AN ASSESSMENT OF THE PEARL ISLANDS ARCHIPELAGO, PACIFIC PANAMA

By

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Abstract

The Pearl Island archipelago is located on the Pacific coast of Panama in the Gulf of Panama, 70 km from Panama City. This mostly uninhabited archipelago consists of 53 basaltic rock islands and numerous islets, relatively uninfluenced by anthropogenic impacts. The archipelago supports numerous small fringing and patch coral reefs that are exploited by artisanal fisheries. Tourism is developing rapidly, although many reefs remain inaccessible to tourists as yet. Natural fluctuations in sea-surface temperatures, through either seasonal upwelling of cold, nutrient-rich deep water, or periodical warming due to El Niño-Southern Oscillation (ENSO) are the major influence on the marine environment and its biota.

A field visit was undertaken at the end of May 2003 to allow for data collection in the northern section of the archipelago. Transect surveys were conducted to determine shallow subtidal habitats through a ground-truthing exercise, data being compared with previous surveys and historical aerial photographs. This and other data appear to suggest that corals are recovering from the devastation caused by the 1982-83 El Niño event, which reduced live coral cover significantly throughout the archipelago. It was intended to undertake ‘time-series’ analysis of the archipelago, the identification of changes in both terrestrial and subtidal habitats through comparison between historical and recent aerial photographs. Unfortunately this was not possible due to the unavailability of recent imagery to the present study. Future work in the archipelago should focus on the sourcing of existing data and the collection of new data, which together will allow the status of the marine environment of this relatively understudied yet complex region to be more comprehensively understood.

Acknowledgements

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Aims & Objectives

This dissertation aims to develop an understanding of the marine environment of the Pearl Islands archipelago, Pacific Panama, through a comprehensive literature review and a field visit to the region. It is intended that this will provide an overview of the archipelago for future studies, and facilitate in their implementation and success.

Both terrestrial and subtidal habitats will be assessed, focussing mainly on the two greatly contrasting northerly islands of Saboga and Contadora. Isla Saboga has a small settlement and is the location of the largest known coral reef in the whole archipelago. In contrast, Isla Contadora is heavily developed and the location of major tourist resorts, an airstrip providing direct links to Panama City, and numerous private residences. Ecological as well as social and economic factors will be assessed for the archipelago. A fieldtrip will be undertaken to conduct subtidal ground-truthing, involving transect surveys to assess benthic habitat types and condition. This will allow for identification of features visible in aerial photographs, both recent and historical. It is then hoped to perform 'time-change analysis' on the images through the use of GIS to determine any major changes in the habitat types during the intervening time period. This information can then be used in the construction of a GIS conceptual model, which will assist in the identification of sites suitable for proposed Marine Protected Area (MPA) status.

Chapter 1 provides an overview of the literature, whilst Chapter 2 discusses natural and anthropogenic influences in the region. Chapter 3 provides a brief history of the Pearl Islands, which are then discussed in a more detailed case study in Chapter 4. Chapters 5 and 6 tackle the issues raised for future studies in this area.

1. Panama & the Tropical Eastern Pacific Biogeographic Zone

The Tropical Eastern Pacific (TEP) ranges from Baja California in northern Mexico to just south of the Equator in southern Ecuador, and is classified as a distinct biogeographic zone with unique fauna and flora (Allen & Robertson, 1994). Coral reefs found in this area are typically small, shallow occurring, species poor and patchily distributed on both mainland shores and offshore islands (Glynn & Maté, 1996). Historically it was believed reefs were absent from this region due to cool eastern boundary continental currents and local upwellings precluding growth (Glynn & D'Croz, 1990). However, during the last 30 years numerous coral reefs have been discovered, studied and described here (Glynn & Stewart, 1973; Glynn, 1976; Glynn, 1977; Wellington, 1982).

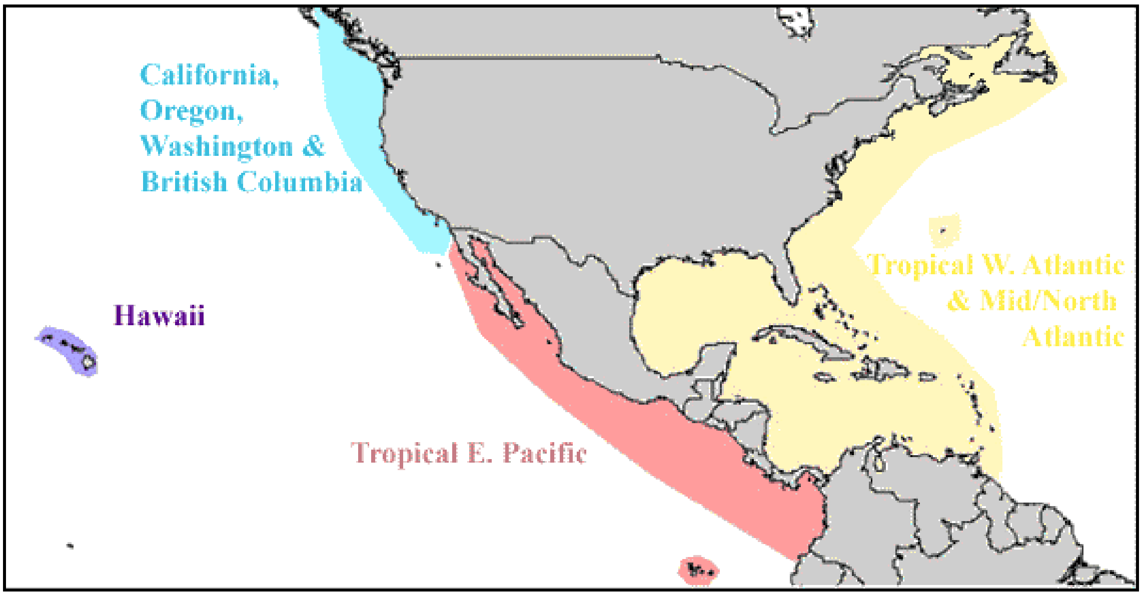


Figure 1.1 The Tropical Eastern Pacific[1]

[1] Source: http://www.reef.org/data/database.htm. Accessed August 2003.

1.1 Climate

The Intertropical Convergence Zone (ITCZ) governs the climate of Panama. The ITCZ can be described as a region that circles the earth, near the equator, where the trade winds of the Northern and Southern hemispheres meet (Figure 1.2). In the equatorial eastern Pacific it forms where the Northeast and Southeast trade winds converge between 5° to 15°N (Glynn & Maté, 1996). Its position defines the pattern of rainfall and wind in Panama (D'Croz & Robertson, 1997), and its seasonal migration has a major influence on the climate, giving Panama distinct wet and dry seasons. Wet season occurs during the months of May to December, when the ITCZ is located over or slightly to the north of the country (D'Croz & Robertson, 1997). This period is characterised by light, variable winds and heavy rainfall. Dry season, from January to April, is experienced during the Northern hemisphere winter when the ITCZ is located to the south of Panama, and is a period characterised by clear skies and predominant Northeast Caribbean trade winds. These winds blow across the low terrain of the Isthmus to the Pacific coast, influencing not only the climate but also the oceanographic conditions in the Panama Bight, in particular within the Gulf of Panama (Glynn & Stewart, 1973; Glynn & Maté, 1996). Similar seasonal patterns of northerly winds and high rainfall are observed in the Gulf of Chiriquí to the west, but higher terrain in Chiriquí Province blocks the north-to-south trade wind circulation, thus preventing major oceanographic influence. As spring approaches the ITCZ migrates northwards, winds lessen and the wet season begins.

Figure 1.2 The ITCZ, located to the south of Panama and represented by the line of white cloud[2]

1.2 Oceanography

Oceanographic conditions vary enormously between the Pacific and the Caribbean coasts of Panama. The Caribbean Sea is characterised by mixed tides with a small tidal range (commonly only 60 cm), nutrient poor waters and a relatively stable thermal regime (D'Croz & Robertson, 1997). Dominant winds on the Caribbean can also create waves of up to three metres, higher than those on the Pacific (Windevoxhel *et al*, 1999). Pacific Panama in contrast experiences semi-diurnal tides with a large tidal range (up to six metres) and two major events which regularly affect coastal oceanography, particularly in the Gulf of Panama; wind-driven seasonal upwelling, and episodic occurrence of sea warming due to the El Niño – Southern Oscillation (D'Croz & Robertson, 1997).

1.2.1 Seasonal upwelling regime

Seasonal upwelling develops during the dry season when the Northeast trade winds cross to the Pacific via the low terrain of the Isthmus mountain range of Central Panama (Figure 1.3).

Figure 1.3 Topography of Panama[3]

Nutrient poor coastal surface water is displaced offshore, and replaced by more saline, cooler and nutrient-rich upwelling deep water (D'Croz & Robertson, 1997). Combined with clear skies and high radiation levels, this can result in plankton blooms and mean primary production levels over twice that of the wet season (Forsbergh, 1969 cited in Glynn & Stewart, 1973). During this period large changes are apparent in the marine

[2] Source: http://www.utexas.edu/depts/grg/huebner/grg306c/graphics/itcz.jpg. Accessed June 2003.
[3] Source: http://www.reefbase.org. Accessed August 2003.

environment of the Gulf of Panama. The nutrient-rich upwelling water may contain up to 50 times more phosphate (PO_4^-) and 35 times more nitrate (NO_3^-) than in the wet season (D'Croz & Robertson, 1997). This reaches a peak during upwelling episodes, and attracts large aggregations of bait fish (anchovies and Atlantic herring) that in turn attract large flocks of seabirds that feed upon them, such as the Brown Pelican. Large pelagic and demersal fish also become more active in the upwelling season, and in some years aggregations of whale sharks, manta rays, porpoises and whales have been reported in the Gulf of Panama (Glynn & Maté, 1996).

Sea surface temperatures (SSTs) usually range between 28° to 29°C during the wet season in Pacific Panama. However they are known to drop significantly in the Gulf of Panama in the dry season and frequently fall below 20°C during upwelling periods (Glynn & Maté, 1996). In contrast, no upwelling occurs in the adjacent Gulf of Chiriquí, and marked differences are observed in the thermal climates for both regions (D'Croz et al, 2001). Surface salinities in both gulfs generally range between 30 and 35 psu (practical salinity units) in the dry season and between 24 and 30 psu in the wet season (Glynn & Maté, 1996). Light penetration and horizontal visibility are greatly reduced in the Gulf of Panama during the dry season due to upwelling nutrients encouraging episodic plankton blooms. This is not seen in the Gulf of Chiriquí, where nutrient levels may be an order of magnitude below that of the upwelling zone in the Gulf of Panama (Glynn & Maté, 1996).

1.2.2 El Niño – Southern Oscillation (ENSO)

El Niño – Southern Oscillation (ENSO) is the term given to a set of atmospheric and oceanographic conditions that periodically alter the atmospheric pressure, winds, rainfall patterns ocean currents and sea level over large areas of the tropical and subtropical Pacific Ocean (Nybakken, 2001). There is evidence that this has occurred for millennia (Trenberth, 2001), and moderate to strong ENSO activity occurs in the TEP on average every 4 years (Quinn *et al*, 1987 cited in Glynn & Maté, 1996). This can result in severe responses in biological communities (Glynn 1984,1990,1993; Eakin 1992; Maté 1997; Guzmán & Cortés 2001), whilst laboratory-based studies have implicated simulated ENSO-like effects (such as elevated and sustained SSTs) as major factors leading to coral mortality (Glynn & D'Croz, 1990; D'Croz *et al*, 2001; Hueerkamp *et al*, 2001).

Before the 1982-83 event, ENSO was thought to be beneficial to coral reefs, enhancing growth through elevated SSTs, and aiding the promotion of coral recruitment through transport of planulae by increased currents. Only after the 1982-83 event (and the massive coral mortality that occurred) was ENSO seen as a potentially negative force on reef building (Colgan, 1990). This event catastrophically affected coastal Pacific coral reefs from northwest Costa Rica to southern Ecuador, as well as offshore islands such as the Galapagos (Glynn, 2001).

Sedimentary records indicate that current sea level in the TEP stabilised approximately 6,500 years ago, with estimations of between 18 and 65 El Niño events of similar or greater magnitude as the 1982-83 event having disturbed the TEP reef-building region over this time (Colgan, 1990). Today's TEP coral reefs differ markedly in size, species composition and species richness from past reefs of the region and other present day Pacific reefs. The closure of the Central American seaway by the rise of the Panamanian Isthmus (approximately 3.5 million years ago) altered global oceanic circulation, and halted the transfer and recruitment of species from the Atlantic to the Pacific Ocean. This deteriorated the reef-building environment of the TEP and led to its current status as an impoverished outpost of the central and western Pacific coral reef domain, which no longer shares any reef-building coral species with the Atlantic region (Glynn, 2001). Eastern Pacific coral reefs are also less extensive and diverse than those of the Caribbean (Windevoxhel *et al*, 1999), with the richest coral communities of the TEP off Panama and the southern coast of Costa Rica. The closure of the Panamanian seaway also initiated the development of modern Pacific circulation, and with it the components necessary for onset of ENSO events. These have acted in conjunction with other physical and biological factors to prevent the build-up of a substantial reef framework. After coral mortality, bioerosion removes much of the coral build-up, preventing the coral community from increasing in diversity or developing a structure resistant to erosion after death. Thus previous growth is not transferred to successive generations and large, persistent reefs are not constructed (Colgan, 1990).

1.3 Biology & Ecology of Corals of the TEP and Pacific Panama

1.3.1 Distribution

From a total of 41 species and 11 genera of zooxanthellate scleractinian corals and hydrocorals known from the TEP region, Pacific Panama is host to 23 species and 10 genera, or 56% and 91% respectively (Glynn & Maté, 1996; Glynn, 2001). Drilling of coral reef cores has determined that the oldest reefs found in the Gulf of Panama are approximately 4,500 years old, and in the Gulf of Chiriquí approximately 5,600 years old. Reefs in the TEP shelf area are thought to have kept pace with a sea level rise of around 10-15 metres over the last 6,000–7,000 years, attaining a vertical thickness of between 10–13 metres (Glynn & Maté, 1996).

Oceanographic differences between the upwelling Gulf of Panama and the non-upwelling Gulf of Chiriquí are thought to be responsible for differences in coral reef growth and structure between the two regions, with reefs in the Gulf of Chiriquí attaining greater size and a higher species richness (Glynn & Maté, 1996). Seasonal upwelling in the Gulf of Panama appears to make conditions unfavourable for development of coral reefs through variability in SSTs, eutrophic conditions, and reduced light penetration through the water column due to increases in phytoplankton (D'Croz & Robertson, 1997). Major biotic differences include the absence of both the Crown-of-Thorns Starfish [*Acanthaster planci* (Linnaeus)] and zooxanthellate hydrocorals (*Millepora,* two species) from the Gulf of Panama (Glynn, 2001). Fish faunas also vary between the two thermally distinct regions (Allen & Robertson, 1994).

1.3.2 Reef structure

The chief reef-building corals *Pocillopora damicornis* (Linnaeus) and *Pocillopora elegans* Dana dominate the reef structure in Pacific Panama due to their rapid growth, high reproductive output, and capability of overtopping other species, forming intermeshing frameworks 2-3 metres in relief (Glynn, 1976). Slower growing but more aggressive 'massive' coral species with dome-shaped morphologies are also present, including *Porites lobata* Dana, *Pavona clavus* Dana and *Pavona gigantea* Verrill (Glynn, 2001). Reefs are not generally well consolidated by crustose coralline algae or underwater cementation, therefore reef frameworks are relatively fragile and develop best in sheltered areas such as bays and the leewards sides of offshore islands (Glynn & Stewart, 1973; Glynn, 2001).

1.3.3 Coral species interaction

Massive species are capable of maintaining space whilst competing with more rapidly growing *Pocillopora* though 'interference competition' (i.e. by extending digestive filaments from their gastrovascular cavities and killing tissues of adjacent competing coral species), thus creating space for their own growth (Nybakken, 2001).

As well as competition between reef building species, corals also experience competition from other reef organisms. The nutrient-rich waters of the TEP not only favour phytoplankton, which can block light utilised by corals, but also benthic filamentous and macroalgae, which compete directly with corals for space and may overgrow them causing mass coral mortality (Glynn, 2001). High calcification rates allow the *Pocillopora* to survive and grow into structures not easily invaded by other benthos, another favourable factor in its dominance of TEP reefs.

1.3.4 Bioerosion

Perhaps the most devastating factor affecting long-term build-up of coral reefs is the process of accelerated bioerosion following coral mortality. About 20 species of molluscs, crustaceans, sea urchins, a sea star and fishes are known to feed on live corals in the TEP (Glynn, 2001). After the 1982-83 El Niño in Panama, the sea urchin *Diadema mexicanum* recruited to the dead *Pocillopora* framework, increasing in mean density from 3 individuals/m^2 to 80 individuals/m^2 (Colgan, 1990). Rates of erosion were calculated at 10-30 g dry weight $CaCO_3$ m^{-2} day^{-1} (Glynn, 1997), and overall carbonate breakdown by other external and internal bioeroders was nearly equal to that of *Diadema*. Total bioerosion ranged from 10 to 20 kg $CaCO_3$ m^{-2} yr^{-1}, exceeding net production rates of 10 kg CaCO3 m-2 yr^{-1} estimated for these reefs before 1983. These figures indicate that many reef formations in the eastern Pacific may disappear should such a rate of erosion be sustained (Glynn, 1997).

At least eight fish species are known to feed on live coral, with strategies ranging from the removal of polyps with little damage to the skeleton [e.g. Butterflyfish (*Chaetodontidae*) and Angelfish (*Pomacentridae*)], to abrading or breaking apart of colonies [Triggerfish (*Balistidae*), Parrotfish (*Scaridae*) and Pufferfish (Tetraodontidae)] (Glynn, 2001). Abrading fish digest the polyps then excrete the skeleton, and are major producers of sand and sediment on reefs (Nybakken, 2001). Examples of bioerosion rates can be seen in Table 1.

Table 1 Rates of Bioerosion by external grazers on Coral reefs of Pacific Panama (Source: modified from Glynn, 1997).

Taxonomic Group	Erosion Rate ($g\ CaCO_3\ m^2\ yr$)	Borer Abundance ($ind.\ m^2$)	Particle size (mm)	Habitat	Locality
Crustacea (hermit crabs)					
Trizopagarus magnificus (Bouvier)	103	27.5	0.12-0.5	Pocilloporid patchreef	Pearl Islands, Panama.
Aniculus elegans Stimpson	8.5	0.02	0.25-3.0		
Echinodernata (sea urchins)					
Diadema mexicanum A. Agassiz	139-277[1] 3,470-10,400[2]	2-4[1] 50-150[2]	0.5-2.0	Lower seaward slope	Gulf of Chiriquí, Panama.
Pisces (Fish)					
Arothron meleagris (Bloch and Schneider)	30	0.004	2-8	Pocilloporid reef	Pearl Islands, Panama.

[1] Normal densities and erosion rates.
[2] After El Niño event 1982-83.

1.3.5 Zonation

Damselfish can effect coral zonation by establishing algal territories from which they exclude grazers and corallivores thus protecting corals and reducing overall bioerosion rates. In the Pearl Islands, Gulf of Panama, the Damselfish *Stegastes acapulcoensis* (Fowler) establishes territories in shallow reef areas, and enhances *Pocillopora* survival through exclusion of grazers and corallivores, whilst biting massive coral species and excluding them from shallow areas. In deeper areas with less topographic complexity, Damselfish numbers drop due to less shelter, and massive species are favoured (Wellington, 1982; Glynn, 2001). In another example from Eakin (1992), vertical erosion rates were reduced by up to 70% at a site on Uva Island, Gulf of Chiriquí, by the presence of Damselfish that excluded *Diadema mexicanum,* whose densities had increased from 3 individuals/m^2 to 50 individuals/m^2 after the El Niño of 1982-83.

1.3.6 Fecundity

Unlike *Pocillopora damicornis* populations found in other parts of the world, TEP populations do not produce planular larvae in reproduction, instead utilising their energy for rapid colony growth and subsequent reproduction via fragmentation (Richmond, 1987). A number of factors have been hypothesised for this adaptation. Biotic factors, such as competition and predation, are less intense in the TEP than in the central and west Pacific, due largely to the absence of the fast growing coral *Acropora spp*., which may overgrow *Pocillopora* elsewhere. Therefore, by showing 'vegetative expansion' as a reproductive strategy *Pocillopora* can monopolise the environment of the TEP (Nybakken, 2001). Heavy larvae predation rates in the TEP also favour colony growth with reproduction via fragmentation. Abiotic factors such as seasonal upwelling and the lack of major physical disturbance such as hurricanes leads to relative stability, and larger *Pocillopora* colonies are found on Panamanian reefs than at other locations where such disturbances occur (e.g. Enetewak Atoll, Marshall Islands, mid-Pacific) (Richmond, 1987). Massive coral mortalities in the TEP are more likely to be caused by El Niño events. This also fits the theory of disturbed environments encouraging the production of propagule, such as at Enetewak Atoll, with stable environments like the TEP favouring clonal growth and reproduction. Temperature fluctuations, as experienced in the TEP, can cause mass mortality of planular larvae, and this may constrain development of planulae and gonads in TEP populations of *Pocillopora damicornis*, thus increasing colony size (Richmond, 1987).

Results from a study by Glynn *et al* (1991) suggested that broadcast spawning (release of eggs and sperm between polyps) found in these corals occurred more frequently in stable environments (i.e. Costa Rica and non-upwelling Gulf of Chiriquí) than in unstable environments (i.e. the Gulf of Panama), where reproduction was confined to warm periods free from upwelling. In agreement with previous studies, no planular larvae were observed to be released from *Pocillopora* corals in Panama, Costa Rica or the Galapagos Islands, and none were found in histological examination of over 700 colonies, suggesting these corals are probably broadcast spawners that produce externally fertilised free-swimming planulae (Glynn *et al*, 1991).

Although larval recruitment has been observed in the TEP, the relatively low rates of such recruitment after the 1982-83 El Niño event suggests recovery of these important frame-building corals may be slow (Glynn *et al*, 1991). This has important implications for the recovery of reefs from other such disturbances, and especially should anthropogenic influences (e.g. sedimentation, runoff, nutrient enrichment) compound natural events.

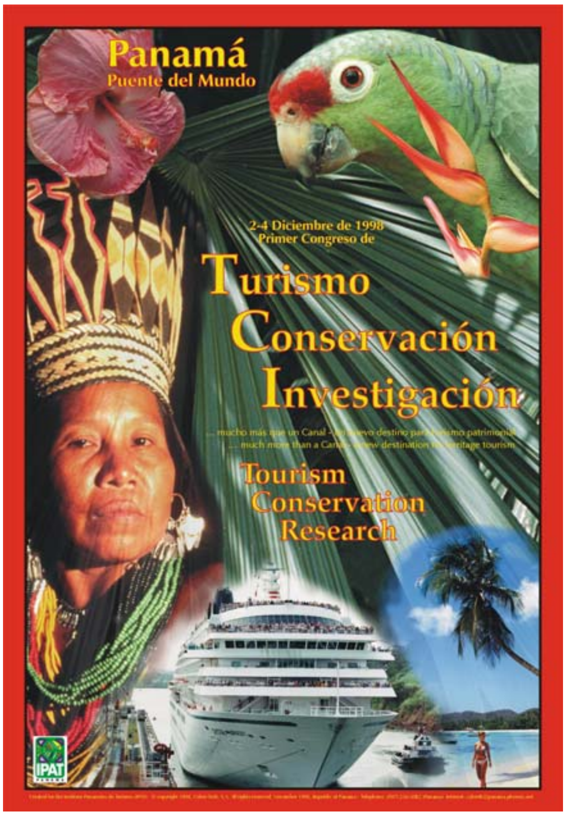
1.4 Management of Marine and Coastal Resources in Panama

1.4.1 Fisheries

Panama landed on average 165,621 tons of living marine resources between 1995 and 1997. It also had the highest per capita consumption of fish in Central America (14.6kg/ person/ year) (Suman, 2002). However, most fish are exported or reduced to fish oil, especially small pelagic species (anchovies and Atlantic herring). Shrimp account for the majority of exports, but the large number of vessels and the improving technology employed overexploits fisheries. Artisanal fishermen, of whom there are estimated to be over 10,000 individuals, account for less than 10% of landings. Primary targets are high value finfish, shellfish, lobster and shrimp for human consumption.

The General Directorate of Marine & Coastal Resources, under the auspices of the Panama Maritime Authority (AMP), regulates fisheries in Panama, and puts particular emphasis on shrimp and small pelagic species, Panama’s most important fisheries. Management regulations employed in the shrimp fishing industry include capped vessel numbers, set mesh sizes, closure of recruitment grounds, and a reduction in fishing effort of 40% for five months a year, in addition to a 70-day closed season. Pelagic fisheries are regulated through vessel hold and engine size restrictions and licensing. However, limited funding means the scientific data required under law on which all fisheries management decisions must be based is insufficient, restricting the measures of control available to the authorities (Suman, 2002). Artisanal fisheries are less tightly regulated, with limits on mesh sizes and net length. Small-scale fisheries benefit by bans placed upon the operation of industrial fisheries in some areas. The dispersed nature of these fisheries means quantitative data are all but impossible to collect and verify.

1.4.2 Tourism in Panama: The TCR approach



"Panama's leisure tourism industry is undeveloped, the nation accustomed to business travellers due to its central banking and insurance role for the region, and leisure travel to Panama being uncommon" (Withiam, 2000).

Figure 1.4 TCR conference poster[4]

The Panamanian Tourism Institute (IPAT) was created in 1960 as an autonomous agency to promote tourism in Panama within the public and private sectors, and to co-ordinate the actions of national institutions that could affect tourism. Panama is currently using a new economic development model developed in recent years that links research and conservation with tourism whilst also providing a source of growth for the

[4] Source: http://www.trail2.com. Accessed May 2003.

Panamanian economy (Ayala, 2000 b). This led to the formation under Executive Decree No 327 on November 30th, 1998, of the TCR Alliance (Tourism-Conservation-Research). The TCR Alliance have adopted the TCR Action Plan for development and implementation of a national strategy for Panama's tourism industry, carried forward under partnership amongst tourism developers, scientific researchers, conservationists, naturalists and local communities (Ayala, 2000 a). The action plan is funded by a variety of sources, including the Panamanian Tourism Institute (IPAT) and the United Nations Development Program (UNDP), and supported by the Panama Environmental Authority (ANAM) (Ayala, 1998).

The Ecotourism model aims to include all sectors of society and help to maintain the natural beauty of an area with development and tourism potential, a real possibility in Panama given that the former Canal Zone has ensured protection of virgin rainforest and other unspoilt features adjacent to urban areas. In 2000, 15 major resorts and hotels had become partners to the TCR model, investing large sums of money in TCR related projects, and contributing funds to the Smithsonian Tropical Research Institute (STRI), who themselves have played a pivotal role in the dissemination of research and discoveries that demonstrate the unique fauna and flora offered by Panama to the Ecotourist (Ayala, 2000 b). STRI have embraced the TCR approach in Panama, Director Ira Rubinhoff recognising the potential benefits offered to all parties from a coalition between scientific research and tourism. It is recognised that scientific interest alone is unlikely to provide sufficient economic incentive to continue the protection of natural areas, thus TCR may allow for more immediate economic gains from an area through tourism, whilst also providing the economic incentive for conservation that science alone may not offer (Rubinhoff, 1998). STRI provides the hotel and tourism industry with access to knowledge and the chance to sponsor future research. STRI have also been heavily involved in the development of 'Heritage Routes' designed in conjunction with the TCR Action Plan (Ayala, 2000 a). Such routes that involve the natural and historical marine heritage of Panama include 'The Pearl Route', 'Route of the 3 Oceans', and 'Route of the Blue Marlin' (Figure 1.5). Each route would be developed to present, protect and enhance the natural heritage whilst contributing to the national economy (Ayala, 2000 a).

1.4.3 Protected Areas

Panama has an extensive system of protected areas with 14 National Parks, one protecting coastal lands and another six that cover coastal lands and waters. The General Environmental Law (No 41, 1st July 1998) created the National Environment Agency (ANAM), concurrent with the formation of the Maritime Agency (AMP). ANAM is the lead institution responsible for national environmental policy, resource planning, enforcement of environmental laws, and administering the Environmental Impact Assessment (EIA) process in Panama (Suman, 2002).

Sectoral management has in the past led to conflicts and wasted resources amongst users and institutions involved in coastal resource management. However, the creation of ANAM under the General Environmental Law has stimulated cross-sector links between sectors, and ANAM now has representatives within all government institutions. The EIA process is administered by ANAM but a lack of qualified personnel, coupled with the strong economic and political momentum (which some projects attract) makes full implementation of the EIA process difficult (Suman, 2002).

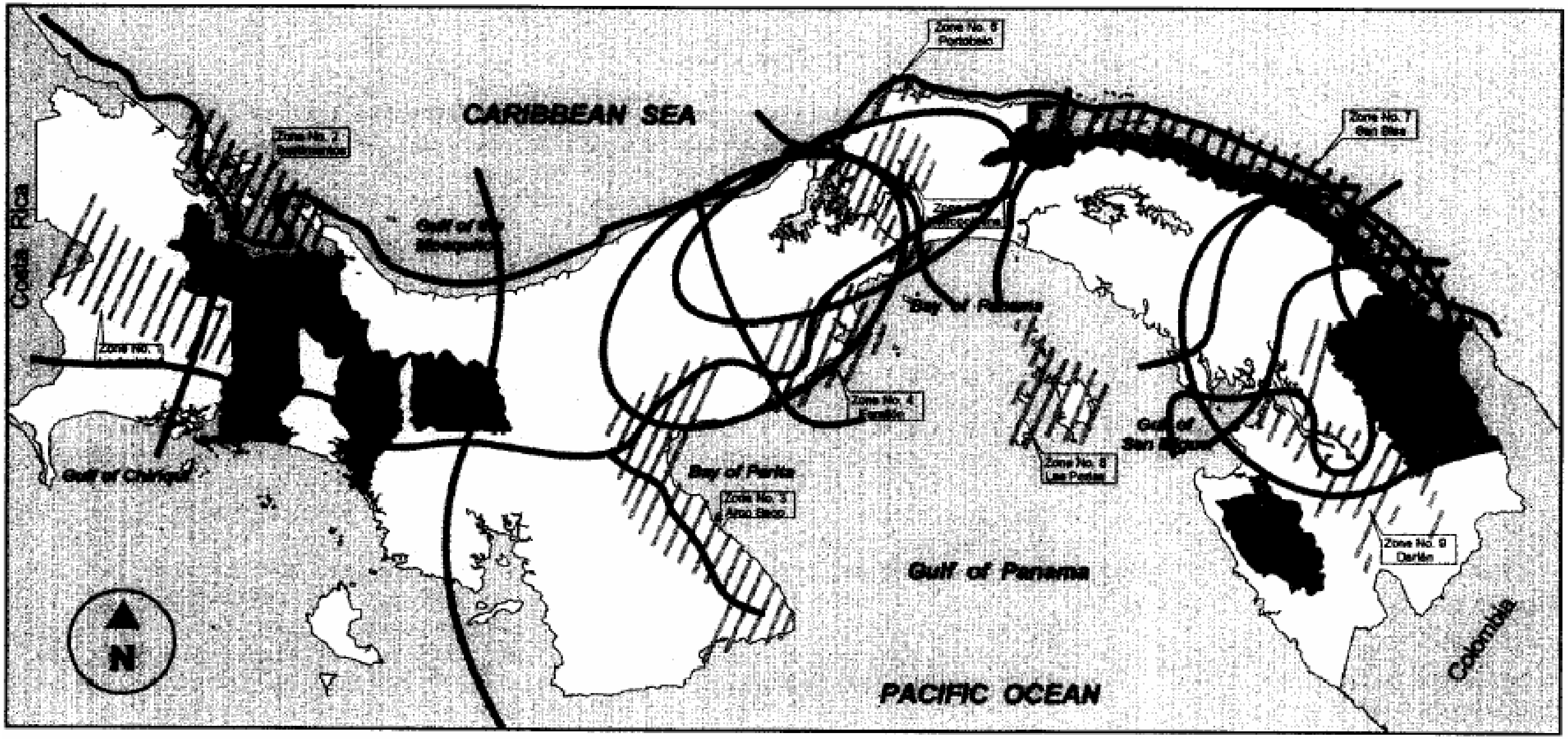


Figure 1.5 Panama's proposed heritage routes (dark lines), tourist areas (hatched) and areas of greatest poverty (solid)

[Source: Ayala, 2000 (a)]

2 Status of Coral Reefs of the World

2.1 Current global status

A recent report has estimated that coral reefs provide nearly US$30 billion in net benefits to the world economy through tourism, fisheries and coastal protection (Cesar *et al*, 2003). The significance of this figure is brought into context by other reports on the health of global coral reef ecosystems. It is estimated that 58% of reefs are at high to moderate risk from human activities (Bryant *et al*, 1998). Up to 27% of worldwide reefs have already been lost, and a further 30% are at risk within the next 30 years based upon current trends (Wilkinson, 2000). This has been exacerbated by human migration to (and over-development of) the coastal zone, leading to unsustainable and over-use of coral reef resources. Unregulated construction and land clearance has resulted in increased sedimentation in coastal waters, sewage and agricultural runoff have contributed to nutrient enrichment, encouraging algal growth and eutrophication, and overfishing and destructive fishing practices have decimated coral reef fish populations and their habitats (Cesar *et al*, 2003). Bleaching of corals is becoming more frequent, 1998 being the worst year on record with 16% of coral reefs effectively destroyed worldwide (Wilkinson, 2002). Tourism and overfishing are detrimental to the coral reef habitat, reducing biodiversity and overall reef health. This in turn has negative effects upon the very activities that utilise and depend upon the coral reef as a resource. Unregulated construction of tourism facilities, along with irresponsible operation of such facilities, threatens not only the coral reefs but also the income they provide to the local population (Cesar *et al*, 2003). Appropriate management measures will be crucial for the long-term maintenance of these ecosystems.

2.2 Natural disturbances to Pacific Panama coral reefs

2.2.1 Low sea surface temperatures

Extremes of temperature restrict offshore reef development in many areas of the TEP, whilst terrestrial runoff greatly restricts reef development on mainland coasts. It has been determined that low SSTs associated with seasonal upwelling are an inhibiting factor in the growth and abundance of corals in the Gulf of Panama (Glynn & Stewart, 1973). Sea water temperatures of 15ºC and 17ºC have been recorded at Saboga Reef, Pearl Islands, in both instances resulting in bleaching and death of *Pocilloporid* corals (Glynn & Maté, 1996). Skeletal growth has been demonstrated to slow markedly in the Pearl Islands during upwelling, with the species *Pocillopora damicornis* showing rates of 0.1–1.0mm mo^{-1} during upwelling and 4.0 – 5.0 mm mo^{-1} after such periods (Glynn & Stewart, 1973). In the Gulf of Chiriquí, where sea surface temperatures are only occasionally as low as 24–25ºC, growth rates can be 3.0–4.0mm mo^{-1} in dry season and 2.0–3.0 mm mo^{-1} in wet season (Glynn & Maté, 1996). Temperature not only influences rate of growth but also the distribution of corals in the Pearl Islands (Glynn & Stewart, 1973).

2.2.2 High sea surface temperatures

High temperature stress caused by elevated SSTs has been implicated in a number of studies investigating the phenomenon of coral bleaching (Glynn, 1990; Glynn & D'Croz, 1990; D'Croz *et al*, 2001; Hueerkamp *et al*, 2001). This is one of the major causal effects on the degradation of coral reefs throughout the TEP region. Bleaching usually results in either the full or partial expulsion of symbiotic zooxanthellate algae and/or their pigments from coral polyp tissues (Hueerkamp *et al*, 2001). If the zooxanthellae are absent for a significant time, the coral will die, leaving behind a white calcium carbonate skeleton devoid of coral polyps (Nybakken, 2001; Douglas, 2003). Particularly strong warming events, such as the 1982-83 El Niño, where temperatures reached mean values of 30-32ºC (i.e. 3-4ºC above normal temperatures) for prolonged periods, not only resulted in coral mortality (Glynn & D'Croz, 1990), but may have begun a cycle of erosion and recolonisation, including the restructuring of coral community composition (Eakin, 1992; Glynn, 1997).

Evidence gathered from studies involving the reef framework-building coral *Pocillopora* spp. suggests high temperatures may have a greater negative effect on corals from the Gulf of Panama than those from the non-upwelling Gulf of Chiriquí. A study by Glynn & D'Croz (1990) suggests this may be due to the lack of upwelling and hence more stable thermal regime experienced by corals from the Gulf of Chiriquí, however reasons for improved survival rates were unknown.

2.2.3 Light availability/emersion/UV radiation

Highly eutrophic systems may also limit coral growth through reduced light penetration caused by abundant plankton, and the promotion of macroalgae and other benthic organisms that may outcompete the corals for space (D'Croz & Robertson, 1997).

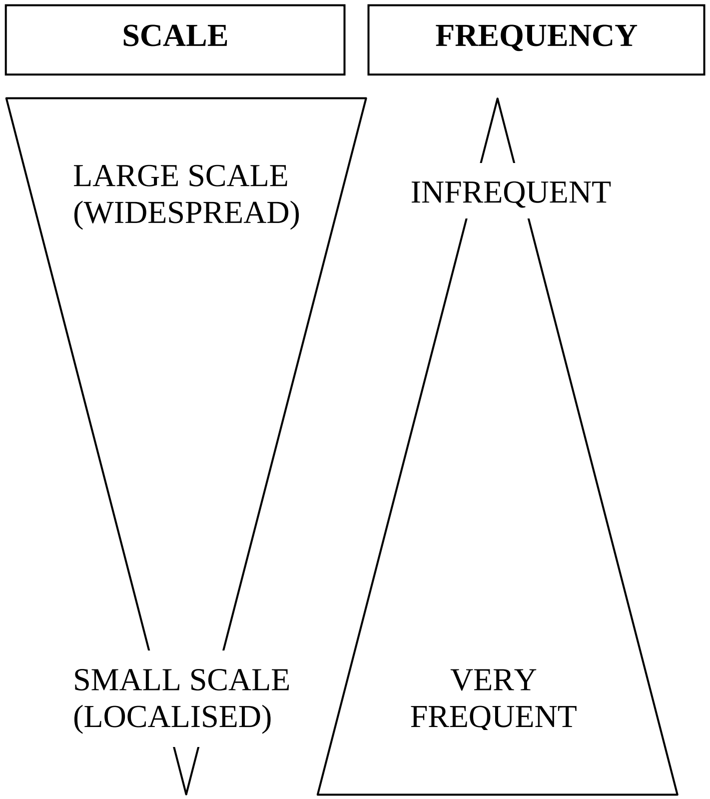
Prolonged emersion events during extreme low tides can devastate the reef flat habitat, which becomes re-established during favourable periods. On mature reefs, the flat is found at around 30cm below Mean Low Water Spring tide level (MLWS). Low tides of

–60 cm or lower (relative to MLWS) usually result in prolonged (approx 2-hours) exposure (Glynn, 1976). During times of clear skies (common during the dry season in Panama), corals on exposed reef flats are subjected to UV-radiation and risk of severe desiccation. Experimental work by Glynn (1976) found that when exposed for 2.5 hours under clear skies over a four-day period under laboratory conditions, 46.2% of *Pocillopora damicornis* colonies were killed. More prolonged exposure but milder atmospheric conditions led to complete mortality, illustrating the devastating effect prolonged emersion can have on certain reef species. Massive species (e.g. *Pavona spp*., *Psammocora spp*.) showed signs of only minor injury. In situ measurements on eight sample areas of the Saboga reef studied colonies of *Pocillopora spp*, showing significant decline in median live cover (39.1%) following extreme low tides in 1975. No massive species were found dead within the study areas.

Reef flats are much less frequently exposed in the Gulf of Panama than in the Gulf of Chiriquí (Wellington, 1982), however mass mortality occurred in January 1974 in both Gulfs after a series of low waters (70 cm below MLWS) during daylight hours. Colonies of *Pocillopora spp*. whitened through loss of tissue within days after the event. After approximately 2–3 weeks algae that had grown on the dead coral skeletons was heavily grazed by fish (Glynn, 1976). This demonstrates that completely natural events are often the primary cause of significant alterations in the structure of coral reefs of the TEP.

Figure 2.1 shows a simplified chart of natural phenomenon that affect the marine environment of the Pearl Islands archipelago, Pacific Panama, whilst Figure 2.2 outlines the major anthropogenic threats to this area.

FIGURE 2.1 NATURAL PHENOMENA AFFECTING THE MARINE ENVIRONMENT OF THE PEARL ISLANDS ARCHIPELAGO.



EL NINO EVENTS (~4-7 YEARS)

SEASONAL UPWELLING REGIME (~1 YEAR)

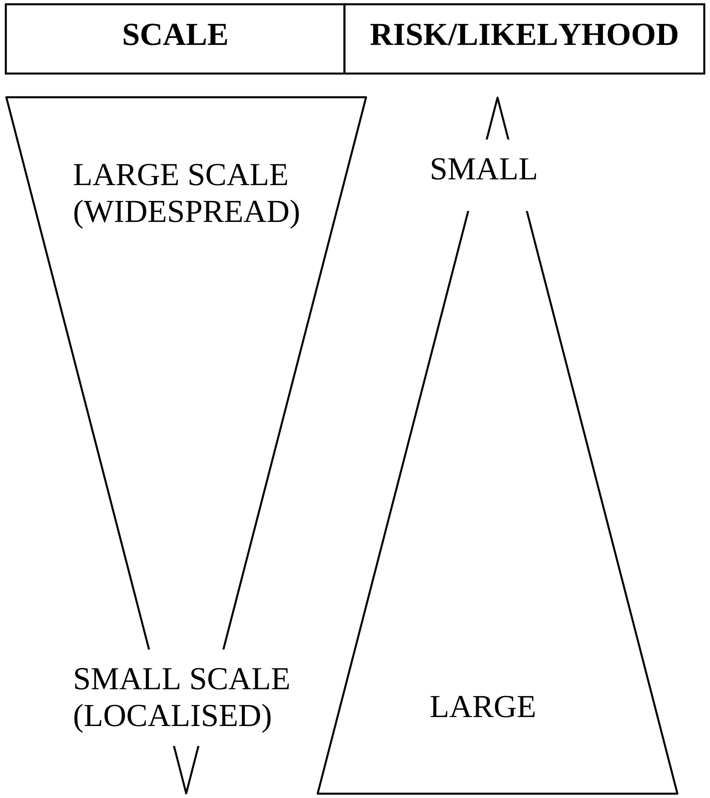
SEDIMENTATION/RUNOFF: (VARIES THROUGHOUT YEAR)

- LOCALISED SMOTHERING
- INTERMITTENT
- SALINITY UNSUITABLE FOR REEF DEVELOPMENT
- (E.G. COASTAL ZONE, RIVER MOUTH, SEASONAL DISCHARGES)

BIOEROSION: (CONTINUOUS CYCLE)

- NATURAL INTERACTIONS BETWEEN REEF CORALS AND BIOTA IN CONSTANT STATE OF FLUX (PREDATION/SPECIES INTERACTION)
- CAN BE INCREASED/EXACERBATED BY ALL ABOVE

FIGURE 2.2 ANTHROPOGENIC THREATS & RISKS TO THE PEARL ISLANDS ARCHIPELAGO.



INDUSTRY: POLLUTION FROM SHIPS, PANAMA CANAL

FISHING:

- MOSTLY ARTISANAL/SMALL-SCALE
- SPORT FISHING OFF CONTINENTAL SHELF
- LARGE PELAGIC SPECIES TARGETED (TUNA)

DEVELOPMENT:

- SEDIMENTATION (SMOTHERING)
- POLLUTION (SEWAGE/NUTRIENT ENRICHMENT)
- RUNOFF INCREASED (REDUCED SALINITY)
- MINING/RESOURCE EXTRACTION

TOURISM:

- BOAT/ANCHOR DAMAGE
- CARELESS SCUBA/SNORKELING
- TRAMPLING OF REEFS
- WASTE GENERATION

2.3 Anthropogenic pressures

Reefs are economically important for food and a strongly developing tourism industry, and face the same range of threats that are damaging reefs world-wide, most significantly sedimentation, untreated sewage, coral and fish exploitation, coastal development and tourism (Pilcher, 2001; Garzón-Ferreira *et al*, 2002).

2.3.1 Development, sedimentation & sewage

Land clearance and agriculture are responsible for increased sediment runoff, especially so in Costa Rica, Ecuador and Colombia, which has resulted in coral reef degradation. It is also likely that highly significant damage is occurring at many other sites, but is simply not known about or reported (Glynn, 2001). A study by Nemeth & Nowlis (2001) determined sedimentation may lead to a decline in live coral cover through contributing to coral stress, leaving corals vulnerable to other factors such as bleaching. Untreated sewage from growing populations may also be responsible for loss of coral cover through an excess input of nutrients leading to algal blooms that outcompete the corals. Water quality and coral condition have been shown to recover quickly after the cessation of sewage input (Henderson, 1992), however useful indicators of sewage stress to coral reefs are still being sought, such as the study by McKenna et al (2001) using *Pocillopora damicornis* fecundity.

2.3.2 Resource exploitation

Coral and fish are extracted and over exploited, in some cases using damaging methods such as dynamite. Overfishing may also be responsible for ecological imbalances on coral reefs, a reduction in the number of fish herbivores and favouring benthic algal growth over coral recruitment (Glynn, 2001). Corals have traditionally been used for construction and landfill by some countries [e.g. The Kuna indians of San Blas archipelago, Caribbean Panama (Guzmán & Guevara, *in press*)]. Harvesting of corals for the tourism curio trade has almost eliminated Pocilloporid corals from many areas (including Taboga Island, Gulf of Panama), even though Panama has developed specific regulations prohibiting the harvesting of hard corals and reef fishes for the aquarium trade (Garzón-Ferreira *et al*, 2002).

The purse-seine net fishery for Yellowfin Tuna *(Thunnus albacares)* still operates in Panamanian waters and, whilst still impacting upon cetaceans and other non-target species, dolphin mortality has been documented as falling from over 133,000 deaths in 1986 to 15,470 in 1992 (Vidal, 1993). This has been mostly accredited to improved release techniques and observer programmes on boats, however the Panamanian Tuna fishery still contributes to the death of thousands of wild dolphins and other cetaceans annually.

2.3.3 Tourism

Tourism is adding to the above pressures, and whilst providing welcome revenue, uncontrolled tourism has led to coral collection, overfishing and damage to corals by boat anchors and inexperienced divers (Halpenny, 2002). Trampling of reefs has been shown to cause high levels of mortality in corals (Rodgers & Cox, 2003), although educational management policies that encourage tourists to be careful have been successfully implemented in other areas (Muthiga & McClanahan, 1997).

Tourism also contributes greatly to increased sedimentation and sewage pollution through increasingly large numbers of visitors and the development of associated facilities. An example of this can currently be observed in Bocas del Toro Province on the Northwest Caribbean coastline of Panama. A rapid expansion in the tourism industry, coupled with a lack of regulated enforcement and an uncoordinated approach (regarding unregulated and unchecked development) has led to an undesirable situation with degradation of coral reefs and the marine environment in the nearby National Park (Suman, 2002). There is still an obvious need for education and awareness to reduce conflicts between users and governments over fisheries and tourism activities within these areas, but MPA status is no guarantee of protection for the area in question.

2.3.4 Ship-based pollution

Whilst not an immediate threat to the Pearl Islands archipelago, the presence of ships waiting to transit the Panama Canal means there is an ever present threat of oil spills in the region, and ballast water on these vessels, which can originate from many different parts of the world, may contain alien organisms that are released into the Gulf of Panama marine environment. These species may establish themselves in their new environment and out compete resident species, changing the whole ecological balance of the Pacific Panama marine environment.

2.4 Current status

From a total marine area of 332,000 km^2, Panama is reported to have coral reefs covering an area of 720 km^2 (Spalding *et al*, 2001). This is in contrast to a figure of 320 km^2 quoted by other sources (Wildevoxhel *et al*, 1999). It is not clear why such a large discrepancy should be present, but varying qualities and scale of data available, and interpretation of total areas may be a reason. It may also be attributable to the continuing discovery of previously unknown reefs in this area, given the difference in time between the reports mentioned. A recent example of this is the discovery that Coiba Island, in the non-upwelling Gulf of Chiriquí, is the location of over 1700 hectares of coral reef, and not 160 hectares as previously estimated[5]. Coiba Island is currently proposed as an MPA, but has not yet become fully designated and is being debated upon by the government. It is likely that if MPA status is not declared there will be development of the tourism industry on this island, something that was impossible until 2002 as the island played host to a penal colony, which restricted previous access.

[5] Source: http://www.stri.org. Accessed June 2003.

2.5 Current monitoring programmes

The Panama Reef Monitoring Network is part of the Marine Environmental Sciences Program run by the Smithsonian Tropical Research Institute (STRI). At present 18 reefs are monitored on both Caribbean and Pacific sides of Panama, with monitoring beginning as early as 1985 at some locations in the Caribbean. In 2000 six sites on the Pacific side were established and added to the program (Figure 2.3). The sites contain areas representing contrasting physical and oceanographic conditions and are all relatively lightly used and far from major centres of population. Percentage cover of Scleractinian (stony) corals and other organisms (e.g. sponges, soft corals, macroalgae, crustose algae) have been recorded through the surveying of reefs using 1m^2 quadrats at varying depths.

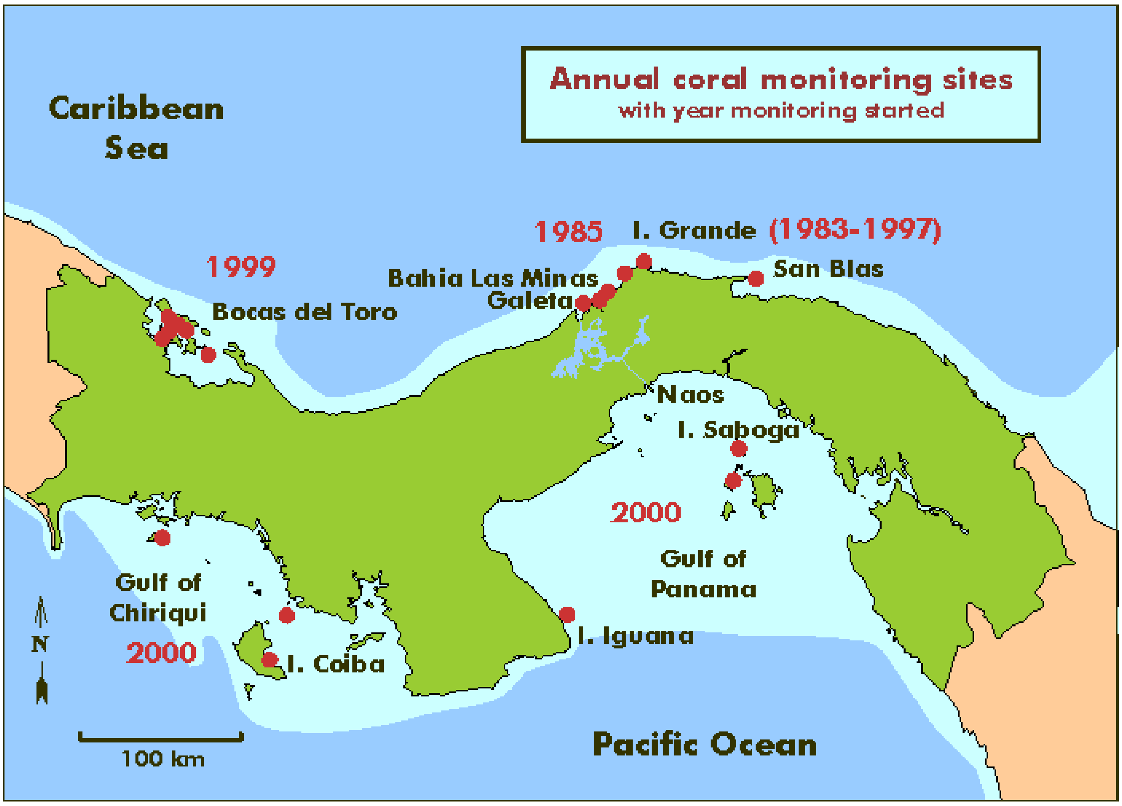


Figure 2.3 STRI coral reef monitoring sites in Panama[6].

[6] Source: www.stri.org/mesp. Accessed May 2003.

2.6 Management options

In Panama 65% of coral reefs are classified as 'reefs at risk' of degradation from human influences. This is in contrast to neighbouring Costa Rica, where 93% of a total of 970 km^2 of reefs are at risk (Spalding *et al*, 2001). As previously mentioned, this can be attributed to greater tourism pressure and development in Costa Rica acting as aggravating factors in the deterioration of reef health and condition. Whereas in Costa Rica recreational diving and unplanned tourism development are the main threats affecting reefs, many reefs in Panama remain inaccessible to recreational divers as yet (Garzón-Ferreira *et al*, 2002). Tourism is considered a priority activity by practically all the Regional Governments of Central America, and is the most important generator of foreign income for Belize and one of the most important for Costa Rica (28.2%) (Wildevoxhel *et al*, 1999). Along with Belize, Honduras and Costa Rica, Panama receives most national and international tourism in coastal areas. It is predicted that MPAs will play an important future role in economic development of these countries. At least 22 existing and 6 proposed MPAs harbouring coral communities and/or coral reefs are now recognised in the TEP region (Glynn, 2001)[see Table 2].

Existing MPAs in Panama have been called 'paper-parks' with ineffectual or non-existent management plans (see Garzón-Ferreira *et al*, 2002). Also, no management practices specifically protect coral reefs, with some reefs included within MPA boundaries, and others with little or no protection (Glynn, 2001), making adequate reef protection extremely piecemeal in approach.

Table 2 Marine Protected Areas of Panama (Existing and Proposed)[7]

Marine Protected Areas - Panama		
MPA Name	**Coral type**	**Anthropogenic Threats**
Parque Nacional de Coiba (P)	Coral reefs (largest known in TEP)	Tourism development[1]; Boat groundings; anchor damage; refuse disposal; shellfish exploitation
Refuge de Vida Silvestre, Isla Iguana (E)	Coral reef	Unknown; (Unexploded Ordnance) ?
Islas de las Perlas (Pearl Islands) (P)	Coral reefs, coral communities	Destructive shellfish exploitation (dynamiting, dredging)
Islas Pacheca and Pachequilla (P)	Coral communities	Unknown
Bahía de los Muertos, Gulf of Chiriquí (P)	Coral reefs	Unknown
Refugio de Vida Silvestre de Isla Caña (E)	Unknown	Unknown
Refugio de Vida Silvestre de Isla Taboga (E)	Coral communities	Anchor damage; refuse disposal

(E) = Existing
(P) = Proposed

[1] Recent proposal for tourism development on Isla Coiba. Previously a Penal colony.

For MPA designation to be effectual, legislation must be supported by appropriate enforcement measures, as restrictions alone are not likely to deter the continuing use and exploitation of marine resources by those forced to do so out of economic necessity (Bryant *et al*, 1998). Also requiring recognition is that MPA status alone cannot safeguard reefs from external influences that may originate outwith the park boundaries (i.e. sedimentation and pollution). As dynamic and open systems, reefs cannot be cut off from these influences and, indeed, are dependent upon this dynamism for the transport of nutrients, larvae and other materials, which are needed to maintain the health of the

[7] Source: data modified from Glynn, 2001.

reef ecosystem. Whilst no internationally binding treaty specifically relates to the protection of coral reefs, there is a range of existing agreements that provide attention to these ecosystems. These include the International Coral Reef Initiative (ICRI), launched in 1995, The Convention on Biological Diversity (1992), and the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), which came into force in 1975. There have also been other programmes and initiatives which provide a framework for governments and non-governmental organisations from many nations to research, monitor, manage and educate people on the values of these vital ecosystems (Bryant *et al*, 1998). The greatest hope for the sustainable use of coral reefs will lie with local communities, since these are the people who benefit most from a healthy coral reef ecosystem, offering a strong incentive for their protection and management (Bryant *et al*, 1998; Wells, 1998).

3 The Pearl Island Archipelago (Islas las Perlas), Pacific Panama

3.1 Description of area

The Pearl Islands archipelago, a group of 53 basaltic rock islands and numerous islets, is located 70 km from Panama City and 31 km from the nearest point on the Panamanian mainland (see Appendix 1 for chart). The islands of the archipelago are varied, the majority unaffected by anthropogenic influences. However increasing tourism development and a historical legacy of misuse have impacted upon the archipelago in a number of ways. The majority of islands are either uninhabited or sparsely populated, and covered in dense tropical rainforest vegetation. The local economy and way of life is supported mainly through small-scale agriculture, artisanal fisheries and, in particular on Isla Contadora and surrounding islands, the tourist industry.

Isla Contadora, in the north of the archipelago, has been the focal point for tourism development and has facilities including an airstrip, electricity generating plant and water supply infrastructure, as well as an excellent paved road network. The island is also home to numerous luxurious private residences. By contrast, Isla San José, found in the southernmost part of the archipelago, has also been used by man, but for a very different purpose (see section 3.3).

The largest aggregations of coral reefs in the Gulf of Panama occur in the Pearl Islands. Coral reefs are developed shoreward of the 6 m isobath, but are more abundant and attain greater dimensions on the north and eastern sides of the islands, where they are sheltered to an extent from upwelling currents (Glynn & Stewart, 1973). For example, calculations by Glynn & Mate (1996) show that a mean of over 61% of all coral reefs occur on northeast shores of islands in the Pearl archipelago. Extensive shelf areas within this range are without reefs due to their location in areas more prone to upwelling currents. The islands are within the 50 m isobath and have a relatively low relief. The waters around the Pearl Islands have been known to produce many world records for game fishing, particularly Black, Blue and Striped Marlin and Pacific Sailfish[8]. Many islands are available on the property market for private sale and ownership[9,10].

3.2 History of archipelago

The archipelago owes its name to the of black-lipped pearl oysters that were once found here in abundance (MacKenzie, 1999). *Pinctada margaritifera mazatlanica* were once common in these waters, and supported a substantial fishery that can be traced back to the 1500's and the era of Vasco Nunez de Balboa, the Spanish conquistador who 'discovered' the Pacific Ocean (Galtsoff, 1950). After visiting a group of islands in the Gulf of Panama he found the waters to be rich in oysters bearing pearls, and named the island group 'Islas de las Perlas', or the Pearl Islands. The island used for counting the pearls before they were shipped to Panama City and then Spain was called Contadora, Spanish for ‘counting house’, and as such the island has retained this name. Many slaves were brought from Africa to dive for the oysters, and the local population of Contadora and surrounding islands are descendants of these slaves (Doggett, 2001). The Pearl Islands fishery was not the only area fished by the Spanish but contributed to other

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[8] http://www.wheretofish.com/panama1.html. Accessed June 2003.
[9] http://www.happywhale.com/panama_las_perlas.html Accessed June 2003.
[10] http://www.vladi-private-islands.de/sales_islands/sites/06_cocos.html Accessed June 2003.

fisheries along the Pacific coast, the pearls being shipped to Spain (Galtsoff, 1950). In the early 1900's the fishery was well developed, but the main products were now the mother-of-pearl shell, exported for making buttons in Europe, and the meat, which was eaten or sold locally. Pearls had nearly disappeared by this time, but uniquely for shellfish fisheries the pearl oyster shell and meat also had value, sometimes considerable (MacKenzie, 1999). After the mid-1920's stocks declined due to overfishing and had nearly disappeared by the 1940's. Today fishing has resumed but on a small scale, and the pearl oysters are only one of a number of exploited species.

3.3 Historical mis-use: Chemical weapons testing on Isla San José, Pearl Islands

The United States chemical warfare program in Panama dates back to the 1930's, when the Pentagon viewed chemical weapons as part of an overall defence strategy for the Panama Canal Zone (CBW, 1999). The Pacific Island campaign of World War II led the US military to source an uninhabited tropical area in which it could conduct tests on the behaviour and effectiveness of chemical agents in tropical climates. An already large US military presence in Panama led to the selection of San José Island, the second largest of the Pearl Island group in the Gulf of Panama. The 'San José Project' began on the 6th of January 1944, with construction of roads, an airstrip and buildings for the operation of experiments and the housing of over 400 enlisted men, 200 officers and civilians (Lindsay-Poland, 1998).

During the project more than 130 tests were conducted on San José Island between May 1944 and the end of 1947 (Stockhardt, 1948 cited in Lindsay-Poland, 1998), composing both aircraft and troop deployed munitions. The island was divided into 11 areas, some used for target practice and others for the testing of chemical agents such as mustard gas, phosgene, cyanogen chloride, hydrogen cyanide and butane (Lindsay-Poland, 1998).

A report produced in July 1998 by the ‘Fellowship of Reconciliation - Task Force on Latin America and the Caribbean’, states that in 18 tests for which records were obtained, 4,397 mortars and bombs were used, mostly on the north side of the island. The report estimates that if other tests averaged the same figure, 31,267 chemical munitions were used during the life of the project. As a rule of thumb amongst explosives disposal professionals (Stauber, 1998 cited by Lindsay-Poland, 1998), an average 10% of all munitions fired would turn out to be ‘duds’ (i.e. would not have detonated on impact). The report concludes that this amounts to over 3,000 potentially unexploded chemical ordnance (UXO) in existence on San José Island. Munitions were also dumped at sea between 1947 and 1948, at a distance of approximately 30 miles from San José (NARA San José Project Files, cited by Lindsay-Poland, 1998).

No formal assessment has been undertaken to determine the actual amount of UXO and possible chemical contamination on the island, however such an operation would be extremely difficult given the amount of ordnance in question and the now dense jungle that covers the island. This may not have posed a problem had the island remained isolated and uninhabited, however there is already a tourism development on the island (The Hacienda del Mar Resort). The Panamanian Tourism Institute (IPAT) has earmarked the Pearl Islands as an area of future potential tourism growth therefore increased human led activity and disturbance on the island is a possibility. This raises questions regarding the future safety and well-being of tourists and other users who visit the island and are unfamiliar with its past and the dangers now posed, especially around the 11 target areas in the north of the island. Given that munitions were dumped at least 30 miles from the island it is unlikely these pose an immediate threat to the inshore shallow marine environment or any people who use it (e.g. tourists, scuba divers), however munitions may be vulnerable to disturbance by activities undertaken in deeper waters such as fishing. More important for inshore and near shore areas may be chemical contamination through leaching and runoff from contaminated testing and storage sites. It is not clear if coastal habitats and environments have been adversely impacted by military activity on San José Island, however this may be a subject that requires attention in the near future, should the island be earmarked for further expansion of tourism and development.

3.4 Status of coral reefs in the Pearl Islands

Analysis of data from the Panama Reef Monitoring Network shows an increase in the percentage of mean live scleractinian coral cover on Saboga reef from 25.6% in 2000 to 28.7% in 2002, an 11% increase in coverage over two years (see Table 3). Algal coverage has fluctuated widely over the same time period, with values from 51% to 62%. Crustose algae have also shown the same pattern of fluctuation as algal coverage, decreasing from 2000-2001, then increasing again from 2001-2002 to near 2000 levels. Dead substrate area almost doubled between 2000-2001 (from 10.8% to 19.6%), whereupon it fell to 6.7% by 2002. The reduction shown by algae and increase in dead substrate in 2001 may be due to increased grazing pressure by reef organisms, or perhaps through a strong upwelling season reducing light penetration in 2001 and limiting the growth of benthic algae. The reduction in dead substrate seen in 2002 corresponds with an increase in algae from 51% to 62% coverage, and may be indicative of more favourable growing conditions for algae and the colonisation of previously bare dead substrate.

Table 3 Panama coral reef monitoring network data for Saboga Reef, Isla Saboga, Pearl Islands archipelago[11].

Year	Taxa	No. of Quadrats	% Mean	St. Dev	St. Error
2000	Algae	60	59.942	24.119	3.114
	Crustose Algae	60	3.717	9.1	1.175
	Dead Substrate	60	10.767	17.728	2.289
	Coral (Scleractinian)	60	25.575	20.416	2.636
2001	Algae	60	51.721	27.972	3.611
	Crustose Algae	60	1.517	3.657	0.472
	Dead Substrate	60	19.592	26.52	3.424
	Coral (Scleractinian)	60	27.171	27.509	3.551
2002	Algae	60	62.061	28.375	3.663
	Crustose Algae	60	2.475	3.681	0.475
	Dead Substrate	60	6.729	16.82	2.171
	Coral (Scleractinian)	60	28.735	28.403	3.667

The data appear to confirm that scleractinian corals are continuing to regenerate slowly each year, showing signs of recovery from the devastating effects experienced during the 1982-83 El Niño event when many reefs in Panama Pacific lost up to 90% of coverage (Glynn, 1990; Glynn & Mate, 1996; Garzón-Ferreira *et al*, 2002). Mortality was 50-100% in the Gulf of Panama, however after the 1997-98 El Niño coral mortality here was minimal, but reached 13% in the Gulf of Chiriqui (Garzón-Ferreira *et al*, 2002). Fluctuations shown by algae and dead substrate are most likely to be the combined result of environmental conditions coupled with grazing and bioerosion by reef organisms.

[11] Source: Dr Hector Guzmán, (STRI), Personal communication (Unpublished data). June 2003.

4 Case Study:

An investigation of Saboga Bay, Isla Saboga, Northern Pearl Islands

For the present study a fieldtrip was undertaken in late May 2003 to allow for the collection of data regarding the shallow subtidal marine environments of the Pearl Island archipelago. It was also deemed a desirable objective to gather and collate information from the local population pertaining to data on topics such as the local economy, fisheries, employment opportunities, and attitudes throughout the local community towards the expansion of the tourism industry.

The collection of physical data regarding subtidal habitats and biota was undertaken in a bay on the eastern side of Saboga Island, one of the most northerly islands of the archipelago and the closest to Contadora Island. Contadora has established itself as a desirable tourism destination through a programme of development started in the 1960's, maps obtained from the Tommy Guardia Institute showing no development on Contadora before this time (see Figure 4.1). Access to the island group was enhanced by the construction of an airstrip, allowing for direct air links with the capital, Panama City. Contadora is by far the most developed of the Pearl Island group, and offers facilities for lodging in the archipelago and easy access to neighbouring islands. Other islands in the group have also seen some development for tourism purposes, but these tend to be exclusive developments aimed at the high end of the market (e.g. Hacienda del Mar Resort, San José Island).

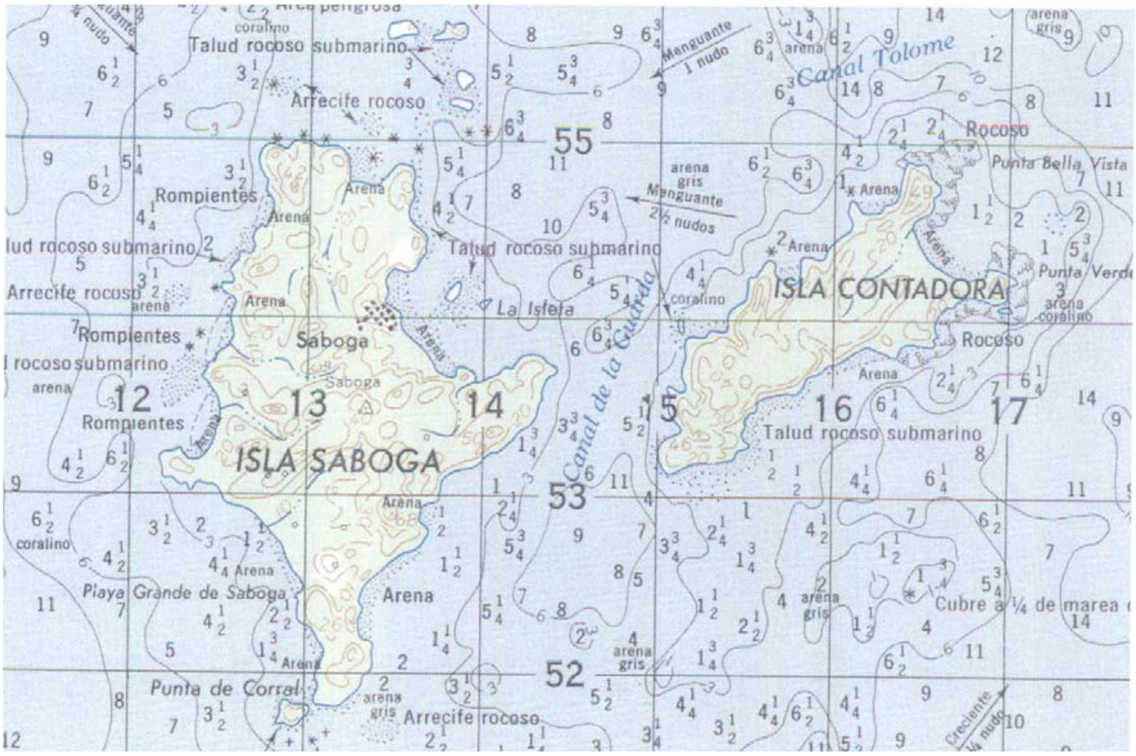

Figure 4.1 Isla Saboga and Isla Contadora, northern Pearl Islands, Pacific Panama[12].

4.1 Description of study site

Saboga Island, the chosen study site, has a maximum elevation of 68 metres above sea level, is drained by ephemeral creeks and covered by a dense bank of semi-deciduous tropical rainforest over the majority of its 2.96 km^2 (Glynn, 1977). A small settlement exists in the northeast of the island, bordering a sheltered bay (see Figures 4.2 & 4.3). Numerous artisanal wooden fishing boats belonging to the local inhabitants are anchored here, and the town has an approximate population of 500 (Resident, pers comm., 2003).

[12] Source: US Army Sheet 4341 – Saboga. 1959.

Figure 4.2 Saboga Town and bay from the air[13].

Figure 4.3 Saboga Town.

[13] Source: All photographs used in Chapter 4 are Authors own, Fieldtrip, 30th May-2nd June 2003.

On the NE shore of the island is located Saboga Reef, the largest coral reef in the Pearl Islands with an area of 14.3 hectares. The reef has an age of approximately 4,500 years with a maximum vertical build-up of 5.6m determined through coring (Glynn & Maté, 1996). The reef is built on a base of tuffaceous sandstone and maximum depth of reef development is at 3-4 m below mean low water. The chief reef-building coral *Pocillopora damicornis* dominates the reef structure, although *Pocillopora elegans* and massive species of *Pavona*, *Porites* and *Gardineroseris* are also present (Glynn & Maté, 1996).

4.2 Objectives of study

Fieldwork undertaken during the present study had two main objectives:

1) To gain a first hand knowledge and understanding of the marine environment in the Pearl Islands archipelago, and to allow for data collection, which could then be used to facilitate the identification of visible features on aerial photographs.
2) To collect information and assess both current pressures and future potential threats (both natural and anthropogenic) to the Pearl Island group.

It was intended that these objectives would allow for the collation of a wide range of data, which could be utilised in any future, larger-scale studies encompassing the entire Pearl Islands archipelago and its marine environments.

4.3 Methodology

4.3.1 In-situ data collection

Subtidal surveys of benthic habitat identification and a visual census of biota were conducted over a two day period in late May 2003. This was at the very beginning of the wet season in Pacific Panama, the ITCZ having moved to a more northerly position over the country, and as such, no upwelling incidents were assumed to be occurring at this time. Surveys were undertaken with snorkelling equipment and followed a simplified variation of the Plotless Belt transect method, as described by Green *et al* (2000). Transect line surveys were conducted following a pre-determined compass bearing from the shore, with depths rarely exceeding 6 m at any one point (in-situ visual estimation by snorkelers).

Transect lines were swum individually, but two parallel transects were swum concurrently at a distance of approximately 20 metres apart, meaning that there was always two snorkelers in the water at any one time. The two snorkelers held as accurate a direction as possible, recording benthic cover and biota through rapid visual assessment techniques over an approximate distance of one metre each side of their position on the surface. This provided a suitably wide field of vision with which to assess coral cover and also biota in the vicinity of the transect line. Data were recorded every 5 metres along the transect line, with distance along the transect estimated by counting number of fin kicks (4) and multiplying these by the average distance travelled per kick cycle (1.25m approximately). This equated to samples being recorded approximately every 5 metres. A more accurate method may have been to use a 10-

metre line and survey in small ‘hops’ (Green *et al*, 2000), however this was deemed impractical and inappropriate given limited time and resources.

The plotless belt transect method was employed as a suitable and straightforward means of gathering data quickly and efficiently, allowing for shallow areas to be surveyed and detailed information to be recorded. It is a fairly simple logistic operation to undertake and can be performed satisfactorily by individuals with basic knowledge and skills. Start points for each transect line were recorded with a hand held Magellan Map 300M Global Positioning System (GPS) receiver with WAAS capability, acquired from Dr Hector Guzmán, Smithsonian Tropical Research Institute (STRI). Co-ordinates were recorded using the Universal Transverse Mercator (UTM) map projection to allow for future input to a Geographical Information System (GIS).

Starting locations for each transect were determined from the shore from which they were to be undertaken. Points were logged with the GPS and a pair of field assistants, each carrying an underwater writing slate and pencil, proceeded to swim their respective transects. A compass worn by the principal snorkeler was used to follow a pre-determined bearing, whilst the second snorkeller gained their direction by swimming parallel to the principal snorkeler. Both logged data regarding benthic habitat and substrates using a classification table that had been premarked on the underwater slates. This allowed for identical recording styles employed by the two snorkelers and the terminology used to identify habitats and biota present, thus allowing the data to be compared at a later date.

Once the snorkelers had swum approximately 150 m from shore, they would swim for

20 m perpendicular to their previous transect line, in opposite directions from each other. Their new position would become the start point for their second transect line, this time on a compass bearing of exactly 180° opposite of the initial bearing (i.e. heading back towards shore). Transect lines were parallel to and approximately 20 m from the previous survey line, so as to minimise the risk of crossing the same area twice (see Figure 4.4).

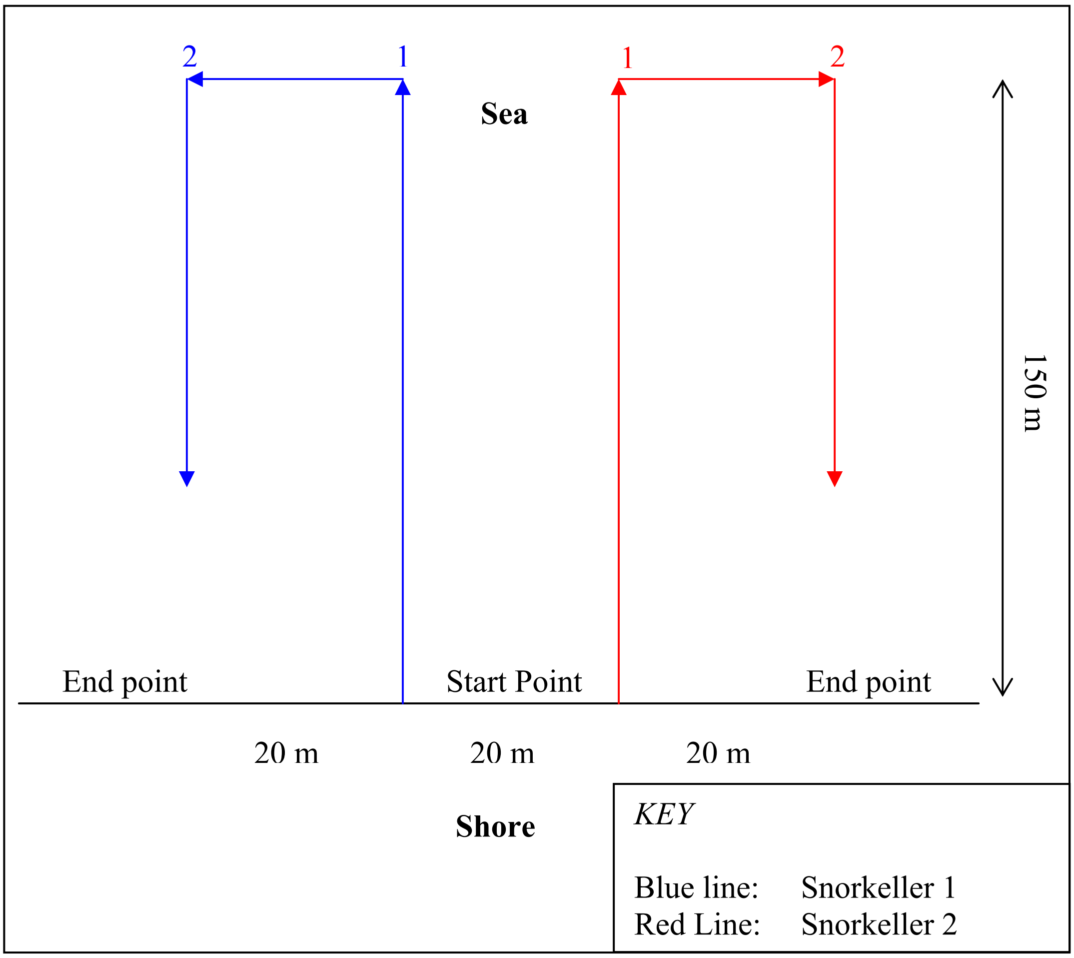

Figure 4.4 Methodology adopted for snorkeling of transect lines.

A total of eight 150 m long transects were completed for this area of Saboga Bay, giving an outline of the benthic habitats present and their current condition. Fish species and other biota were also identified where possible, and the use of an underwater camera allowed for species identification once back in the laboratory. This also allowed for coral condition to be recorded for future analysis. It should be noted that two transects of approximately 600m length were swum on the first day, as it was initially planned to conduct all transects from the main beach. However time constraints proved this to be impractical and therefore the alternative approach was undertaken. Tables outlining results of the transects can be seen in Appendix 2. Pictures and a list of fish species observed during the transect surveys can be viewed in Appendix 3.

During the field visit opportunistic interviews were conducted with locals and fishermen in the hope of obtaining information that may be useful to any future studies in the archipelago. Results are presented in section 4.4.

4.3.2 Image acquisition and processing

Aerial photographs of Saboga Island for the years 1971 (scale 1:12,000) and 1972 (scale 1:20,000) were obtained from the Tommy Guardia National Geographic Institute in Panama City. The 1971 photographs were used for the purposes of this study, given their larger scale and hence greater resolution, plus the fact that there was little if any change apparent in both land and subtidal coverage in the year between the two sets. Topographic maps of the Pearl Islands were also obtained from Tommy Guardia, with a scale of 1:50,000 and a Universal Transverse Mercator (UTM) map projection. Maps covering the Pearl Island archipelago are in Zone 17, the UTM system having 60 zones, each 6 degrees of longitude in width, numbered eastward from the International Dateline[14]. A digital scanned copy of the topographic map was imported into IDRISI32

[14] Source: IDRISI32 GIS Software help menu. July, 2003.

GIS through the conversion of a Bitmap file into a raster layer. It was then necessary to assign a suitable co-ordinate system to the scanned map. This was achieved through the selection of UTM co-ordinates read from Ground Control Points (GCPs) selected on the original map, and the reading of the corresponding X and Y co-ordinates at the same points on the scanned map. The X and Y co-ordinates generated and assigned by IDRISI are different to most co-ordinate systems in that the origin is located at the top-left corner of the image, and not the bottom-left corner. It was therefore necessary to create a 'correspondence file' in IDRISI, which would allow the scanned paper map raster image to be georeferenced to an appropriate co-ordinate reference system using the pre-selected GCPs. Two sets of X and Y co-ordinates were noted for each control point, the first set from the original referencing system (IDRISI co-ordinates), and the second set from the new referencing system (i.e. UTM co-ordinates). The correspondence file could then be used in the REFORMAT>RESAMPLE module which allows a simple equation (first-order polynomial) to transform the original image into a georeferenced form. This provides the scanned map with the correct co-ordinate system, and makes it possible to perform a geometric correction on an aerial photograph of the same area.

The 1:12,000 scale photograph of Saboga Bay was scanned using a Hewlett-Packard Scanjet document feeder linked to a Viglin Pentium 4 'Contender' workstation at Heriot-Watt University. By comparing the photograph with the map, six GCPs were selected and their UTM co-ordinates noted. The appropriate UTM reference system for the locality of the Pearl Islands was created through use of the UTM Reference File generator function in IDRISI, allowing for the correct Datum (North American 1927 (NAD27) - Canal Zone) and spheroid (Clarke 1866) to be applied to the image.

The scanned photograph image was georeferenced with the REFORMAT>RESAMPLE module using a linear equation. It was not necessary to apply a more complex equation to the image due to the relatively small area covered and that such a first-order polynomial equation adequately corrects for rotation, which was the main reason for the transformation. Also, due to the nature and size of the area, and the lack of 'hard' man-made and easily identifiable permanent structures and features, it was not possible to obtain a large number of GCPs, which would have been required had a more complex equation been applied. To achieve the geometric correction the nearest neighbour resample type was used, being the best for photographs due to less distortion and alteration of the original image (Green *et al*, 2000).

The accuracy of the polynomial transformation is assessed by the calculation of the Root Mean Square (RMS) error for each GCP. A high RMS error indicates that a GCP may be unreliable as a result of either choosing an inappropriate GCP, or errors in reading co-ordinates or fixing positions on a map with a cursor. If the errors cannot be corrected, the GCP should be discarded. In the current study it was difficult to maintain accuracy when comparing a 1:50,000 topographic map with a 1:12,000 aerial photograph. Also, as already mentioned, the lack of man-made structures on Saboga Island, coupled with the difficulty in accurately pinpointing them on a small scale map meant that the RMS error for three of the six GCPs were unacceptably high, therefore they were discarded one by one until the calculation showed a RMS of nearly zero. The RMS error is a measure of the goodness of fit of GCPs to the polynomial used; therefore it gives a general indication of the accuracy of the geometric correction (Green *et al*, 2000). As the minimum number of GCPs for a linear calculation is three it was decided that this was an adequate conversion given limited data available and the final use of the imagery. The three eventual GCPs used in the transformation were GCPs 3, 4 and 6 (see Appendix 4).

4.4 Results

Whilst it is not possible to directly compare the results of this study with the findings of the Panama Reef Monitoring Network (Table 3.1) due to differences in data collection techniques, it is valuable to note that the present study estimated mean live scleractinian coral cover on Saboga reef to be approximately 31.3% (see Table 4 below).

Table 4 Results from Transect surveys, Saboga Reef, May 2003.

Year	Taxa	Number of samples	% Mean Cover	St. Dev	St Error
2003	Algae, Crustose Algae, Dead Substrate	367	68.733	26.138	1.364
	Coral (Scleractinian)	367	31.267	26.138	1/364

This represents another slight increase in mean live coral cover and mirrors the trend seen in data from the Panama Reef Monitoring Network surveys. Algae, crustose algae and dead substrate were not classified as separate categories in the present study, therefore no direct comparisons can be made with data from previous years. It will be extremely valuable for any future such studies to obtain monitoring data from STRI for each subsequent year. These data were obtained after the current study had undertaken its fieldwork, therefore it was not known in which format data had been obtained previously. It would be more useful if future studies were to adopt similar techniques to those employed by STRI, should resources allow. However, for the present study it is concluded that the data obtained have proven to be of value in providing an overview of benthic habitat condition and distribution. A quick visual census of reef fish numbers and species was also undertaken concurrently with the benthic habitat survey.

4.5 Summary of social and economic factors in the Pearl Islands

Saboga is estimated to have a current population of around 400-500 people (Resident, pers. comm., 2003). It was suggested that approximately this number again have left the island to seek employment opportunities in Panama City and other locations on the Panamanian mainland. Of the remaining population a high percentage (especially females) work in the resort complexes on Isla Contadora, namely the Hotel Contadora Resort & Casino complex. The results of a survey of local people are shown below.

Fisheries

The main points taken from discussions with local fishermen included:

1) Exploitation of artisanal fisheries is undertaken at a sustainable level (e.g. size limits for oyster, lobster). It was cited that this is in contrast to other such fisheries in Panama, namely that of the Kuna Indians (San Blas Archipelago, Caribbean Panama), where indiscriminate harvesting occurs.
2) Certain species are not targeted (e.g. marine turtles) due to the realisation of value of living specimens through tourism, again in contrast to other fisheries around Panama.
3) Fishermen have diversified into providing a service for tourists (i.e. boat and snorkelling trips).
4) Fisheries are exclusively Panamanian around the islands, with species such as Snapper and Sea Bass targeted.

5) Catches are consumed directly by locals and also sold to tourism developments and resorts. It was not possible to ascertain the exact destinations of catch.
6) It is likely that inshore fisheries target species that are found living in and around *Pocillopora* fringing reefs. This may lead to localised damage to reefs through careless net deployment. There was no indication of so-called 'destructive' fishing practices (e.g. dynamite, cyanide) found by the current study however this does not mean that they have not been utilised in the past (See Table 2).
7) About 75 fishermen harvest Black-lipped pearl oysters on Isla del Rey, 50 on Pedro Gonzalez and 20 on Casaya. They also seek finfish and shrimp as well as oysters, and will sometimes fish for more than one species in any day (MacKenzie, 1999). The oyster fisheries are not deemed to have a significant impact upon the coral reef framework due to the non-destructive collection methods employed by the fishermen (see MacKenzie, 1999).

Figure 4.5 Fishing boats, Saboga Bay, Isla Saboga.

Infrastructure

Although a popular island for tourism, infrastructure on Isla Contadora is inadequate to cope with increasing demands.

Water Supply

1) Water is supplied from a lake adjacent to the airstrip. Water levels were very low during the field visit at the end of the dry season.
2) Frequent gaps in supply were noted during the course of the fieldtrip. It was noted that if the Contadora Resort hotel is using a lot of water, pressure is lost to the rest of the island and airlocks are a frequent occurrence.
3) There is a pumping station on the island but prohibitive costs of running such a facility mean it is rarely used outside of the peak tourist season.

Electricity Supply

1) Isla Contadora and Isla Saboga currently get electricity from a small oil-fired production plant west of the airstrip on Contadora (Figure 4.6).
2) Electricity is expensive due to the need to import fuel for the plant, however it was not possible to obtain exact figures during the fieldtrip.
3) Supply is intermittent, with many power cuts in a system unable to cope with demand. It is likely that the major resort developments have private back-up generators.
4) Isla Saboga is supplied via sub-sea cable between the islands (Figure 4.7). There

is only one small residential settlement on this island.

5) A new larger capacity power plant was being constructed during the field visit. This is located on a headland on Isla Saboga, directly opposite Isla Contadora, and overlooking Saboga Reef (Figures 4.8-4.10).
6) Oil is transported to Isla Contadora by barge from the mainland. It is unloaded through a pipeline on the northern side of the island and transferred to storage tanks. The barge witnessed during the field visit was in extremely bad condition, and a sheen of oil was observed both immediately around the vessel and the adjacent waters and shoreline whilst the cargo was being unloaded (Figure 4.11). It is not clear how often this procedure occurs, but it is likely that it is weekly or fortnightly. It is assumed that unloading occurs on suitable tides. The barge was present for over 5 hours when observed on Saturday 31st May 2003, and a thick sheen of oil was observed in nearby inshore waters.

Tourism

1) The Contadora resort has 354 beds available for rent and is frequently booked to capacity during the peak tourist season, which runs concurrent with the dry season of mid-December to mid-April.
2) This resort remains the largest employer, certainly in the most northerly islands, and possibly the whole archipelago, therefore the local economy has become dependent upon it. Other major resorts include the Hotel Punta Galleon, and the Villas of Contadora, a complex of luxury detached villas owned by the exclusive US magazine International Living[15].

[15] Source: http://www.internationalliving.com/contadora/

3) An increase in tourism levels is likely given the Pearl Islands are currently the location of ‘Survivor’, the American reality television show. Exposure to large television audiences in the US may encourage a ‘boom’ in local tourism.
4) No plans for future tourism development could be found for other islands in the north of the archipelago, however construction work was underway on a number of projects on Isla Contadora. Proposals are also at an advance stage for a large development on Isla del Rey, the archipelago’s largest island[16].
5) Waste from the tourism industry appears to be disposed of in a remote part of northern Isla Contadora. It is not clear whether recycling is encouraged, but it is thought unlikely (Figures 4.12 & 4.13).
6) Snorkelling and skin diving on the fringing reefs of Contadora appears to be a particularly popular pastime for tourists, given their accessibility and location in areas often sheltered from strong currents.
7) A glass-bottomed boat currently in operation around Isla Contadora perhaps offers the most desirable option for allowing tourists to observe the reefs.
8) Increasing boat numbers, especially those of private yachts may lead to damage through carelessly deployed anchors and localised pollution from bilge pumps and sewage.

[16] Source: http://www.desarrollobahia.com/resort.htm. Accessed July 2003.

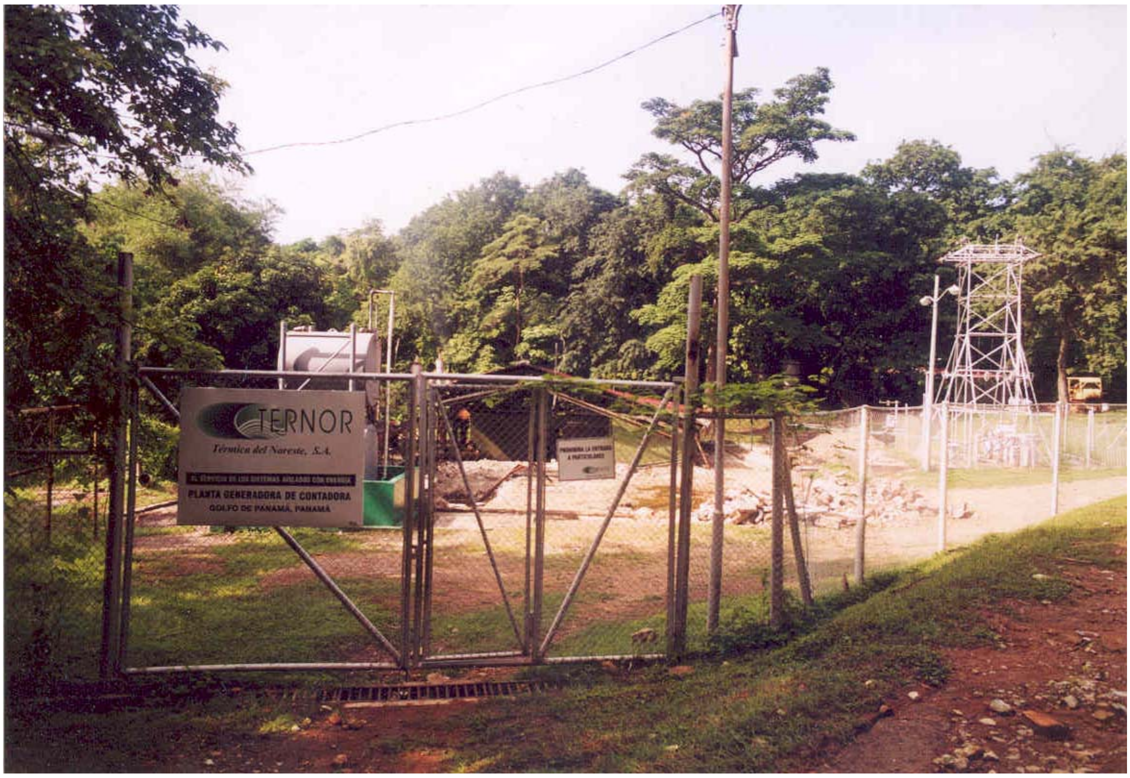

Figure 4.6 Electricity plant, Isla Contadora.


Figure 4.7 Subsea electricity cable from Isla Contadora to Isla Saboga (pictured).

Figure 4.8 Aerial view of new electricity plant construction site, Isla Saboga.

Figure 4.9 View of construction site from the sea, Isla Saboga.

Figure 4.10 Erosion and sedimentation from construction site, Isla Saboga.

Figure 4.11 Barge used to transport oil to the Pearl Islands archipelago. Isla Contadora.

Figure 4.12 Rubbish dump, Isla Contadora.

Figure 4.13 Rubbish dump, Isla Contadora

4.6 Discussion and recommendations

4.6.1 Overview

Tourism will continue to expand in the Pearl Islands, especially in the more accessible islands such as Saboga. This will increase the pressure on surrounding coral reefs through SCUBA-diver inflicted damage and associated increases in boat numbers and as such anchor damage and waste generation. More remote islands will also be visited, spreading the effects wider throughout the archipelago. Whilst this may relieve the pressure on some of the more commonly visited and accessible reefs, it may also be to the detriment of reefs previously unaffected by anthropogenic influences. Inexperience amongst tourists may lead to trampling on some of the shallower areas of these reefs at low tide, and ignorance may lead to the collection of souvenirs, both activities that can damage reefs greatly (Spalding et al, 2001; Wilkinson et al, 2000, 2002; Halpenny, 2002; Cesar et al, 2003).

4.6.2 Improvements to methodology

Unfortunately, due to errors encountered in the georeferencing process it was not possible to correlate the image with the GPS readings obtained in the field. Inaccuracies in using a base map of 1:50,000 scale meant that it proved difficult to accurately identify features to be used as GCPs and the resulting resampled image became inaccurate. GPS readings were not obtained in the field for hard objects such as corners of buildings. Had this been done a more satisfactory and accurate georeferencing exercise could have been undertaken. Therefore with regard to any future studies in the area, where base maps used are likely to be of the same scale and historical age, it is recommended that a number of GCPs are identified from imagery of the study area, and previous to the in-situ survey, which can then be subsequently identified in the field and their co-ordinates taken with a high-accuracy handheld GPS.

Deeper water habitats (i.e. those greater than 6 m depth on a 1.9+ m low tide) were deemed to be outwith the scope of the present study and were thus were not investigated, due to the increasing logistical complexity involved in the accurate survey of habitats at depth. This would have required the use of SCUBA equipment, which may be available to future studies in this area. Qualified marine biologist personnel would have allowed for a more detailed and thorough approach in the identification and assessment of benthic habitats, especially in the quantification of percentage coral living/dead, and also positive identification of fish species and other biota.

A more comprehensive approach to the undertaking of a full ‘ground-truthing’ exercise may involve the use of a vessel or small boat for the entire duration of the fieldwork. This could be utilised in the surveying of points from across the whole area, through quicker access to specific points of interest in the bay and over a larger study area. The vessel could be used as a floating platform from which to perform surveys and to pinpoint the geographical position of each survey point with handheld GPS. Pre-determined points of interest could be identified from aerial photographs and located accurately with the GPS to identify co-ordinates. Detailed survey of habitat types at each point, coupled with photographic evidence, would allow for a more full ground truthing exercise to take place, and allow for a detailed habitat map to be developed for the study area. This may then be extrapolated to aid in the identification of other such sites in the Pearl Islands, possibly through classification of satellite imagery. Unfortunately time restrictions, availability of suitable craft and financial limitations made this preferred method/technique unavailable to the present study. However this may be a more appropriate method for any future studies conducted in the area where available resources are not as limiting a factor. The transect data collected have concentrated on Saboga reef to facilitate in the identification of changes since the aerial photograph imagery was obtained (1971), and to establish the condition of the reef at present, given that construction work is now being undertaken on the peninsula adjacent to the reef. Unfortunately due to the limited timescale available it was not possible to obtain more recent aerial photographs for the study area, which would have allowed for a direct comparison over 30 years of possible and likely change to both benthic and terrestrial habitats. It was intended to use GIS to analyse a 'time series' of change for the study area, allowing for calculation of areas and their subsequent change in their spatial dimensions. It is not clear whether the Tommy Guardia Institute had such imagery in its collection. Any future studies are recommended to source imagery from private sources.

5 Data acquisition, GIS development and MPA site selection.

5.1 Data acquisition

In contrast to many land-based studies, datasets for the marine environment tend to have been created by a wide variety of organisations with varying goals, thus data can be disparate in its areal coverage, level of detail and relevance to the present situation (Wright *et al*, 1998). It will be necessary for any future studies of the Pearl Islands archipelago to establish the existence and availability of datasets relevant to the marine and coastal environments of the study area.

5.1.1 Types of data

Data can be obtained through two main routes:

1) Primary (direct capture) data, and;
2) Secondary (derived) data (Bartlett, 2001).

In the case of primary data, a field visit to the area of interest can provide a description of the attributes of interest, and also the relationships between them through direct field survey and measurement. Satellite or airborne imagery, ship-board instruments (sonar) or automatic data loggers may also be employed, however these techniques are often expensive, time-consuming, require specialist equipment or personnel, or may not be logistically feasible.

Secondary data may include published or archive materials (e.g. maps, charts, aerial photographs, satellite imagery and other observations). Whilst these data are often cheaper and more accessible than primary data, there are some weaknesses involved. Unless accompanied with good documentation and metadata, there will be a degree of uncertainty in the reliability and accuracy of the data, rendering the user vulnerable to the propagation of errors through their own work (see Table 5).

5.1.2 Questionnaire survey

A possible solution to quickly gauge the amount of existing data available to any future studies would be to distribute a short questionnaire survey to relevant organisations and agencies involved in the collation of such data for Panama. This would provide an inventory of data type and availability and could provide a great deal of useful information, and also help to avoid duplication of effort on the part of the researchers. A suggested format for a sample questionnaire is shown in Appendix 5. This could also form the basis for a Data Quality Report for data compiled as a result of new research, and should accompany all new datasets to outline exactly how such datasets were compiled. An organisation that may be useful to contact are PROCIG (Projecto Centro Americano de Información, www.procig.org), who appear to be attempting to coordinate the gathering, sharing and dissemination of data in Central American countries. Contacts listed for Panama include the Tommy Guardia National Geographic Institute (www.mop.gob.pa/igntg), The Environment Agency ANAM (www.anam.gob.pa) and SENACYT (Secretaria Nacional de Ciencia y Tecnología, www.senacyt.gob.pa).

Table 5 Sources of error in data[17].

Error	Potential problem
Obvious	
Error	**Potential problem**
Age of data	• May be too old to be relevant; • Past collection standards unknown, non-existent or currently unacceptable; • Much may have changed since data collected (e.g. erosion, deposition etc).
Areal cover	• Uniform coverage may not be available; • For certain data types, atmospheric conditions can be a problem (e.g. remotely sensed imagery and cloud cover).
Source map scale	• Restricts type, quantity and quality of data; • Need to match appropriate scale to level of detail required by project.
Density of observations	• Many observations required for resolution allowing spatial analysis and determination of patterns.
Relevance	• Using other features to measure feature of interest (e.g. type of habitat present to predict species present). Does not allow for accurate measurement of feature of interest.
False readings	• E.g. Satellite imagery can give false positive and negative readings for certain features.
Format	• Errors through scale/projection conversions; • Change from raster → vector data can change pixel resolution.
Cost	• Extensive and reliable data expensive to obtain or convert.
Natural variations and Original measurements	
Error	**Potential problem**
Positional accuracy	• Lack of sharp delineation in natural world; • Faulty/biased fieldwork, digitising errors, scanning errors; • False accuracy i.e. reading locational information from datasets to levels of accuracy beyond which they were created (e.g. zooming function on maps).
Content accuracy	• Qualitative accuracy errors (e.g. incorrect labeling of features); • Quantitative accuracy errors (e.g. faulty instrumentation/calibration) • Mistakes made in the field may be undetectable in GIS unless user has corroborating information available; • Information on how observations made and instrumentation used valuable in assessing content accuracy.
Attribute accuracy	• Inaccuracies due to data collection, or misunderstandings of definitions. • Need to establish required level of precision required for information about attribute.
Variation in data	• Measurement error, faulty equipment, observation or bias; • May also be natural variation (e.g. seasonal salinity fluctuations).
Processing errors	• Can occur at any time of data manipulation (e.g computing original measurements, digitising and georeferencing, overlaying, rasterisation of a vector map).
Compounding error	
Propagation	• One error leads to another (i.e. if registration point mis-digitised in one layer, all subsequent layers which use this layer to register will propagate the first error). • Solution: Use the largest scale map to register points.
Cascading error	• Erroneous, imprecise and inaccurate information can skew a GIS when combined selectively into new layers and coverages; • Can have effects which are difficult to predict; • May be additive or multiplative, varies from individual situations; • Need to calibrate GIS to data of known accuracy.

[17] Source: data modified from Meyer *et al*, 2001.

5.2 Development of a conceptual model for GIS

Before a GIS database can be constructed, it is necessary to establish a conceptual model in order to represent the features of the real world of interest to the study. The four phases involved in the design of a GIS are:

1) External design;
2) Conceptual design;
3) Logical design; and
4) Internal design (Source: Li, 2001).

Only the first two stages will be dealt with in the present study.

External design involves a simplification of the real world according to the requirements of the project, resulting in a list describing the spatial and attribute data to be included. In the next stage, Conceptual design, a model for organising the data is constructed, with spatial objects defined as entities and attributes associated with these entities, the result being termed an ‘Entity-Relation’ (ER) Model (Li, 2001). Both external and conceptual design models for the development of a GIS for the Pearl Island archipelago can be seen in Appendix 6.

5.3 Site selection process

The process of MPA site selection requires four essential steps: collection, analysis and synthesis of data leading to the identification of candidate sites, followed by the application of criteria to select specific sites for protection (Salm & Rice, 1995). The likelihood of incomplete data requires for field studies to provide information, which can then be analysed to identify areas of resource concentration, human activities, and threats. A GIS allows for the displaying of such data as ‘layers’, which can be combined to produce composite images showing where anthropogenic influences and threats may be greatest to the resources or habitats of protection interest. Layers may also be ‘graded’ during data synthesis to display the level of threat produced when one or more layers overlap in a specific area. This technique can be used to identify candidate sites where protection may be a priority. Spatial relationships between resources and activities may also be defined through this process and conflicting uses mitigated through effective management policy. Whilst it is a desirable objective for any MPA to preserve and conserve pristine conditions, areas that may have potential for restoration projects should not be dismissed, such as those near to development or located within areas of significant human activity. In the case of the Pearl Islands archipelago this could refer to areas where coral reefs are showing signs of recovery after the severe El Niño events of the past few decades (e.g. Saboga Reef, see Tables 3 & 4, this report).

The application of selection criteria such as economic, social, ecological and regional factors ensure objectivity in the site selection process, and will vary depending on the goals of the MPA. Such criteria give priority to certain sites through the use of a scoring or ranking system, with scores summed for each site and compared and priority sites identified on the basis of the highest scores. The feasibility of such a designation may be decided by a further criterion, the ‘pragmatic approach’. This is essentially a function of the urgency of designation imposed by threats that prompt action, ending in site protection. The MPA must take into consideration the size required to allow for ecological connectivity and the scale of environmental stressors, both anthropogenic and natural, otherwise influences outwith the MPA boundary may lead to its possible degradation and destruction (Salm & Rice, 1995). It will be important that the MPA exercises sufficient control over land-based activities as well as marine issues, given the inextricable link between the two.

Issues such as seasonality may influence site selection processes. The Gulf of Panama experiences large fluctuations in temperature, salinity and light penetration during upwelling episodes, which influences the marine life in the Pearl Island archipelago. The strength, duration and location of this type of episode could be identified and utilised in the site selection process through a better understanding of the oceanographic processes that govern the marine life of this location. Population dynamics of corals or fish species of the TEP region could be incorporated into the GIS to provide information on species spawning, optimum living conditions, migration routes and habits, and their links with the upwelling regime. This improved understanding between the oceanographic and ecological factors may help facilitate in the site selection process (Valavanis, 2002). Any MPA will need to take into account the degree to which coral reefs are open or closed to exogenous factors (e.g. larval immigration/recruitment rates, sediment input rates) to be able to determine whether a reef will be able to recover from any activities or pressures which have impacted adversely upon it.

6 Discussion & Recommendations

6.1 Using GIS for the assimilation of data: Pearl Islands Archipelago, Panama

Maps of the Pearl Island archipelago available from the Tommy Guardia National Geographic Institute were limited to those produced by the US Army in the 1950's. The scale of 1:50,000, whilst not detailed, are sufficient to give outlines and topography of the island group. Age of the maps is a concern, mostly for Contadora, where there has been an almost complete development of the island since this time. These maps contain general bathymetric readings, but accuracy of data is questionable given the age of the maps. It is presumed that more up-to-date charts (such as Chart No 1401: Southern Approaches to the Panama Canal 30,000, 13/03/2003) may include the Pearl Islands archipelago and be available from agencies such as the United Kingdom Hydrographic Office (UKHO).

Aerial photographs of the Pearl Islands were also obtained from the Tommy Guardia National Geographic Institute, however coverage is restricted to settlements, precluding their usefulness regarding the whole of the archipelago, which is mostly uninhabited. These images are from the 1970's, thus are missing most development such as on Isla Contadora. Also, there will almost certainly have also been changes to land cover and sub-tidal habitats since this time. Should more recent images be obtained it will be possible to construct a 'time-series' of change for the archipelago, both of land use/cover and of sub tidal environments. Recent (August 2000) Landsat 7 ETM+ imagery of the archipelago has been obtained by STRI. This was in a period free from upwelling and cloud cover, thus sub-tidal habitats and features were identifiable from the image due to increased visibility at this time. However large differences in spatial resolution meant it was not possible to compare these two formats of imagery directly. This imagery will be most useful in determining sub-tidal features of interest throughout the archipelago, which can then be investigated more thoroughly through broad scale ground truthing and survey in any future studies. Higher resolution data, such as SPOT may also be purchased to provide more accurate data to facilitate future management decisions.

Data required for input to a GIS are unlikely to exist for this area, or if it does, may not be freely available. A legacy of sectoral management in the marine and coastal areas, coupled with inter-agency suspicion suggests it may prove extremely difficult for a third party to gain access to said data. Agencies may be reluctant to supply data they have collated even though it could be viewed as 'public property' (i.e. work funded by tax payers). This can be an issue where government funded agencies refuse access to data, even if the inquiring project does not stand to use the information for financial gain or other non-commercial purposes.

The collection of new data should specifically ensure that the format and mode of obtaining and recording be compatible with input to a GIS. This will allow for the spatial interrogation of new datasets with already existing data that may have been entered into a GIS, such as remotely sensed data (e.g. Landsat imagery or aerial photographs). One advantage of collecting new data is the control that the project manager can put over the quality and accuracy of the data obtained. This reduces the chance of inheriting errors from data collected by a third party where quality control may not have been strictly adhered to and not such a crucial factor, depending on the original purpose of the data collection.

6.2 Information and data beneficial to future projects

6.2.1 Tourism & development

IPAT maintains a National Register of Tourism (Registro Nacional de Turismo), on which all tourism developments are listed and categorised, providing IPAT with a means of controlling development and a coordinated, central database for information and management purposes. It is possible that a list of all proposed developments exists also, however the current study was unable to obtain this document. IPAT provided a list of all currently existing tourism accommodation for the whole of Panama, suggesting that if a 'proposed development register' exists, it would be obtainable for future studies in Panama and in particular in the Pearl Islands.

It would be extremely useful to obtain a copy of the Sectoral Plan for Tourism Development in Panama (IPAT: "Plan maestro de desarollo turistico de Panama; 1993 – 2002"), which has recently expired. The document described the attributes, limitations and needs for nine tourism zones, including the Pearl Islands. There may be an updated development plan based upon previous progress and newly identified future needs. This would also then highlight a range of issues, including potential areas of conflict between development for the tourism industry and impacts upon the natural environment.

In 1995, IPAT established regulations ('Environmental Standards') to maintain environmental protection for tourism projects in coastal areas should they be outwith the legislative control offered by a National Park designation (Suman, 2002). Unfortunately the present study was unable to obtain a copy of these standards from IPAT, however it is recommended that future studies obtain a copy of these regulations given that as yet the Pearl Islands are relatively unprotected by government laws, and possess sensitive and valuable natural habitats such as coral reefs and mangroves.

6.2.2 Resource extraction – fishing/mining

Government agencies such as ANAM hold inventories of marine and coastal resources and figures on fisheries and resource extraction rates (i.e. sand mining). Suman (2002) quotes a number of figures involving many sectors involved in the use, management and exploitation of Panama's marine resources. Unlike in the San Blas archipelago in the Caribbean, where the indigenous Kuna Indians mine coral for building (Garzón-Ferreira *et al*, 2002), it is prohibited to mine coral elsewhere in Panama (except for fossil coral) and as such no mining of coral occurs in the Pearl Islands. However there does appear to be a mining concession in operation, possibly for subtidal sand. The General Directorate of Mineral Resources (DGRM) of the Ministry of Commerce and Industry (MICI) regulates the mining industry and grants permits and concessions; therefore it may be pertinent for future studies to consult with DGRM. This would ascertain the level of mining operations should they still be occurring, their location in the archipelago, and the substance being mined.

6.2.3 Language difficulties

It is possible that data pertaining to the Pearl Islands archipelago is in existence, and held by the various government and non-governmental organizations within Panama. Future studies will have to take difficulties of communication into account, and it will be of utmost importance that fluent Spanish speakers are able to liaise with said agencies to glean this information, and its availability. It may also be pertinent to involve agencies such as ANAM in the process of MPA site selection and designation, given the impacts and effects such a decision may have not just on the preservation and hopeful recovery of the marine ecosystems of the Pearl Islands, but also on the local community who depend upon the areas for survival. Indeed the designation of an MPA in this area may eventually be more of a benefit to economic activities such as fisheries and tourism, rather than solely as a measure to protect coral reefs and biota, given the frequent occurrence of strong El Niño events and their associated stresses and impacts on the marine environment of Pacific Panama (see Chapters 1 & 2, this report).

7 Conclusion

This scoping study was not able to obtain any established data sets for the Pearl Islands Archipelago, in either raw or digital format. Communication difficulties hampered efforts to gain data, but it is also likely that data do not exist for this little-studied area of Panama. The long history of sectoral management involving the coastal and marine resources of Panama, coupled with political instability over many years and other issues receiving greater priority (i.e. the Panama Canal), indicate that it should be no surprise that data are often lacking or difficult to obtain.

It will be necessary to evaluate current uses and future potential areas of conflict, focusing on issues such as expansion of the tourism industry in particular as a large potential threat to the marine environment given the problems associated with increased construction, numbers of visitors and the management and disposal of their associated wastes. The islands are already showing unsustainable development trends (e.g. lack of adequate water supply and distribution network). This will lead to adverse effects for not only the local economy but also the local population and the environment, such as has happened in other parts of the world (Gössling, 2001).

The TCR action plan (see Section 1.4.2), initiated in the late 1990's, will play a key role in the successful protection and conservation of Panama's largely unspoilt natural environment. It will be crucial that the principles of the action plan are adhered to, and that financial and economic considerations are not allowed to take precedence over good and sustainable environmental practice. Should this happen, the TCR action plan will appear little more than a 'good idea', and Panama will have lost its opportunity to become a unique role model to the rest of the world in the sustainable development of its tourism industry. Once the natural beauty of a place has been lost, tourists will stop visiting that place and move elsewhere, therefore not only will the natural riches have been lost or destroyed, but the economy which had developed around and depended upon them will also be lost, leading to economic hardship for the local population who had become dependent upon it.

The TEP coral reef ecosystem has developed in relative isolation over a long period of time in a relatively stable environment (Kjerfve *et al*, 2001). Such reef communities lack the ability to adjust to unusual stress and thus can be extremely vulnerable to environmental change. It will be important for their restoration and preservation that damaging influences are removed and access to reefs and their resources controlled or removed. Careful management and planning in the Pearl Islands Archipelago may hope to mitigate against such degradation, and designation of an MPA within the archipelago may go some way to achieving this aim. However, it will be crucial to involve the local population for the outset if any such designation is to be enforced effectively. Panama, and indeed marine conservation, does not need another 'Paper Park'.

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Appendix 1

Appendix 2

Snorkeler # 1 Transect # 1 (White) Date: 31st May 2003

Sample Point	**Bottom Type**	**If Coral in cover**		**Start Point**	
		% Live	**% Dead/sand/rubble**	**Easting**	**Northing**
1	Sand/Sediment	0	100	17714311	953972
2	Sand/Sediment	0	100		
3	Sand/Sediment	0	100	**Time**	
4	Sand/Sediment	0	100	**8.30a.m.**	
5	Sand/Sediment	0	100		
6	Coral	1	99	**Low Tide**	**Height**
7	Sand/Sediment	0	100	**11.03a.m.**	**1.9m +**
8	Coral	1	99		
9	Coral	1	99		
10	Coral	1	99		
11	Coral	35	65		
12	Coral	30	70		
13	Coral	95	5		
14	Coral	99	1		
15	Coral	15	85		
16	Coral	10	90		
17	Coral	10	90		
18	Coral	50	50		
19	Coral	5	95		
20	Coral	20	80		
21	Coral	20	80		
22	Coral	90	10		
23	Coral	95	5		
24	Coral	5	95		
25	Coral	5	95		
26	Coral	5	95		
27	Coral	15	85		

Snorkeler # 1 Transect # 2 (White) Date: 31st May 2003

Sample Point	Bottom Type	If Coral in cover		Start Point	
		% Live	% Dead/sand/rubble	Easting	Northing
1	Algae/Coral	10	90	17714265	953957
2	Coral	40	60		
3	Coral	10	90	**Time**	
4	Coral	10	90	**9.15a.m.**	
5	Coral	1	99		
6	Coral	1	99		
7	Sand/Sediment	0	100		
8	Coral	1	99		
9	Coral	1	99		
10	Coral	1	99		
11	Coral	1	99		
12	Coral	1	99		
13	Coral	1	99		
14	Coral	1	99		
15	Coral	70	30		
16	Coral	80	20		
17	Coral	5	95		
18	Coral	10	90		
19	Coral	20	80		
20	Coral	40	60		
21	Coral	90	10		
22	Coral	95	5		
23	Coral	95	5		
24	Coral	90	10		
25	Coral	90	10		
26	Coral	90	10		
27	Coral	70	30		

Snorkeler # 1 Transect # 3 (White) Date: 31st May 2003

Sample Point	**Bottom Type**	**If Coral in cover**		**Start Point**	
		% Live	**% Dead/sand/rubble**	**Easting**	**Northing**
1	Sand/Algae	0	100	17714204	953921
2	Sand/Algae	0	100		
3	Sand/Algae	0	100	**Time**	
4	Sand/Algae/Coral	5	95	**10.30a.m.**	
5	Sand/Rock/Coral	25	75		
6	Sand/Rock/Coral	50	50		
7	Sand/Rock/Coral	70	30		
8	Sand/Coral	1	99		
9	Sand/Rock/Coral	40	60		
10	Coral	35	65		
11	Coral	15	85		
12	Coral	20	80		
13	Coral	70	30		
14	Coral	60	40		
15	Coral	70	30		
16	Coral	60	40		
17	Coral	50	50		
18	Coral	35	65		
19	Coral	60	40		
20	Coral	80	20		
21	Coral	75	25		
22	Coral	75	25		
23	Coral	60	40		
24	Coral	70	30		
25	Coral	65	35		
26	Coral	60	40		
27	Coral	75	25		

Snorkeler # 1 Transect # 4 (White) Date: 31st May 2003

Sample Point	Bottom Type	If Coral in cover		Start Point	
		% Live	% Dead/sand/rubble	Easting	Northing
1	Sand/Rock	0	100	17714237	953960
2	Sand/Rock	0	100		
3	Sand/Rock	0	100	**Time**	
4	Algae/Coral	1	99	**11.15a.m.**	
5	Algae/Coral	15	85		
6	Sediment/Rock/Coral	1	99		
7	Coral (100% Dead)	0	100		
8	Coral (100% Dead)	0	100		
9	Coral (100% Dead)	0	100		
10	Coral (100% Dead)	0	100		
11	Coral (100% Dead)	0	100		
12	Coral (100% Dead)	0	100		
13	Coral (100% Dead)	0	100		
14	Coral	1	99		
15	Algae/Coral	5	95		
16	Coral	1	99		
17	Coral	1	99		
18	Coral	1	99		
19	Coral	1	99		
20	Coral	10	90		
21	Coral	30	70		
22	Coral	15	85		
23	Coral	20	80		
24	Coral	15	85		
25	Coral	90	10		
26	Coral	95	5		
27	Coral	90	10		

Snorkeler #1 | Transect # 5 (White) | Date: 30th May 2003

Sample Point	**Bottom Type**	**If Coral in cover**		**Start Point**	
		% Live	**% Dead/sand/rubble**	**Easting**	**Northing**
1	Sediment/Sand	0	100	17713909	953892
2	Sediment/Sand	0	100		
3	Sediment/Sand	0	100	**Time**	
4	Sediment/Sand	0	100	**9.00a.m.**	
5	Sediment/Sand	0	100		
6	Sediment/Sand	0	100	**Low Tide**	**Height**
7	Coral	40	60	**11.39a.m.**	**1.9m +**
8	Coral	40	60		
9	Coral	40	60		
10	Coral	60	40		
11	Coral	20	80		
12	Coral	25	75		
13	Coral	20	80		
14	Coral	25	75		
15	Coral	20	80		
16	Coral	20	80		
17	Coral	30	70		
18	Coral	15	85		
19	Coral	15	85		
20	Coral	40	60		
21	Coral	15	85		
22	Coral	15	85		
23	Coral	20	80		
24	Coral	40	60		
25	Coral	35	65		
26	Coral	20	80		
27	Coral	25	75		
28	Coral	15	85		
29	Coral	20	80		
30	Coral	30	70		
31	Coral	35	65		
32	Coral	30	70		
33	Coral	25	75		
34	Coral	30	70		
35	Coral	30	70		
36	Coral	35	65		
37	Coral	30	70		
38	Coral	10	90		
39	Coral	15	85		
40	Coral	20	80		
41	Coral	30	70		
42	Coral	20	80		
43	Coral	30	70		
44	Coral	15	85		
45	Coral	20	80		
46	Coral	10	90		
47	Coral	10	90		
48	Coral	50	50		
49	Coral	35	65		
50	Sediment/Sand	0	100		

Sample Point	Bottom Type	If Coral in cover		Start Point	
		% Live	% Dead/sand/rubble	Easting	Northing
51	Coral	25	75		
52	Coral	30	70		
53	Coral	20	80		
54	Coral	30	70		
55	Coral	35	65		
56	Coral	35	65		
57	Coral	15	85		
58	Coral	25	75		
59	Coral (Massive - 8-10m)	30	70		
60	Coral	25	75		
61	Coral	80	20		
62	Coral	50	50		
63	Coral	80	20		
64	Coral	55	45		
65	Coral (some massive)	75	25		
66	Coral	50	50		
67	Coral	45	55		
68	Sand	55	45		
69	Sand	40	60		
70	Sand / Some coral	25	75		
71	Coral	40	60		
72	Coral	30	70		
73	Coral	50	50		
74	Coral	30	70		
75	Coral	80	20		
76	Coral	60	40		
77	Coral	75	25		
78	Coral	70	30		
79	Coral	80	20		
80	Coral	85	15		

Snorkeler # 2 Transect # 1 (Black) Date: 31st May 2003

Sample Point	**Bottom Type**	**If Coral in cover**		**Start Point**	
		% Live	**% Dead/sand/rubble**	**Easting**	**Northing**
1	Rock	0	100	17714327	953961
2	Coral	30	70		
3	Coral	10	90	**Time**	
4	Coral	15	85	**8.30a.m.**	
5	Coral	50	50		
6	Coral	70	30	**Low Tide**	**Height**
7	Coral	50	50	**11.03a.m.**	**1.9m +**
8	Coral	70	30		
9	Coral	60	40		
10	Coral	50	50		
11	Coral	30	70		
12	Coral (+ 6 massives)	20	80		
13	Coral	0	100		
14	Coral	5	95		
15	Coral (+ 10 massives)	10	90		
16	Coral (+ 5 massives)	5	95		
17	Coral	5	95		
18	Coral (+ 1 massive)	10	90		
19	Coral	15	85		
20	Coral	30	70		
21	Coral	30	70		
22	Coral	60	40		
23	Coral	70	30		
24	Coral	90	10		
25	Coral	100	0		
26	Coral	85	15		
27	Coral	85	15		

Snorkeler # 2 Transect # 2 (Black) Date: 31st May 2003

Sample Point	Bottom Type	If Coral in cover		Start Point	
		% Live	% Dead/sand/rubble	Easting	Northing
1	Rock	0	100	17714360	953959
2	Rock	0	100		
3	Rock	0	100	**Time**	
4	Coral	50	50	**9.15a.m.**	
5	Coral	60	40		
6	Coral	60	40		
7	Coral	60	40		
8	Coral	60	40		
9	Coral	50	50		
10	Coral	40	60		
11	Coral	40	60		
12	Coral	50	50		
13	Coral	60	40		
14	Coral	30	70		
15	Coral	25	75		
16	Coral	20	80		
17	Coral	15	85		
18	Coral (1 massive)	10	90		
19	Coral (1 massive)	10	90		
20	Coral	5	95		
21	Coral	0	100		
22	Coral (1 massive)	0	100		
23	Coral (2 massives)	0	100		
24	Coral (5 massives)	5	95		
25	Coral (2 massives)	5	95		
26	Coral (2 massives)	5	95		
27	Coral	10	90		

Snorkeler # 2 Transect # 3 (Black) Date: 31st May 2003

Sample Point	Bottom Type	If Coral in cover		Start Point	
		% Live	% Dead/sand/rubble	Easting	Northing
1	Rock	0	100	17714185	953922
2	Sand	0	100		
3	Coral	50	50	**Time**	
4	Coral	30	70	**10.30a.m.**	
5	Coral (Electricity cable)	35	65		
6	Coral	70	30		
7	Coral	45	55		
8	Coral	50	50		
9	Coral	35	65		
10	Coral	50	50		
11	Coral	25	75		
12	Coral	40	60		
13	Coral (3 large massive heads)	50	50		
14	Coral (2 massives)	35	65		
15	Coral	60	40		
16	Coral	35	65		
17	Coral	30	70		
18	Coral	50	50		
19	Coral	50	50		
20	Coral	50	50		
21	Coral	40	60		
22	Coral	40	60		
23	Coral	40	60		
24	Coral	50	50		
25	Coral	50	50		
26	Coral	60	40		
27	Coral (1 massive)	20	80		

Snorkeler # 2 Transect # 4 (Black) Date: 31st May 2003

Sample Point	**Bottom Type**	**If Coral in cover**		**Start Point**	
		% Live	**% Dead/sand/rubble**	**Easting**	**Northing**
1	Sand	0	100	17714145	953915
2	Sand	0	100		
3	Coral	40	60	**Time**	
4	Coral	45	55	**11.15a.m.**	
5	Coral	50	50		
6	Coral	35	65		
7	Coral	35	65		
8	Coral (Electricity Cable)	50	50		
9	Coral	40	60		
10	Coral	50	50		
11	Coral	25	75		
12	Coral	30	70		
13	Coral	20	80		
14	Coral	35	65		
15	Coral (5 Massives)	35	65		
16	Coral	40	60		
17	Coral	30	70		
18	Coral	30	70		
19	Coral	40	60		
20	Coral	35	65		
21	Coral	35	65		
22	Coral (1 Massive)	40	60		
23	Coral	30	70		
24	Coral	35	65		
25	Coral	40	60		
26	Coral	50	50		
27	Coral	50	50		

Snorkeler #2 Transect # 5 (Black) Date: 30th May 2003

Sample Point	Bottom Type	If Coral in cover		Start Point	
		% Live	% Dead/sand/rubble	Easting	Northing
1	Sand	0	100	17713896	953906
2	Sand	0	100		
3	Sand	0	100	**Time**	
4	Sand	0	100	**9.00a.m.**	
5	Sand / Dead Coral	0	100		
6	Sand / Dead Coral	0	100	**Low Tide**	**Height**
7	Sand / Coral	50	50	**11.39a.m.**	**1.9m +**
8	Sand / Coral	50	50		
9	Sand / Coral	25	75		
10	Coral	20	80		
11	Coral	20	80		
12	Coral	25	75		
13	Coral	15	85		
14	Coral	40	60		
15	Coral	45	55		
16	Coral (Some encrusting)	30	70		
17	Coral	20	80		
18	Coral	40	60		
19	Coral	30	70		
20	Coral	20	80		
21	Coral	30	70		
22	Coral	30	70		
23	Coral	20	80		
24	Coral	10	90		
25	Coral	20	80		
26	Coral	30	70		
27	Coral	20	80		
28	Coral	10	90		
29	Coral	20	80		
30	Coral	10	90		
31	Coral	30	70		
32	Coral	20	80		
33	Coral	10	90		
34	Coral	30	70		
35	Coral	30	70		
36	Coral	30	70		
37	Coral	20	80		
38	Coral	20	80		
39	Coral	20	80		
40	Coral	30	70		
41	Coral	30	70		
42	Coral	40	60		
43	Coral	40	60		
44	Coral	40	60		
45	Coral	40	60		
46	Coral	30	70		
47	Coral	20	80		
48	Coral	30	70		
49	Coral	40	60		
50	Coral (Massive Coral)	60	40		

Snorkeler #2 Transect # 5 (Black) Date: 30th May 2003

Sample Point	Bottom Type	If Coral in cover		Start Point	
		% Live	% Dead/sand/rubble	Easting	Northing
51	Coral	50	50		
52	Coral	40	60		
53	Coral	20	80		
54	Coral	5	95		
55	Coral	60	40		
56	Coral	70	30		
57	Coral	80	20		
58	Coral	95	5		
59	Coral (Massive - 8-10m)	90	10		
60	Coral	90	10		
61	Coral	5	95		
62	Coral	0	100		
63	Coral	0	100		
64	Coral	20	80		
65	Coral (some massive)	40	60		
66	Coral	50	50		
67	Coral	10	90		
68	Sand	0	100		
69	Sand	0	100		
70	Sand / Some coral	20	80		
71	Coral	30	70		

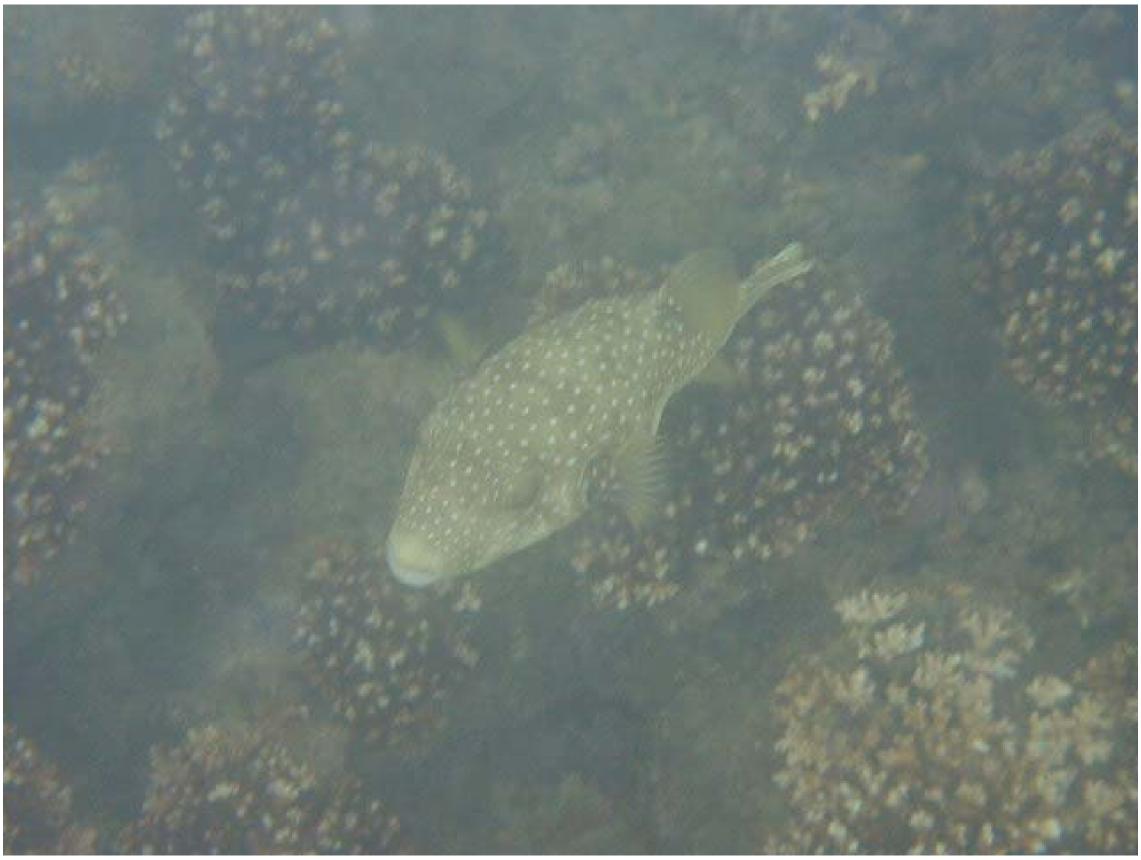
Appendix 3

Table 4.1 List of species observed during transect surveys.

1	Blunthead Triggerfish	*Psuedobalistes nanfragium*
2	King Angelfish	*Holacanthus passer*
3	Spotted Green Puffer	*Arothron hispidus*
4	Panamanian Sergeant Damselfish	*Abudefduf troschelii*
5	Banded Serrano	*Serranus psittacinus*
6	Black Spiny Sea Urchin	*Diadema savignyi*
7	Black-lipped Pearl Oyster	*Pinctada margaritifera*
8	Blue-chin Parrotfish	*Scarus ghobban*
9	Bumphead Parrotfish	*Scarrus perrico*
10	Barberfish	*Johnrandallio nigrirostris*
11	Spotted Scorpionfish	*Scorpaena plumieri mystes*
12	Reef Cornetfish	*Fistularia commersonii*
13	Three-banded Butterflyfish	*Chaetodon humeralis*
14	Freckled Porcupinefish	*Diodon holocanthus*
15	Hawksbill Turtle	*Eretmochelys imbricata*

(I) Blunthead Triggerfish *(Psuedobalistes nanfragium)*.

(II) King Angelfish *(Holacanthus passer)*.



(III) Spotted Green Puffer *(Arothron hispidus)*.

(IV) Panamanian Sergeant Damselfish *(Abudefduf troschelii)* with smaller Banded Serrano *(Serranus psittacinus)*.

(V) Black Spiny Sea Urchin *(Diadema savignyi) grazing on algae.*

(VI) Black-lipped Pearl Oyster (*Pinctada margaritifera).*

(VII) Blue-chin Parrotfish, terminal phase *(Scarus ghobban)*.

(VIII) Bumphead Parrotfish *(Scarrus perrico)*.

(VIIII) Barberfish *(Johnrandallio nigrirostris)*.

(X) Spotted Scorpionfish *(Scorpaena plumieri mystes)*.

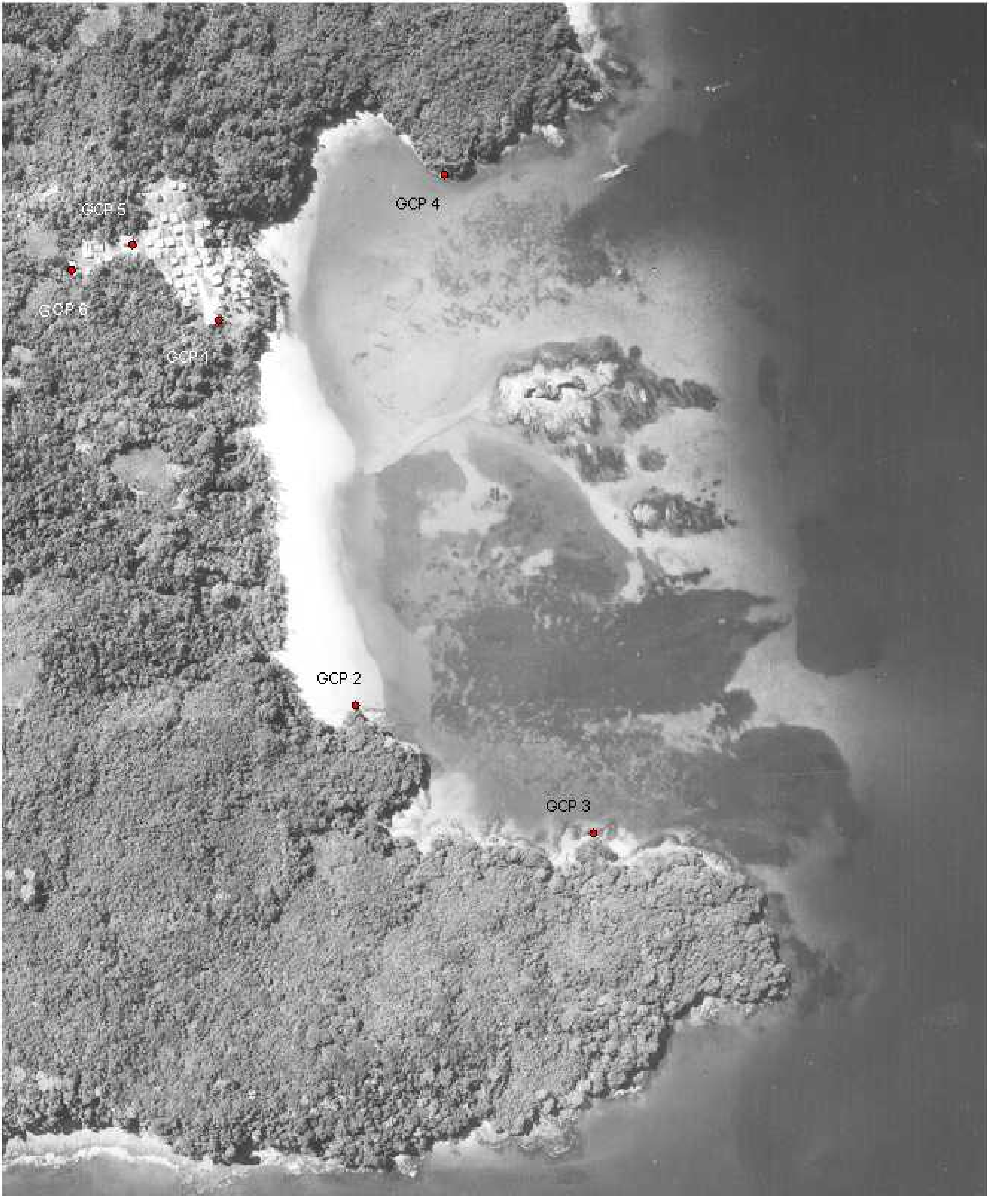
(XI) Hawksbill Turtle *(Eretmochelys imbricata)*.

(XII) Hawksbill Turtle *(Eretmochelys imbricata)*.

Appendix 4

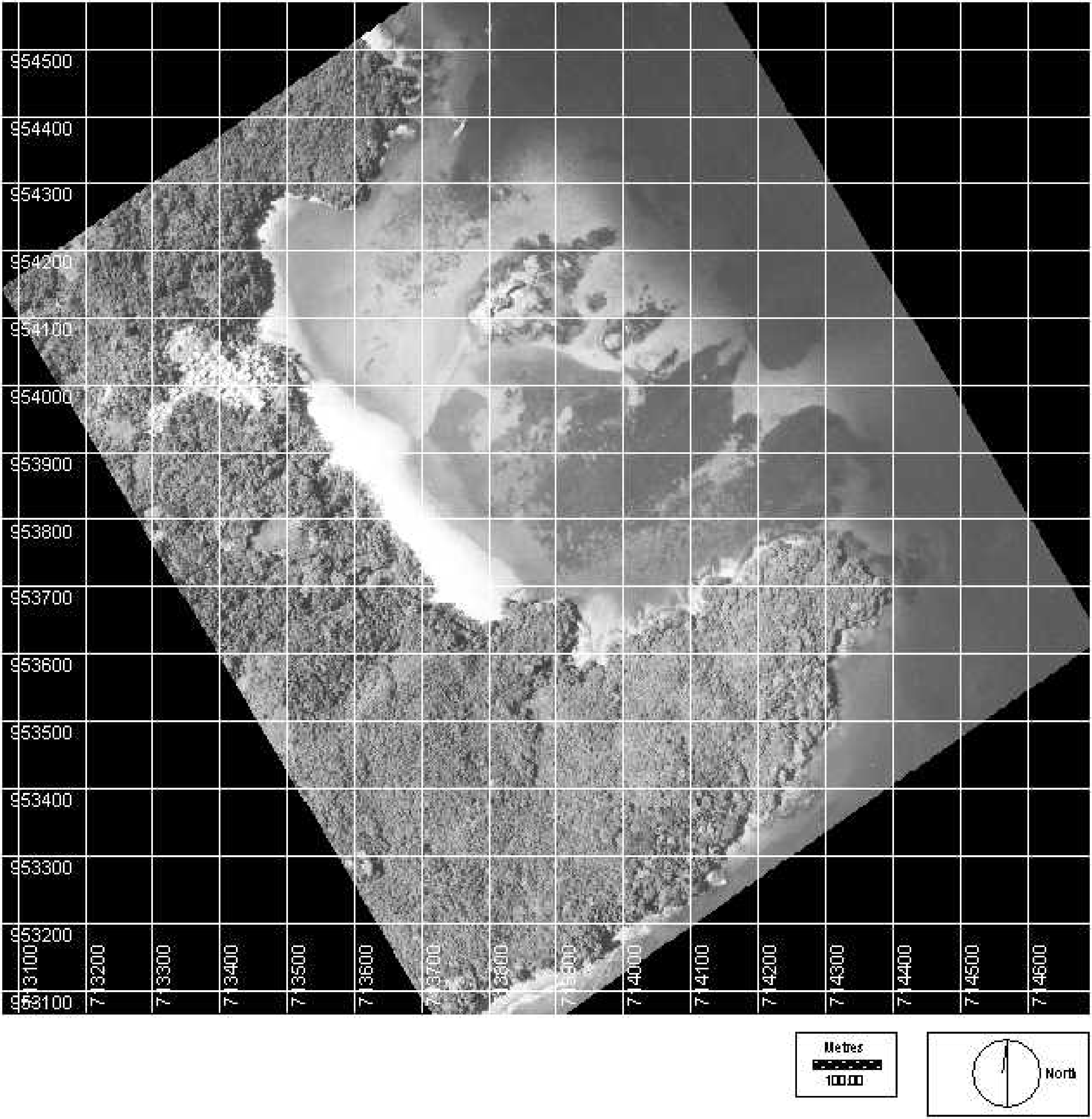
Saboga Bay - Isla Saboga, Pearl Islands

Selection of Ground Control Points (GCPs) for georeferencing of aerial photograph



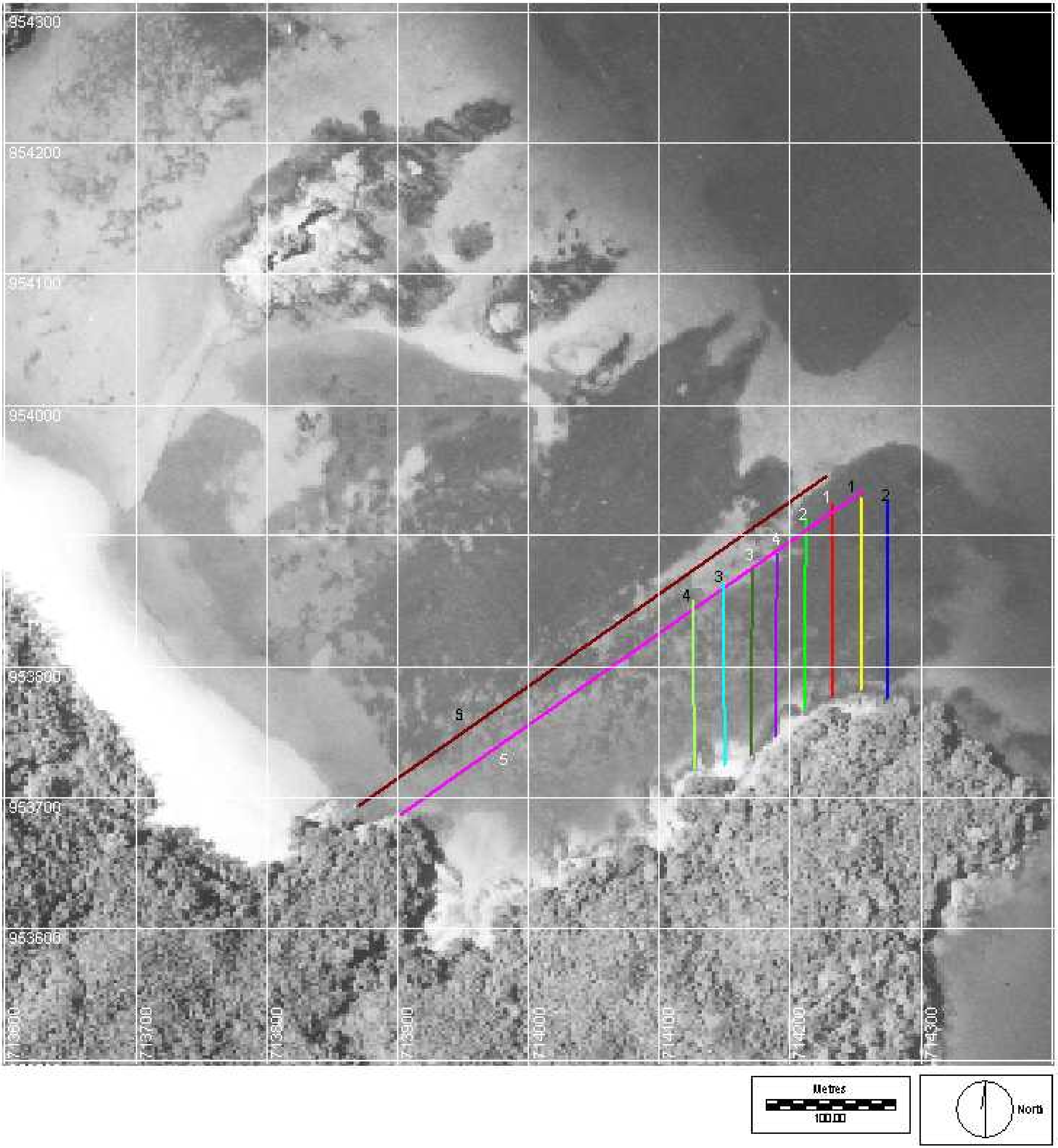
Saboga Bay - Isla Saboga, Pearl Islands

Georeferenced Aerial Photograph (UTM Map projection)



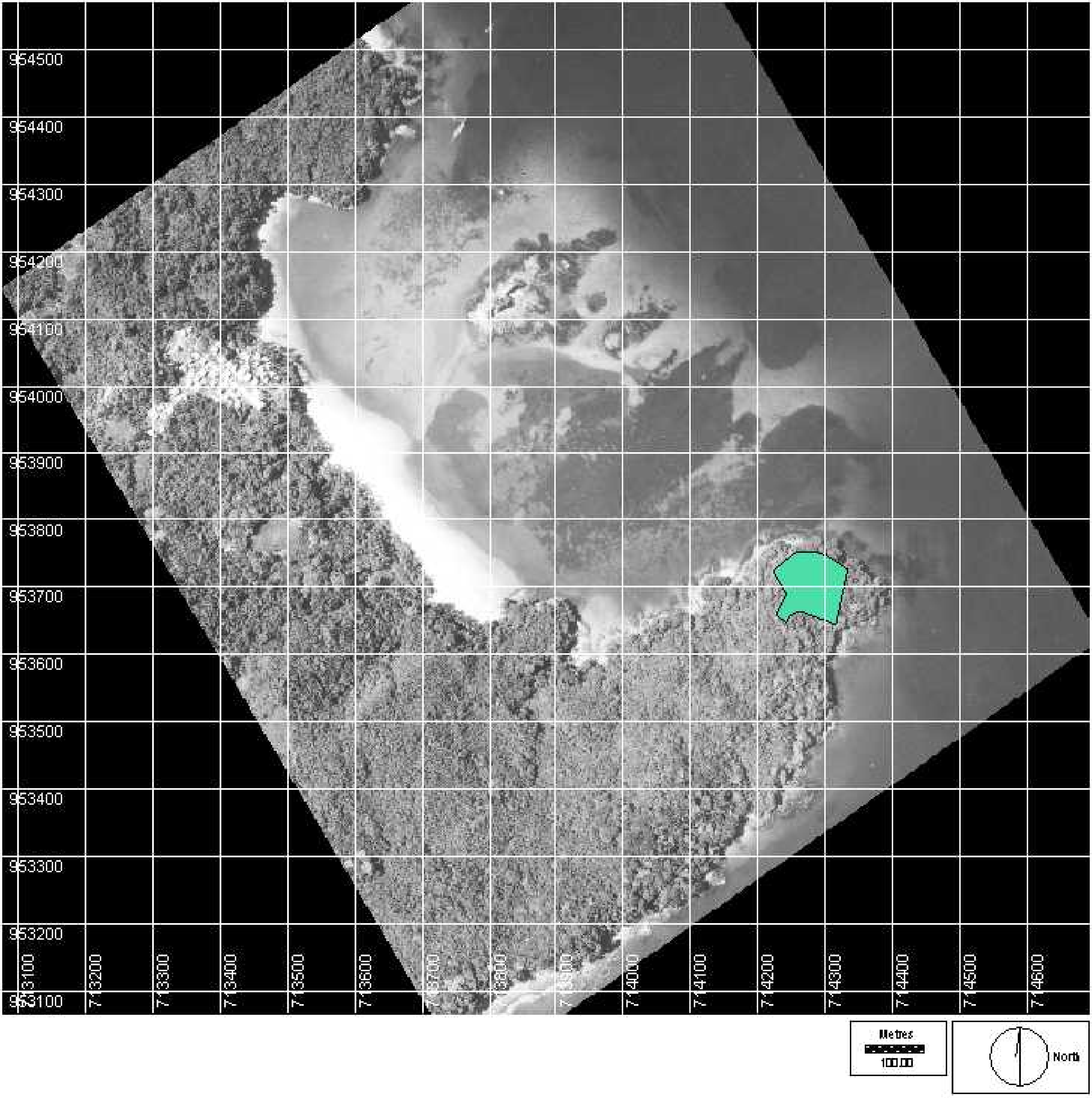
Saboga Bay - Isla Saboga, Pearl Islands

Location of Transects (See text for explanation of transect numbers)



Saboga Bay - Isla Saboga, Pearl Islands

Approximate location of new electricity generating plant



Appendix 5

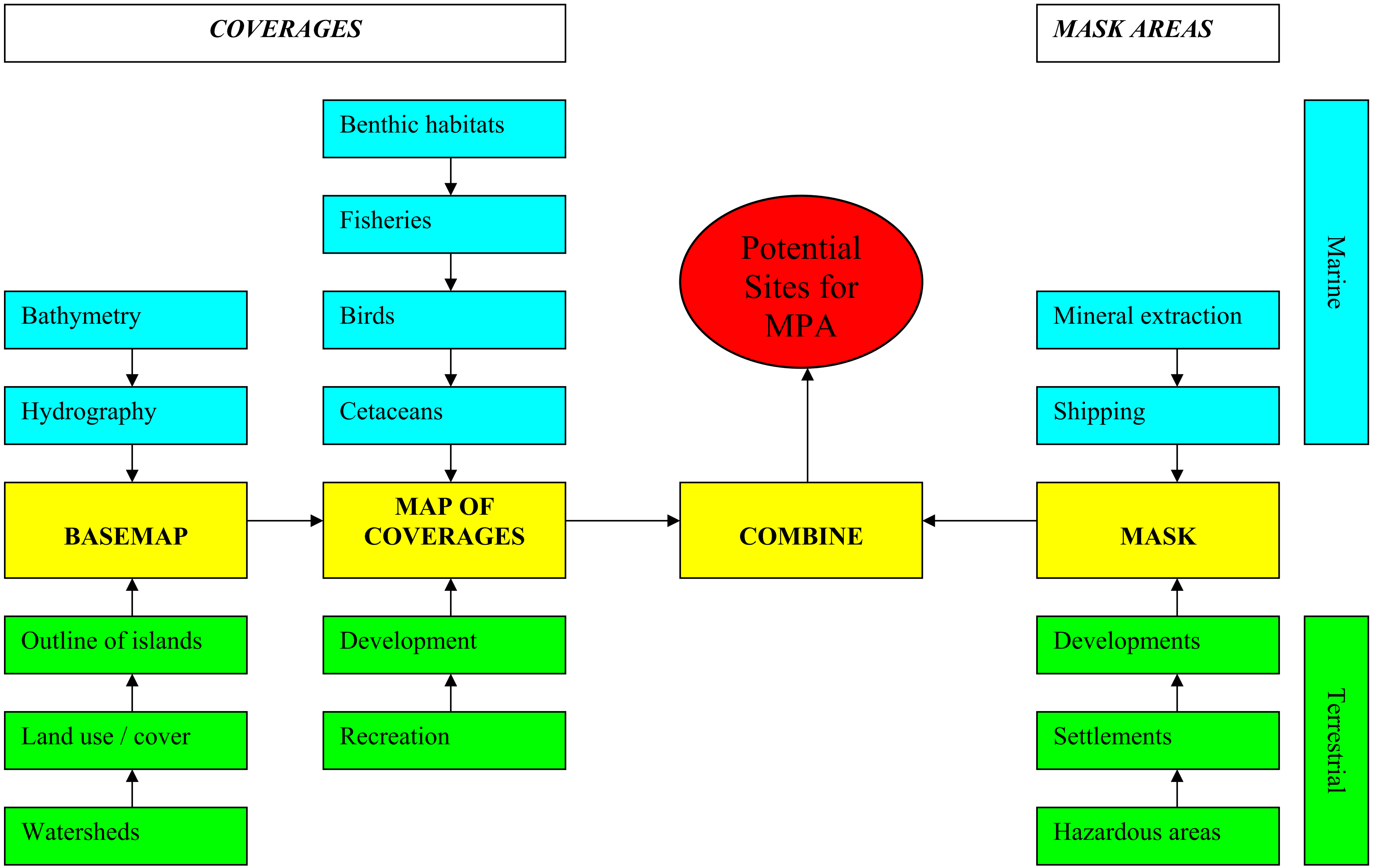
Appendix 5 Sample Questionnaire for datasets relating to Pacific Panama and the Pearl Islands Archipelago

1)	Format of Data:	Digital		Non-Digital			
	If digital:						
	Format	Raster		Vector		Other?	
		Database		Spreadsheet			
	If other please descibe:						
	If non-digital:						
	Format	Paper maps		Paper records		Other?	
	If other please descibe:						
2)	If digital, at what scale were the data digitised?:						
		1:1,250		1:25,000		1:500,000	
		1:2,500		1:50,000		1:1,000,000	
		1:5,000		1:100,000			
		1:10,000		1:250,000		Other?	
	If other please describe:						
3)	How are data spatially referenced (which coordinate system)?						
		UTM		Lat/Long		Other?	
	If other please describe:						
4)	Map Projection:						
5)	Map Datum:						
6)	Map Spheroid:						
7)	What GIS or graphical software is used (please include version eg ArcGIS 8.3)?						
8)	How was the original dataset created/captured?						
9)	When were the data created?						
10)	How often are the data updated?			Daily		Yearly	
				Weekly		1-5 years	
				Monthly		Over 5 years	

	Date of most recent update?					
11)	Format of basemap used:		Paper		Own survey	
			Digital vector		Satellite images	
			Digital raster		Aerial photos	
12)	Scale of basemap used:					
13)	If satellite images, which sensor?					
14)	Resolution of images?					
15)	Known sources of error in data? If so please describe:					
16)	Who owns data?					
17)	Are data:	Available		Confidential		Copyright
		Restricted		Sensitive		Commercial
18)	Are there charges for use of data?		Yes		No	
	If yes, cost?					
19)	What is the size of dataset (in Megabytes)?					
20)	Who is the contact person regarding the dataset?					
	Name:					
	Position:					
	Telephone:					
	E-mail:					
	Postal Address					
21)	What is the procedure to order the dataset?					

Appendix 6

Appendix 6 Conceptual Model for a GIS, Pearl Islands Archipelago, Pacific Panama



Appendix 7

Appendix 7 Suggestions for future projects to the Pearl Islands Archipelago

Organisation	Suggestion
ANAM	• Obtain copies of inventories compiled by ANAM regarding marine and coastal resources. These will indicate target species, locations and resource extraction rates.
PROCIG	• Contact PROCIG (see Section 5.1.2). This may be a good starting point in assessing the amount and availability of data.
IPAT	• Obtain copy of sectoral plan for tourism development that has just expired (see Section 6.2.1). • Source new plan for next 10 years. • Obtain register of proposed tourism developments if this exists (similar to National Register of Tourism). • Assess TCR action plan status. Is it working, or has it been shelved?
Ministry of Commerce & Industry (MICI)	• Find out if any mining concessions are currently in operation within the Pearl Islands archipelago.
United Kingdom Hydrographic Office	• Obtain a copy of Chart No 1401: Southern Approaches to the Panama Canal, Scale 30,000, 13/03/2003.
Tommy Guardia National Geographic Institute	• Investigate whether recent aerial photographs of the archipelago exist. If so obtain these.
Satellite Imagery	• Investigate availability and resolution of imagery from a variety of suppliers (Quickbird, SPOT, IKONOS). Obtain quotations and purchase if possible.
Sourcing of Data	• Utilise a questionnaire (in Spanish) similar to that shown in Appendix 5 (this report).
Spanish speakers	• Employ the use of fluent Spanish speaking persons to assist in the obtaining and verifying of data pertaining to the Pearl Islands. • Will also be of immense use when liaising with local population of Pearl Islands. • Survey of tourists; activities, attitudes to marine environment and proposed MPA status.
Involve the local community	• Conduct wide surveys of locals to ascertain fishing activities, perceived threats to archipelago, attitudes towards expansion of the tourism industry. • For any MPA designation to be successful it will be crucial to maintain the support of the local population. • Create posts for the employment of locals (ie wardens, education officer).