (Perkins, 1983).

Despite the availability of stereoscopic monochrome photographs from the British Forces, lack of access to a stereo-plotter in Belize constrained their use. Base mapping of the atoll was further complicated by the lack of topographic control (the Lands and Survey Department has only a single survey control point for Turneffe Atoll). Given these constraints, a novel approach to mapping was adopted. Thirty-seven monochrome photographs (courtesy of the British Forces Belize) provided overlapping coverage of the entire atoll at a scale of 1:30,000. No attempt was made to remove aircraft-induced distortion and each photograph was digitised as an individual coverage. To allow georeferencing and integration of digital coverage at a later stage, reference (registration) points were added that could be easily identified in adjacent photographs and located in the field (e.g., island promontories, corners of mangrove creeks).

The co-ordinates of 12 of the reference points were obtained using DGPS. The standard deviation of differentially corrected positions varied between 0.2 and 4.9 m. Although it was unnecessary to identify the co-ordinates of each reference point, a broad geographic spread of points was required to avoid bias in the geometric correction process. Each of the 37 digital coverages (formerly photographs) was georeferenced individually by choosing the four ground control points with the squarest geometry about each coverage. This process was facilitated by the powerful rubber sheeting capability of GIS, which fits a digital coverage to ground control points with minimal loss of spatial accuracy. Once each digital coverage was georeferenced, all coverages were combined into a single file. The resulting map of the entire Turneffe Atoll was edited to remove regions of duplication between adjacent coverages and, finally, the image was cleaned, the topology built, and the polygons classified. The result was a great improvement over any other map available.

Satellite Remote Sensing and GIS

In 1993, CCC conducted a rapid ecological assessment of the Sapodilla Cays (Figure 1), which are considered by the CZMU to warrant urgent protection because of recent pressures from tourism and illegal fishing. The benthic geomorphological zones in a SPOT Panchromatic satellite image were classified using data collected by CCC volunteers and georeferenced using DGPS (Mumby et al., 1994). The classified image was transferred from the remote sensing software (ERDAS) to ARC/INFO (via the GRID module) to provide a georeferenced resource map on which other information was superimposed as part of the CZMU's management plan for the Sapodilla Cays. GIS provides an ideal environment in which to manipulate classified satellite imagery (Donoghue et al., 1994; Omoregie & Babu, 1994; Populus et al., 1994; Ricketts, 1992). Transferring the image to a GIS also allows easy modification of the original classification. This may be necessary because some geomorphological zones are over-classified, under-classified, or simply mis-classified during image analysis. Providing that supportive data are available, these geomorphological zones, present as polygons in a GIS, can be modified or reclassified.

Data Integration and Co-operation

In Belize, as elsewhere, processes affecting the coastal zone are inherently linked to activities throughout the country (e.g., use of agrochemicals). As such, a workable management plan must consider the often competing demands of a wide range of activities and resource users (De Vries, 1985; Schauser et al., 1992; Tang, 1994). While this is actively acknowledged at the level of policy in the Coastal Zone Management Technical Committee, efforts are currently underway to introduce similar co-operation in the data gathering and analytical organisations. This has led to the establishment of the LIC and a data sharing agreement (DSA), which enables the GIS technology at the LIC to be used to its full capability while ensuring that data collection and analytical efforts are shared and duplication reduced.

The LIC was established within the Ministry of Natural Resources in June 1992 to serve as a central depository for land information. Through financial assistance and training from the U.K. Overseas Development Administration and the U.S. Agency for International Development, comprehensive GIS and land information system facilities have been developed incorporating a network of SUN workstations running the ARC/INFO software (Hyde, 1991; Robinson et al., 1989; Gray & Belisle, 1993). The GIS already includes numerous data sets, such as land use, land capability, archaeological sites, land parcels, watershed, drainage, and road networks, and it is widely used by policy makers and planners.

The LIC also facilitates marine resource management through its links to the Fisheries Department, the CZMU, and NGOs. In 1993, the LIC played a key role in the preparation of the proposed South Water Cay Marine Reserve management plan (McCorry et al., 1993). A series of GIS coverages were produced from data held in various departments. These included geodetic control points and land ownership (Lands and Survey Department); bird and turtle nesting sites, crocodile activity, location of protected areas, existing conservation status, fisheries, and recreational usage (Department of Fisheries and Coastal Zone Management Unit); mangrove status and land use (Department of Forestry); archaeological sites (Department of Archaeology-data held at the LIC); physical, biological, and bathymetric data (CCC); attribute data from the scientific literature (terrestrial habitats); and location of research undertaken throughout the area. Presentation of these data on a standard (GIS) map format allowed planners to make a clear interrogation and assimilation of the information.

Marine protected area planning is achieved using a multiple-use zoning scheme that affords three hierarchical levels of restriction to development/activities in addition to providing for more

specialised management needs where appropriate (see Gibson, 1986). The proposed boundaries of the South Water Cay Marine Reserve management zones were placed primarily to accommodate existing fisheries and recreational usage and protect representative portions of the major marine and terrestrial habitats within the area. This required examination of nine GIS data layers, although those of fisheries activity, recreational activity, and habitat inventory were most fundamental to the planners' needs (see McCorry et al., 1993, for further details). Visual evaluation of this information was adequate for the purposes of planning, and therefore the GIS was not required to conduct user-defined queries on the data set (e.g., display of regions with particular usage combinations or physical characteristics).

The proposed management zones were added to the GIS, which will permit easy modification throughout the public consultation phase. In addition, zone boundaries can be accurately and easily defined for legal purposes.

The existence of a centralised facility handling land information has already brought many benefits. Principal among these has been the ability to make available to planners a standardised and up-to-date set of information. For example, land parcels or mangrove areas will be consistently represented regardless of whether the management plan falls under the mandate of a Special Development Area development plan, the Forest Department, or the Fisheries Department. Similarly, once an organisation updates a data layer in the GIS, the modified information becomes available for others (although restrictions can be placed on this). In short, the planning process is integrated at the most basic level.

As more data are incorporated into the LIC, it will continue to expand its facility to assist resource managers. Of particular importance is the establishment of a Conservation and Environmental Database System (CEDS), which will integrate the data gathering activities of government departments and NGOs under the terms of a DSA. In addition to the equipment and technicians housed in the LIC, the CEDS will consist of policy and technical committees and a secretariat. The aim of the CEDS is to co-ordinate environmental data gathering and dissemination and overcome the current situation in which a wide range of organisations operate independently and data circulation is restricted.

In practice, the aim of the LIC and CEDS development is not to create a central governing institution but to maximise and encourage the strengths and capabilities of member organisations (some 20 NGOs, government departments, and educational institutions have already joined). Groups such as the CZMU will be encouraged to develop their own GIS capabilities and receive data from the LIC in return for access to relevant data on the coastal zone. This is already underway through donation of ARC/INFO software by the Environmental Systems Research Institute and hardware procurement under the Global Environment Facility/United Nations Development Programming.

In addition to data exchange among decision makers and researchers, it is imperative that GIS products are made available to other interested parties including the general public, developers, and students (Somers et al., 1989). Many of the data held at the LIC are available and may be procured at low cost.

Conclusions

In terms of assessing the status of marine resources, GIS has proven to be a powerful and flexible tool for the mapping of remote coastal areas, particularly when conventional photogrammetric techniques cannot be applied. Furthermore, the ability of GIS to integrate data drawn from a wide range of sources and rapidly produce easily accessible products makes it highly suitable for management planning.

The experience of applying GIS technology to integrated coastal zone management in Belize has continued to evolve as the needs of the marine managers and the understanding of the capabilities of GIS have drawn closer. Aside from the technical problems of implementing the hardware and

software and retaining trained staff, GIS continues to generate valuable products, which serve to justify its adoption in Belize. However, it must be made clear that the success of a GIS system depends on the suitability of the GIS application and the status of the institutional framework into which it is incorporated, particularly if data are drawn from multiple sources. Belize has benefited because it has a framework capable of expanding as new users and applications arise. The principal benefit is that planning activities in all areas of government are integrated at a most basic level. This is significant, not only in the production of management plans but also in daily management of the coastal zone. Adoption of GIS as the basis for information management and storage is allowing managers and planners to view the process in a far more dynamic way than has previously been the case.

Marine resource surveys, improved base mapping, and permanent monitoring data can now be entered into the GIS, which, in addition to allowing the synthesis of management plans, also incrementally improves the quality of the overall database and, subsequently, the quality of decision making.

References

- August, P., J. Michaud, C. Labash, and C. Smith. 1994.
GPS for environmental applications : Accuracy and precision of locational data. *Photogrammetric Engineering & Remote Sensing* 60(1):41-45.
- Bainbridge, S. J., and R. F. Reichelt. 1988.
An assessment of ground truthing methods for coral reef remote sensing data. *Proceedings of the 6th International Coral Reef Symposium* 2:439-444
- Belize Centre for Environmental Studies. 1990.
Belize critical habitat survey. Belize: Belize Centre for Environmental Studies. 165 pp.
- Clark, A. F., and S. O. Rohmann. 1994.
Mapping and analysing benthic habitats in the Florida Keys National Marine Sanctuary. *Proceedings of the Second Thematic Conference on Remote Sensing of Marine and Coastal Environments*. New Orleans, 2:542-545.
- Coastal Area Management and Planning Network. 1989.
The status of integrated coastal zone management: A global assessment. *Summary report of a workshop convened at Charleston, South Carolina, July 4 - 9*. Rosenstiel School of Marine Sciences, University of Miami.
- de Vel, O. Y., and W. Bour. 1990.
The structural and thematic mapping of coral reefs using high resolution SPOT data: Application to the Tetembia Reef (New Caledonia). *Geocartography International* 5(2):27-34.
- De Vries, M. F. 1985.
The use of GIS to integrate remote sensing and other natural resource data. *Proceedings of the 19th International Symposium on Remote Sensing of the Environment* 1:135-140.
- Donoghue, D. N. M., D. C. Reid Thomas, and Y. Zong. 1994.
Mapping and monitoring the inter-tidal zone of the east coast of England using remote sensing techniques and a coastal monitoring GIS. *Proceedings of the Second Thematic Conference on Remote Sensing of Marine and Coastal Environments*, New Orleans 1:665-676.
- Ferguson, R. L., L. L. Wood, and D. B. Graham. 1993.
Monitoring spatial change in seagrass habitat with aerial photography. *Photogrammetric Engineering & Remote Sensing* 59(6):1033-1038.
- Friel, C., and K. Haddad. 1992.
GIS manages marine resources. *GIS World* 5(9):33-36.
- Fuller, D., L. Handley, J. Barras, and S. Robb. 1994.
The use of GIS and image processing technology for wetland planning, protection and restoration in coastal Louisiana. *Proceedings of the Second Thematic Conference on Remote Sensing of Marine and Coastal Environments*. New Orleans 1:97-101.

Gibson, J. 1986.

Hol Chan Marine Reserve draft management plan, pp.15 -18. New York: New York Zoological Society.

Gray, D. A., and L. Belisle. 1993.

The role of GIS in integrated resource management in Belize, Central America. *Proceedings of GIS '93*. February 14-18, Vancouver.

Hildebrand, L. P., and F. J. Norrena. 1992.

Approaches and progress toward effective integrated coastal zone management. *Marine Pollution Bulletin* 25:94-97.

Hyde, R. F. 1991.

The feasibility of a land information system for Belize, Central America. *International Journal of Geographical Information Systems* 5(1):99-109.

Kelly, D., R. P. Cote, B. Nicholls, and P. J. Ricketts. 1987.

Developing a strategic assessment and planning framework for the marine environment. *Journal of Environmental Management* 25:219-230.

Land Information Centre (LIC). 1994.

The land use of Belize, 1994. Technical report. Belmopan: Ministry of Natural Resources.

Loubersac, L., A. L. Dahl, P. Collotte, O. Lemaire, L. D'ozouville, and A. Grotte. 1988.

Impact assessment of cyclone sally on the almost Atoll of Aitutaki (Cook Islands) by remote sensing. *Proceedings of the 6th International Coral Reef Symposium*. Australia 2:455-462.

Luczkovich, J. L., T. W. Wagner, J. L. Michalek, and R. W. Stoffle. 1993.

Discrimination of coral reefs, seagrass meadows, and sand bottom types from space: A Dominican Republic case study. *Photogrammetric Engineering & Remote Sensing* 59(3):385-389.

McCorry, D., P. J. Mumby, P.S. Raines, and J. M. Ridley. 1993.

Draft management plan for the South Water Cay Marine Reserve. Department of Fisheries & Agriculture, Government of Belize, in press.

Mumby, P. J., M. A. Baker, P. S. Raines, and A. T. Phillips. 1994.

The potential of SPOT panchromatic imagery as a tool for mapping coral reefs. *Proceedings of the Second Thematic Conference on Remote Sensing of Marine and Coastal Environments*. New Orleans 1:259-267.

Omoriegic, C., and V. R. R. M. Babu. 1994.

Linking remote sensing and GIS with natural resources management. *Proceedings of the Second Thematic Conference on Remote Sensing of Marine and Coastal Environments*. New Orleans 1:609-612.

Perkins, J. S. 1983.

The Belize harrier reef ecosystem: An assessment of its resources, conservation status and management. New York: New York Zoological Society. 148 pp.

Populus, J., F. Moreau, D. Coquelet, and J.-P. Xavier. 1994.

An assessment of environmental sensitivity to marine pollution's: Solutions with remote sensing and GIS. *Proceedings of the Second Thematic Conference on Remote Sensing of Marine and Coastal Environments*. New Orleans 1:461-472.

Raines, P. S., J. M. Ridley, D. McCorry, and P. J. Mumby. 1992.

Coral Cay Conservation - survey techniques and their application in Belize. *Proceedings of the International Coral Reef Symposium*. Guam 1:122-126.

Ricketts, P. J. 1992.

Current approaches in GIS for coastal management. *Marine Pollution Bulletin* 25:82-87.

Ricketts, P. J., A. R. McIver, and M. J. A. Butler. 1989.

Integrated information systems: The key to coastal zone management. *Coastal Zone* 1989 5:4138-4150.

Robinson, G. M., D. A. Gray, R. G. Healey, and P. A. Furley. 1989.

Developing a GIS for agricultural development in Belize, Central America. *Applied Geography* 9:81-94.

- Schauser, U. H., D. Boedeker, S. Matusek, and H. Klug. 1992.
The use of GIS for Wadden Sea conservation. *Proceedings of the 7th International Wadden Sea Symposium*, 1992, eds. D. Amelan, N. Dankers, C. J. Smit, and M. Scholl. 20:281-283.
- Smith, L. K. 1991.
Environmental management models, with special reference to GIS systems. Summary, ENS'91 *International Environment Northern Seas Conference and Exhibition*, Stavanger, August.
- Smith, S. R., and J. C. Ogden, Eds. 1993.
Status and recent history of coral reefs at the CARICOMP Network of Caribbean Marine Laboratories. *Case histories for the colloquium and forum on global aspects of coral reefs: Health, hazards and history*. University of Miami. M:43-49.
- Somers, R., B. Jones, and S. Snyder. 1989.
Managing and disseminating data necessary for coastal wetland management in South Carolina. *Coastal Zone '89* 5:4125-4128.
- Tang, W. S. M. 1994.
The applications of GIS to conservation in Hong Kong. *Proceedings of GIS '94*. Vancouver 601-608.
- Tortell, P. 1992.
Coastal zone sensitivity mapping and its role in marine environmental management. *Marine Pollution Bulletin* 25:88-93.
- Trimble Navigation Ltd. 1993.
GPS prolite. Surveying & Mapping Division. 645 North Mary Avenue, Sunnyvale. California.
- Zainal, A. J. M., D. H. Dalby, and I. S. Robinson. 1993.
Monitoring marine ecological changes on the east coast of Bahrain with Landsat TM. *Photogrammetric Engineering & Remote Sensing* 59(3):415-421.

Figure 1

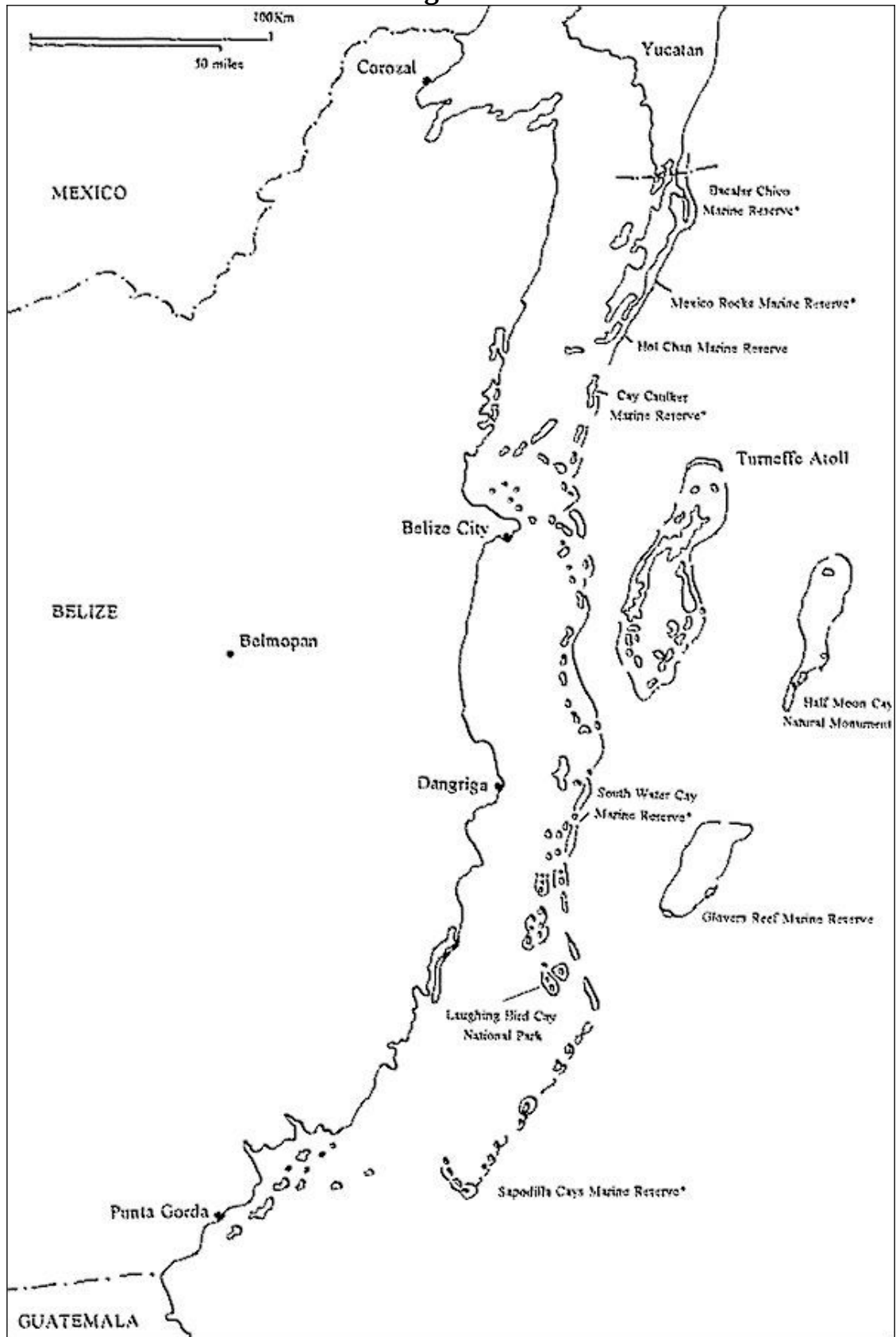


Figure 1. The approximate extent of the Belize barrier reef, showing the location of established protected areas in the coastal zone; * denotes proposed marine protected areas.

Figure 2

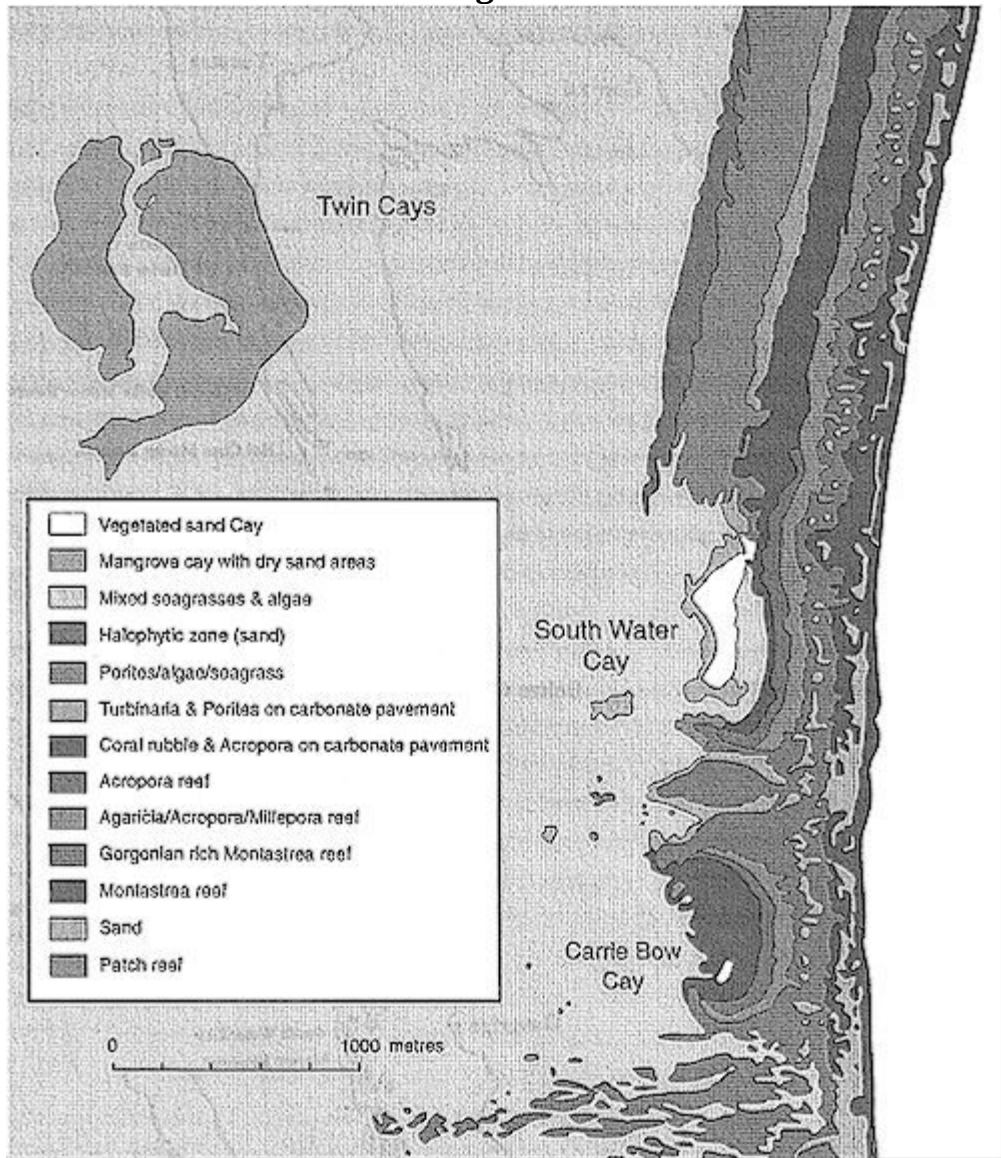


Figure 2. Excerpt from the resource map of the proposed South Water Cay Marine Reserve. Polygons are delineated from aerial photographs and classified using data collected by Coral Cay Conservation. Reef polygons are labelled in sequence from left (halophytic zone) to right (sand). The complete resource map includes some habitats not displayed in this excerpt. (Source: McCorry et al., 1993.)