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Towards an assessment of the natural and human use impacts on the marine environment of the Abrolhos Islands

VOLUME 1
Summary of existing information and current levels of human use

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Fish for the future

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Fisheries research in Western Australia

The Fisheries Research Division of the Department of Fisheries is based at the Western Australian Marine Research Laboratories, P.O. Box 20, North Beach (Perth), Western Australia, 6020. The Marine Research Laboratories serve as the centre for fisheries research in the State of Western Australia.

Research programs conducted by the Fisheries Research Division and laboratories investigate basic fish biology, stock identity and levels, population dynamics, environmental factors, and other factors related to commercial fisheries, recreational fisheries and aquaculture. The Fisheries Research Division also maintains the State data base of catch and effort fisheries statistics.

The primary function of the Fisheries Research Division is to provide scientific advice to government in the formulation of management policies for developing and sustaining Western Australian fisheries.

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Executive summary

Introduction

The State Territorial Waters surrounding the Abrolhos Islands are gazetted as a Fish Habitat Protection Area and vested with the Minister for Fisheries under the *Fish Resources Management Act 1994*. Three Fisheries Management Papers have identified management priorities for the marine environment at the Abrolhos Islands:

- Management of the Houtman Abrolhos System
- Aquaculture Plan for the Houtman Abrolhos Islands
- Sustainable Tourism Plan for the Houtman Abrolhos Islands.

These plans and other national and international obligations to examine the effect of extractive and non-extractive anthropogenic activities on marine habitats (eg. *Environment Protection and Biodiversity Conservation Act 1999*) led to a one year project entitled "Towards an assessment of natural and human use impacts on the marine habitats of the Abrolhos Islands. Phase 1: Data consolidation and scoping". The project was funded by the Fisheries Research and Development Corporation (project no. 2000/166). Available data from a number of sources were collated and presented in this report to provide an overview of current knowledge about the marine ecosystems of the Abrolhos Islands and its uses.

Marine environment at the Abrolhos Islands

The Abrolhos Islands are bathed by the warm waters of the Leeuwin Current, and the Abrolhos coral reefs are the southern most in the Indian Ocean. The Abrolhos marine ecosystem is a unique assemblage of tropical and temperate species of algae, fish, reef corals and other invertebrates. The tropical coral reefs occur beside and amongst temperate algae species. Superimposed on the tropical/temperate species-overlap are endemic species, some of which are commercially important, such as the western rock lobster (*Panulirus cygnus*) and the baldchin groper (*Choerodon rubescens*).

In 1994, the Marine Parks and Reserves Selection Working Group acknowledged the Abrolhos Islands as the most significant area on the Western Australian coast, and the most worthy of reservation.

Natural impacts

The Abrolhos is subject to persistent strong winds, in excess of 32 km/h for 44% of the time. Large swells are experienced during the winter months and winter storms are significant. Most swells approach from the south west. Tropical cyclones affect the Abrolhos on average every five years, although two cyclones within a year have been noted before. The last cyclone to affect the Abrolhos was in May 1988.

The impact of weather on the marine environment at the Abrolhos is profound. The marine habitats are shaped by exposure to wave swell energy with the western seaward areas of the island groups dominated by macroalgae and lacking well developed coral communities. In contrast the eastern leeward lagoons support rich coral communities with high rates of reef accretion.

Storms and cyclones cause significant physical disturbance of the reef system at the Abrolhos, eg. removal of macroalgal stands and the breaking of fragile coral structures. The effects of storms can be illustrated by looking at the rates of accretion and erosion around the islands. A series of aerial photographs of Beacon Island over a 32 year period showed significant changes in the island's shape due to the deposition and removal of coral rubble. Most of the islands in the eastern parts of the Abrolhos are formed from the accretion of dead coral.

Examination of other natural impacts to the marine environment were not found to be significant. Predators such as the crown of thorns starfish (*Acanthaster planci*) and the predatory snail *Drupella cornus* have not been observed in plague proportions. There are no confirmed reports of coral bleaching at the Abrolhos Islands. Oxygen depletion in relation to coral spawning occurs infrequently and at a very localised level, with a low incidence of fish and crustacean kills.

Human use impacts

Currently four commercial fisheries operate at the Abrolhos for:

- Rock lobster (*Panulirus cyngus*)
- Saucer scallop (*Amusium balloti*)
- Finfish (various species)
- Aquaculture of pearl oyster (*Pinctada margaritifera*).

Recreational activities at the islands are undertaken mainly by tourists comprising:

- Visiting family and friends of rock lobster fishers
- People onboard private vessels
- Charter boat customers.

Presently, only visiting family and friends of rock lobster fishers are allowed to stay on the islands during the season; all other tourism is boat based.

The spatial and temporal distribution of commercial fishing at the Abrolhos was determined by the following methods:

a) Interviews with stakeholders asking:
    - Where fishing activities occured
    - How much fishing effort was expended at each location
    - How activities changed throughout the year

b) Extraction of information from logbooks

c) Aerial surveys to determine pot numbers and to examine changes in the distribution of fishing effort throughout the season (rock lobster fishery only).

Tourists and charter boat operators were interviewed about their recreational activities to determine:

- Type of recreational activity (eg. SCUBA diving, birdwatching etc)
- Location of activities
- Frequency that activities were undertaken
- Whether anchoring occurred in relation to conducting activities.

Extensive mapping of the marine habitats at the Abrolhos to a depth of 20m was undertaken by Hatcher *et al.,* (1988). The mapping categorised the marine environment into geomorphological units, based on topography and composition of the substratum.
The sensitivity of the marine habitats to physical damage (e.g. storms and fishing gear) also was mapped. Information relating to the distribution and intensity of human use activities was overlaid onto the habitat mapping using Geographical Information Systems software.

Rock lobster industry – fishing effort

The rock lobster fishery has grown from its early recreational infancy in the 1880s to become a highly successful commercial industry, which over the past ten years has yielded an average of about 1700t per season worth (ex-vessel) between $30 and $50 million.

One hundred and forty nine vessels fished about 13,800 pots in 2000, during a season which lasts for 3.5 months, commencing on March 15 and ending June 30.

Levels of fishing effort have been reduced by about 20% to approximately 1.1 million pot lifts since the introduction of the current management regulations in 1993/94. Just over half (52%) of a season's fishing effort (≅568,000 pot lifts) is expended in the shallow (0-20m) waters of the Abrolhos with an average of 273,000, 196,600 and 98,300 pot lifts occurring in the shallows of the Wallabi/North Island, Easter and Pelsaert Groups respectively. Levels of effort are consistent through March, April and May but decline in June.

Interview, aerial survey and existing commercial fishery data bases were used to assess the impact of potting on the marine habitats.

The distribution of pots across geomorphological units showed that pot deployments on submerged platforms and exposed reefs comprised between 45% and 65% of the fishing effort in the shallows of each group. In the Wallabi/North Is. and Easter Groups, isolated patch reefs also were important fishing grounds. These three geomorphological units generally comprise the western and central parts of the island groups and for the most part are composed of habitats that are resistant to pot damage. Although some corals are present in such habitat, much of it included limestone reef with stands of macroalgae. In contrast the fragile sheltered reef slopes of the eastern parts of the Pelsaert Group were important fishing grounds, perhaps due to the smaller amount of patch reef in that group.

When related to the sensitivity of biological communities within the geomorphological units, it was obvious that minimal effort (between 2.4% and 5.4% of the shallow water pot lifts) was centred on fragile habitats within the Wallabi/North Is. and Easter Groups, whereas 23.8% of shallow water effort was undertaken in the fragile communities of the Pelsaert Group.

The aerial survey of pots confirmed this pattern and further indicated a slight seasonal shift in pots from the more robust western and central parts of the Abrolhos to the more fragile regions of the three groups. This was likely the result of declining catch rates in the high abundance lobster habitats and the partial shift to speculative fishing in the more fragile habitats. While the shift is not likely to be statistically significant, given the uncertainty surrounding the estimates, it is consistent with fishers' anecdotal information on their fishing activities.

Pot densities were calculated and compared with estimates from a previous study conducted in 1988. Densities from all data sets from both studies showed similar results. The results from the current study suggest that all types of habitat around and within the reef perimeters of the Abrolhos Island are fished with a relatively low intensity of generally much less than 15 pots per hectare during the 3.5 month season.

Using the assumption that a rock lobster pot will disturb an area of 4 sq. metres every time it is deployed, the percentage surface area of fragile habitat affected by potting can be estimated. The assumption was used to indicate a "worst case" scenario. For fragile habitats in each of the island groups, pots were estimated to disturb between 0.2% and 0.3% of the habitat. The estimates for moderately sensitive biological communities are between 0.2% and 0.4%.

Due to the low densities of pots set in fragile areas during a season, disturbance is likely to be isolated rather than general. However, the actual extent to which damage is caused by pot fishing in these sensitive communities is unknown and is in need of investigation. The biological impact on the corals also needs to be quantified, given recently recorded rapid rates of growth for branching *Acropora* and that the regeneration of coral colonies from fragments is possible. It also is important to note that rock lobster fishing is prohibited between July 1 and March 14, allowing a substantial recovery period of 8.5 months for any damaged habitat.

Damage to reef structures from the passage, or anchoring, of rock lobster vessels was considered minimal.

Issues for consideration

- Pot fishing in fragile areas: what is the extent of any disturbance? What is the response (growth and regeneration) of corals? What is the contribution of lobsters in these areas to catches.

- The frequency of groundings by rock lobster vessels and extent of damage caused. "Collateral damage"?
- Boat anchors and moorings and physical damage.

Scallop industry – fishing effort

The scallop season is from the first Tuesday in April to May 31, and most boats only fish the first two to three weeks after which the catch declines significantly. During the 2001 season, 16 boats fished for scallops at the Abrolhos.

The location and intensity of trawling activities varies annually in relation to the patchiness of annual settlement and the determination of the areas of abundance through a pre-season research survey.

Fishing activity is usually to the east of the island groups to waters deeper than 30m and also in between the island groups.

Trawling is concentrated in sandy areas where scallops settle. However, some incidental and exploratory fishing does occur in vulnerable habitats such as algae/marine plants, sponge gardens and reef habitats.

Issues for consideration

- Incidental trawling occurs in sensitive habitats such as algal marine plants, garden and reef habitats.

Commercial wetline industry – fishing effort

Wetline fishing occurs all year round in many different locations throughout the Abrolhos.

A lot of wetlining activity occurs away from the Abrolhos Islands in deeper water. An examination of catch and effort data over the past six years identified that wetlining activities at the islands was sporadic. The fleet was highly variable, usually composed of around 30 boats. Most boats tended to fish for several weeks per year, although every year there were around five boats which reported fishing more than 100 days. The average number of days fished was 39 and the range 1-195 days.

Within the Fish Habitat and Protection Area (FHPA) there were only a few boats which fished regularly, on average around three to five. The few boats that operated within the FHPA fished sporadically, not targeting any area in particular. Anchoring tended to occur away from reef areas allowing the boat to drift near to the reef. Despite this, damage to sensitive habitats may still occur in some instances.

Issues for consideration

- Exact locations where fishing and anchoring occured were not identified.
- Commercial wetline activities within the shallows are excessive (Anon. (1998), Management of the Houtman Abrolhos System, Fisheries Management Paper 117).

Aquaculture

There are six licensed aquaculture sites for the black pearl *(Pinctada margaritifera)* at the Abrolhos. Most licenses are over areas of sand, although reef structures with fragile corals are present in some areas. Only 214 ha of the licensed area (≃ 1000 ha) are utilised for the growout of approximately 210,000 shell. Ninety-five percent of this activity is in the Pelsaert Group. All aquaculture activities must take place within the overall context of the Abrolhos Islands Management Plan.

Issues for consideration

- Potential impacts could arise from the use of anchors for long lines and damage from dislodged longlines to reef structures. Boat anchors and moorings could also be a potential problem.

Recreational activities

The number of family and friends of rock lobster fishers present on the Abrolhos usually is low, although during the peak Easter period, numbers are estimated to be as high as 4000. The number of private vessels visiting the islands was not quantified. Information about tourist activities was dominated by data from interviews with charter boat operators. Approximately 15 charter boats currently operate at the Abrolhos Islands.

SCUBA diving was the most popular recreational activity from charter boats and tended to be concentrated in the eastern part of the island groups. These areas are more protected from swell and wind and as a result contain more appealing biological communities e.g tabulate and branching corals etc.

The activities of the family and friends of rock lobster fishers were mainly fishing, diving and visiting the islands. Transport principally was by dinghy but occasionally by a rock lobster vessel.

Private boat owners mainly visited over long weekends and school holiday periods. Yachts tended to anchor in one location and utilised a small dinghy for fishing and diving and to go ashore. Power boats tended to be more mobile, although often returning to the same anchorage at night. The main activities undertaken by power boat owners were fishing, diving and visiting various islands.

Certain locations were very popular for recreation and these tended to be safe anchorages or good dive sites. At the Wallabi Group the popular locations were: Turtle Bay, Fish Point, Long Island, Beacon Island and Batavia Wreck site. Popular areas in the Easter Group were: Morely and Wooded Islands, Anemone Lump, Leo's Island and north of Rat Island. In the Pelsaert Group, frequently visited locations were the old guano jetty, the Coral Patches and Hummock Island. In each island group there was a concentration of recreational activities within Reef Observation Areas.

Issues for consideration

- Popular areas, which receive a high concentration of divers and anchoring, need to be monitored especially if fragile biological communities are present. The carrying capacity of reefs at the Abrolhos Islands needs to be considered.

- Private boat owners and friends and family of rock lobster fishers were under represented in interviews.
- A requirement for additional moorings and an education program for divers and visitors needs to be assessed.

Exploration drilling for petroleum

Four petroleum exploration wells were drilled in waters surrounding the Abrolhos in the late 1960s and 1970s. These wells have been capped and abandoned. The Department of Minerals and Energy released further areas in Western Australia (including the Abrolhos) for petroleum exploration this year. These areas are outside of the Fish Habitat Protection Area. Exploration is likely to be seismic with further development unlikely in the near future.

Issues for consideration

- Potential issues associated with petroleum drilling are ecotoxicology and turbidity.

Conclusions

Commercial fishery uses of the Abrolhos resources having the greatest potential to impact on the habitat were the western rock lobster fishery and the scallop trawl fishery. The rock lobster fishers spent much of their time fishing in areas where biological communities were robust and only a small percentage of their effort was targeted in fragile areas. The impact of potting was minor with the probability of localised disturbance in specific areas as distinct from widespread general damage.

The trawl fleet operated over unconsolidated sediments both adjacent to and away from the Abrolhos Islands reef habitats. The trawl grounds can be markedly different from season to season due to the patchiness of recruitment. Occasionally trawls impact on sensitive demersal sponge “gardens”, however, the scallop season is short and so any physical impact is limited to a confined period each year.

Recreational activity is likely to have little physical impact on the Abrolhos marine habitats so long as it is managed well. Most recreational vessel anchorages are in unconsolidated sediments and of little concern, but the extent to which pleasure craft and charter boat anchoring impacts on biologically sensitive communities is unknown. SCUBA diving is a popular activity and most dives are restricted to a few popular dive sites in each island group. The potential for divers to damage fragile communities (particularly *Acropora* spp) by physical contact, has not been quantified.

Reef Observation Areas (ROAs) were established in the Abrolhos in 1994 for conservation and biodiversity reference area use. They cover large areas of biologically diverse and visually interesting habitats, and have been very successful and are used frequently by snorkelling and SCUBA diving visitors.

Many separate studies have identified the presence of an unusual tropical and temperate mix of species and a high diversity of species and habitats. These features indicate the marine system is healthy. The Abrolhos is fortunate enough to be placed far out of reach of the general public and, with the exception of managed commercial fishing, has been left relatively undisturbed.

The human disturbance of Abrolhos Islands marine habitats is likely to be inconsequential when compared to natural damage such as storm events. Nevertheless, natural damage is periodic and anthropogenic disturbance is low level and isolated but may be persistent, and the effects of damage of this nature might be cumulative.

The Abrolhos Islands reef systems are at high latitude and competition for space and light is intense between corals and macroalgae. This macroalgae – coral interaction requires investigation and may hold the key to assessing reef health.

Extractive and non-extractive human activities at the Abrolhos will result in some physical disturbance to fragile biological communities which can be minimised with the implementation of appropriate education and management strategies. Sound scientific research is the key to the success of such initiatives. Nevertheless, the prospect of some anthropogenic physical disturbance remains and, given the commitment to sustainable multiple use of the Abrolhos marine resources, the level at which this disturbance is considered to be unacceptable, is a matter for community debate.

1.0 Introduction

The Houtman Abrolhos Islands (hereinafter referred to as the Abrolhos) are a complex of 122 low lying islands and reefs located at the edge of the continental shelf between 28° 15'S and 29° 00'S. The Abrolhos are located approximately 60km offshore from Geraldton. There are three major island groups: North Island-Wallabi Group; Easter Group and Pelsaert (Southern) Group, separated by the Middle and Zeewijk Channels respectively (Figure 1.1).

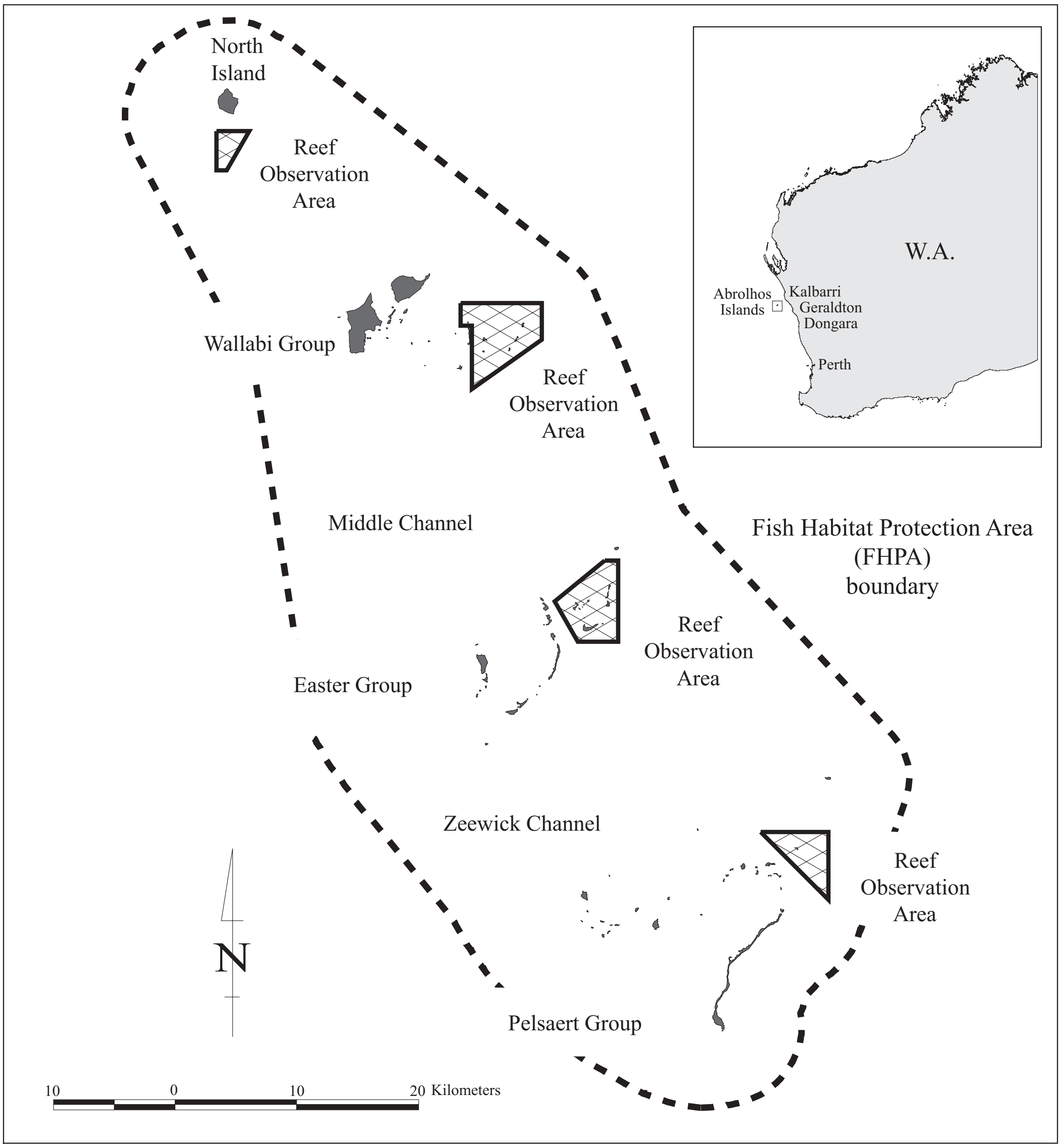


Figure 1. The Abrolhos Islands.

The islands of the Abrolhos have a significant flora and fauna which have persisted since the separation of the larger islands from the mainland. Most of the islands support bird breeding colonies with populations of some species of international significance (Anon. 1998). The warm waters of the Leeuwin Current bathe the Abrolhos and its marine habitats and provide the environment for a unique assemblage of temperate and tropical species. The Abrolhos coral reefs are the southern most in the Indian Ocean and amongst the highest latitude coral reef systems in the world.

The islands are vested in the Minister for Fisheries as “A” Class Reserve No. 20253, for the purposes of conservation of flora and fauna, tourism and for purposes associated with the fishing industry. The islands are listed in the Register of the National Estate under the *Australian Heritage Act 1975*.

The Abrolhos Islands were gazetted as Western Australia’s first Fish Habitat Protection Area (FHPA) under the *Fish Resources Management Act 1994*. In addition, they were recognised by the Marine Parks and Reserves Selection Working Group as the most significant area on the Western Australian coast and the most worthy of reservation (Anon. 1994).

The Abrolhos has considerable economic importance in terms of commercial fishing. By far the most important fishery is for the western rock lobster (*Panulirus cygnus)*. Rock lobster fishing began in the 1940s and now yields an average catch of around 1700 tonnes (t) valued at around $45 million in 1999/2000. Due to the small size at which lobsters mature in this area and their abundance, egg production from Abrolhos rock lobsters accounted for approximately 50% of the total fishery egg production (Chubb 2000) and is a primary key to the sustainability of this nationally significant fishery, worth $200-$400 million annually.

In 2000, the western rock lobster fishery was awarded the world’s first certification as an ecologically sustainable fishery by the Marine Stewardship Council. Certification involved an evaluation, by an independent body, of the health of the fishery resource, the care taken in protecting the marine ecosystem and the operations utilised in managing the fishery.

The second most important commercial fishery at the Abrolhos Islands is the trawl fishery for the saucer scallop (*Amusium balloti*). The catch is highly variable; 8.8t in 1997 – 526t in 1994, the latter worth $3 million. Finfish, valued at approximately $1 million annually, comprise the third most important commercial fishery at the Abrolhos.

In recent years, the Abrolhos also has become a focus for aquaculture and tourism. Currently six licences for growing black-lipped pearl oysters (*Pinctada margaritifera*) have been issued and two applications are under consideration. The main form of tourism at the islands is from private vessels (eg. yachts) and charter vessels (including rock lobster carrier boats) carrying tourist passengers. Tourists are not permitted to stay on the islands unless guests of fishers, however, the recently released tourism management plan examines options for future land-based tourism at the Abrolhos (Anon. 2001).

Despite a history of fishing activities and growing interest from the recreational, aquaculture and tourist sectors, virtually no environmental impact studies have been conducted at the islands. This was noted in the Abrolhos Islands Management Plan, hereinafter referred to as the management plan (Anon. 1998). A key strategy identified was the requirement for a study of the benthic habitats to determine reef health and quantify the effects of human activities (eg. fishing, current tourist activities, etc) on the marine habitats of the Abrolhos. It is also important to recognise the more general responsibilities that the state of Western Australia has with respect to the Commonwealth under its Oceans Policy and *Environment Protection and Biodiversity Conservation Act 1999* and also the ongoing environmental stewardship considerations that the conferring of accreditation by the Marine Stewardship Council on the western rock lobster fishery entail.

As a result of the various needs for research data, this project was developed to consolidate existing qualitative and quantitative information and to provide strategic direction for future research. This direction will lead to a better understanding of human-use and natural impacts at the Abrolhos to ensure ecologically sustainable multiple use of this unique area under the umbrella of the existing Management Plan (Anon. 1998). The one year project entitled, "*Towards an assessment of natural and human-use impacts on the marine habitats of the Abrolhos Islands. Phase 1: Data consolidation and scoping*" was funded by the Fisheries Research and Development Corporation (FRDC project no. 2000/166).

The objectives of this project were:

1. To collate existing research information relating to human use impacts and natural perturbations in Abrolhos marine habitats to provide a detailed overview of the status of current knowledge about the marine ecosystem of the Abrolhos Islands.

2. To conduct limited field work to determine the spatial and temporal distribution of commercial fishing and recreation activities and provide general descriptions/ground truthing of habitat/community types at the Abrolhos as baseline/background data for presentation at the workshop.

3. To conduct a scientific workshop including community representatives and technical experts to determine the objectives and formulate a dedicated research programme to provide quantitative monitoring data for use in the sustainable management of the Abrolhos Islands Fish Habitat Protection Area.

This report fulfils the first two objectives and presents the current state of knowledge of natural and anthropogenic (human) physical impacts on Abrolhos marine habitats. It contains, for the first time, a summary of existing relevant research both published and unpublished and new data on the extent of the spatial and temporal use of the Abrolhos by all user groups. This report, whilst a stand alone status report, in draft form also was a companion volume of background information for attendees at the workshop in Geraldton held on July 11-13, 2001, where the project's third objective was achieved.

This study did not examine water quality at the Abrolhos. Nutrient inputs to the ocean at the Abrolhos from humans are minimal in comparison to bird faeces. Recent studies have estimated that the seabirds at the Abrolhos consume around 12,000 tonnes of fish annually (Dr. C. Surmon, Murdoch University, Western Australia, pers. comm.). A significant proportion of the nutrients consumed in the seabirds diet later is concentrated as faeces on islands where they roost and nest. It is these deposits, often several meters deep, that the guano miners sought in the 1800s. During rainfall events nutrients from faeces are leached into the marine environment, and plumes of dark water close to islands are often reported after heavy rain (C. J. Dibden, Department of Fisheries, Western Australia, pers. comm.). A study conducted in May 1998 on a reef nearby to one island with many fishing camps found no pattern of nutrient elevation. It concluded that human activity had no clear adverse impacts on nutrient balances in Abrolhos waters (Marine Science and Associates 1998).

2.0 Vesting and tenure

The State Territorial Waters surrounding the Abrolhos are gazetted as a Fish Habitat Protection Area under the *Fish Resources Management Act 1994*. The Department of Fisheries is responsible legislatively for the management of commercial and recreational fishing and aquaculture in the waters of the Abrolhos Islands (Figure 1.1).

The relevant objects of Section 3 of the *Fish Resources Management Act 1994* include:

1. To conserve fish and protect their environment; and
2. To enable the management of fish habitat protection areas and manage the Abrolhos Islands reserve.

Four Abrolhos Islands Reef Observation Areas (ROAs), one at each island group, were established under the *Fisheries Management Act 1905* in May 1994. All marine species including molluscs, algae, coral and finfish are protected in ROAs with the exception of rock lobsters which may be taken by commercial and recreational fishers using pots during the season.

The Department of Fisheries is the principle agency operating at the Abrolhos Islands throughout the year, with a concerted managerial and compliance role during the annual Abrolhos rock lobster season (15 March-30 June). However, other government agencies also have legislative responsibilities for the Abrolhos. They are:

- Department of Conservation and Land Management
- Western Australian Museum
- Department of Planning and Infrastructure
- Department of Environmental Protection
- Department of Minerals and Petroleum
- Western Australian Police Service.

For a review of these agencies and the scope of their responsibilities see the Abrolhos Islands Management Plan (Anon. 1998).

3.0 Methods

This study identifies the various human use and natural elements potentially able to physically impact the marine habitats at the Abrolhos. Physical impacts refer to structural damage from natural sources such as storms and predators and human activities such as the use of anchors, fishing gear (pots, trawl nets and fishing line), and impacts from boat hulls, divers and snorkellers. The approach was to map the different marine habitats at the Abrolhos, identify the sensitivity of these habitats to physical damage and correlate these levels of fragility with information gathered in this, and in previous studies about natural disturbances and human activities.

3.1 Identification and mapping of habitats

Thorough habitat mapping for the Abrolhos was conducted by Hatcher *et al.,* (1988) and Marine Science Associates (1995). Whilst these studies are complementary, each classified the habitats using different methods, the former from aerial photos (1:25,000) and extensive ground truthing and the latter from satellite imagery and ground-truthing. It was considered unnecessary to remap the habitats at the Abrolhos and so the Hatcher *et al.,* (1988) classification system was used since it provided the greatest detail (to depths of approx. 20m) and covered the largest area.

Hatcher *et al.,* (1988) identified six hierarchical units of classification. The broadest unit was each reef group e.g. Wallabi Group and the finest scale of classification was an ecological unit, a unique combination of all hierarchical units of classification occurring at only one set of global co-ordinates (Table 3.1). Nearly 200 unique ecological units were defined.

Table 3.1. The hierarchy of Abrolhos Islands marine habitats according to the classification by Hatcher *et al.,* (1988).

Reef Groups Ecosystems (3)	
Geographic Regions (8)	
Geomorphological Classes (12)	Hydrodynamic Classes (6)
Biological Communities (13)	
Ecological Units (192)	

For the purposes of this study we chose to use the geomorphological classification for activity mapping purposes. The geomorphological units are based on the topography and composition of the substratum and are easily identifiable at a large scale and on aerial photographs. This level was chosen because each unit contains similar biota across island groups and the scale of the units was appropriate to the spatial distribution of human activity. The units at each island group are illustrated in Figures 3.1 a - c.

The fieldwork was conducted in January 2001 to ground truth and to characterise visually the geomorphological units. It involved completing 30m video transects and noting life-forms (English *et al.,* 1997) in each geomorphological unit across approximately west-east tracks arbitrarily selected across each island group. Two tracks were surveyed in the Wallabi and Pelsaert Groups and three in the Easter Group. The tracks were selected to represent the geomorphology of each group (Figures 3.1 d - f). The tracks were variable in length from

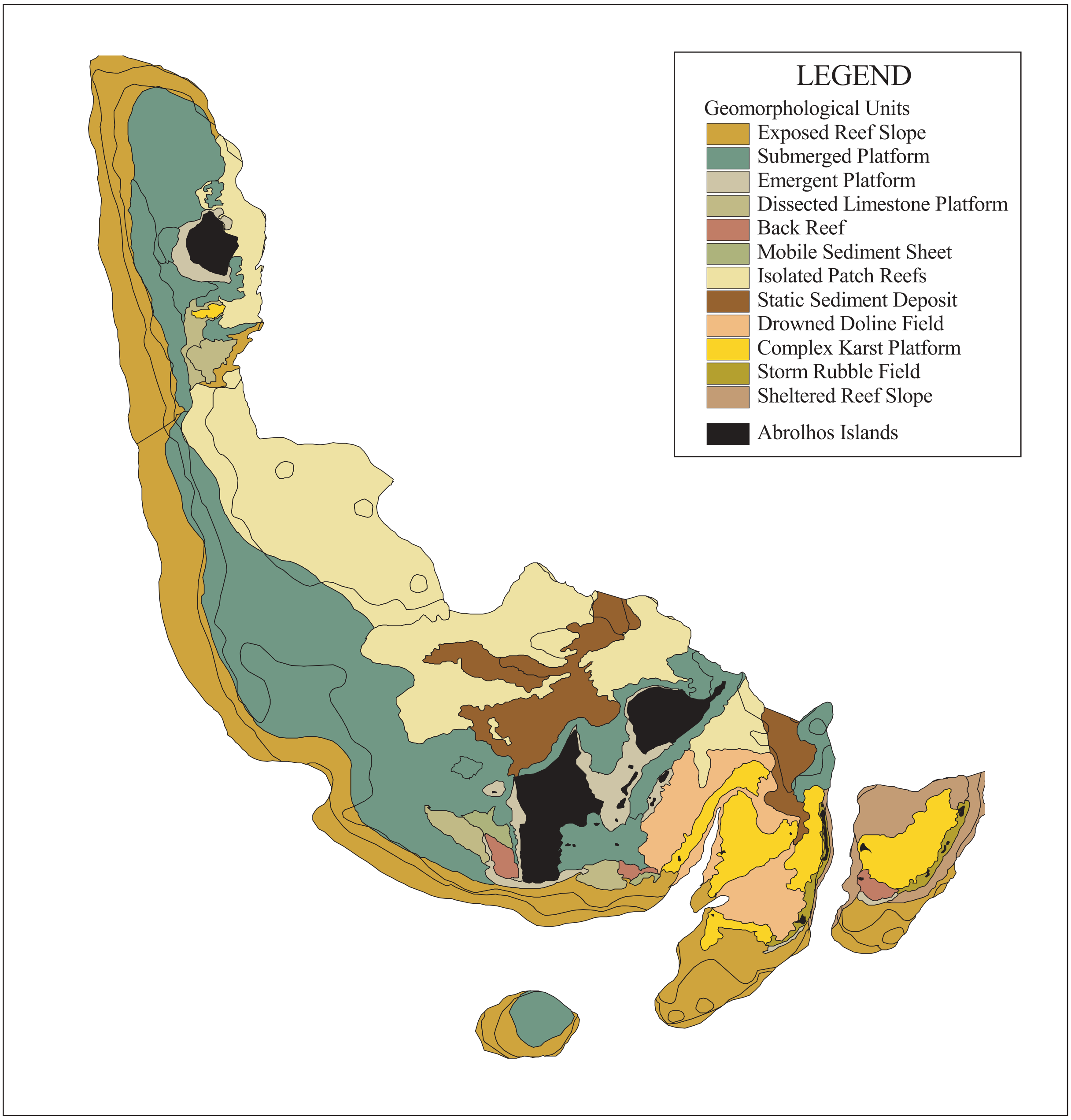


Figure 3.1a. Geomorphological units mapped at North Island and Wallabi Group (after Hatcher *et al.*, 1988).

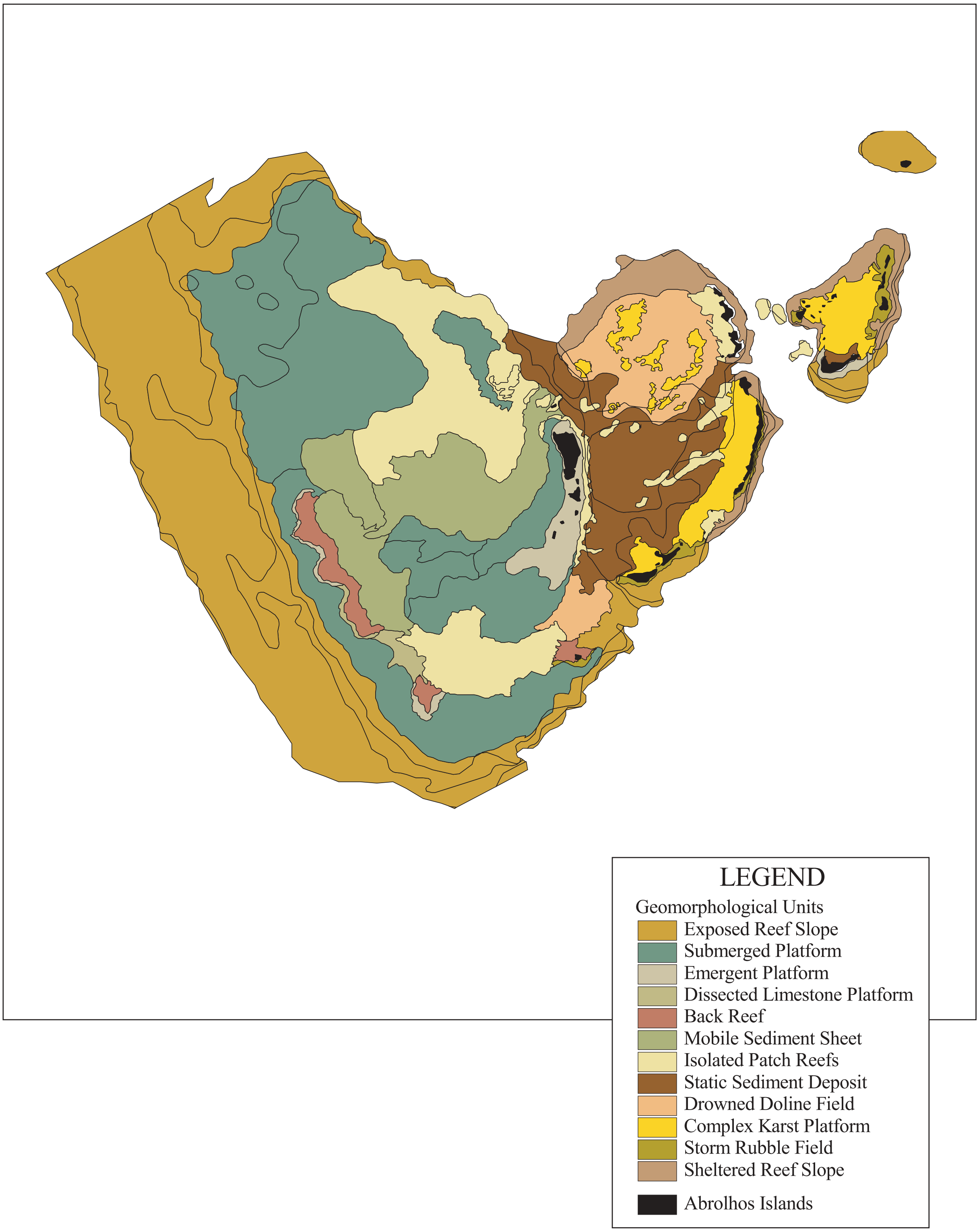


Figure 3.1b. Geomorphological units mapped at Easter Group (after Hatcher *et al.*, 1988).

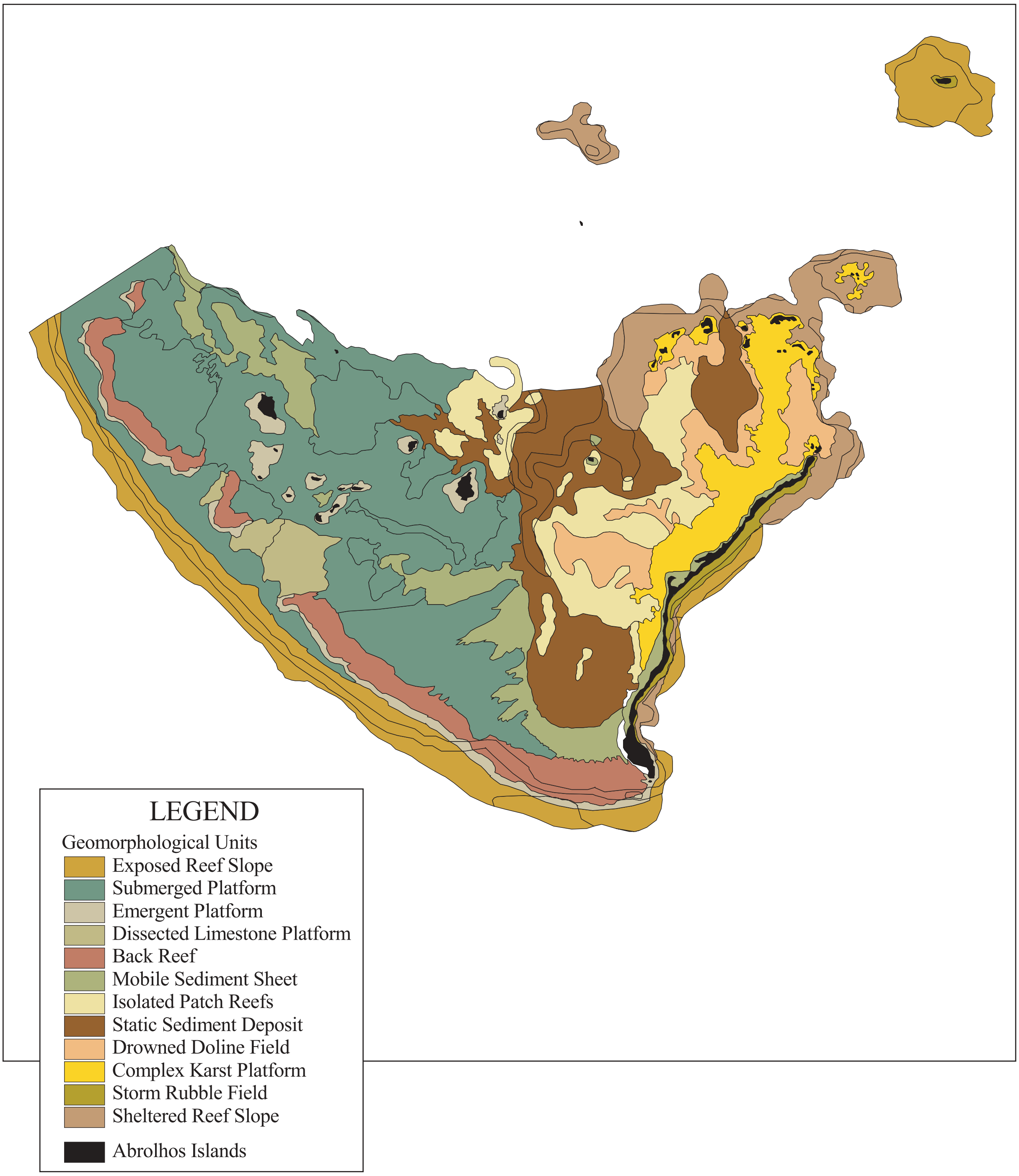


Figure 3.1c. Geomorphological units mapped at Pelsaert Group (after Hatcher *et al.,* 1988).

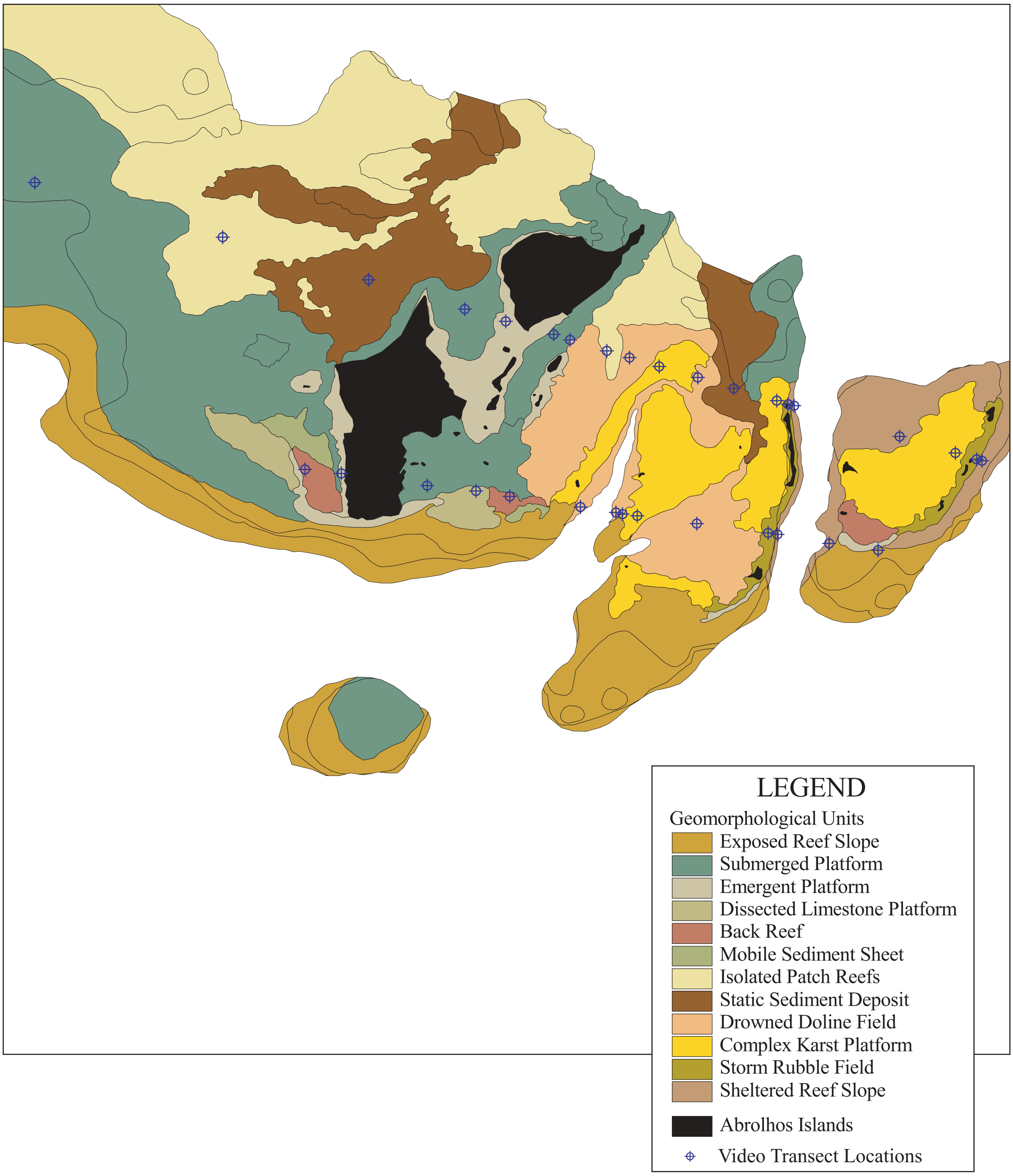


Figure 3.1d. Video transect locations in the Wallabi Group.

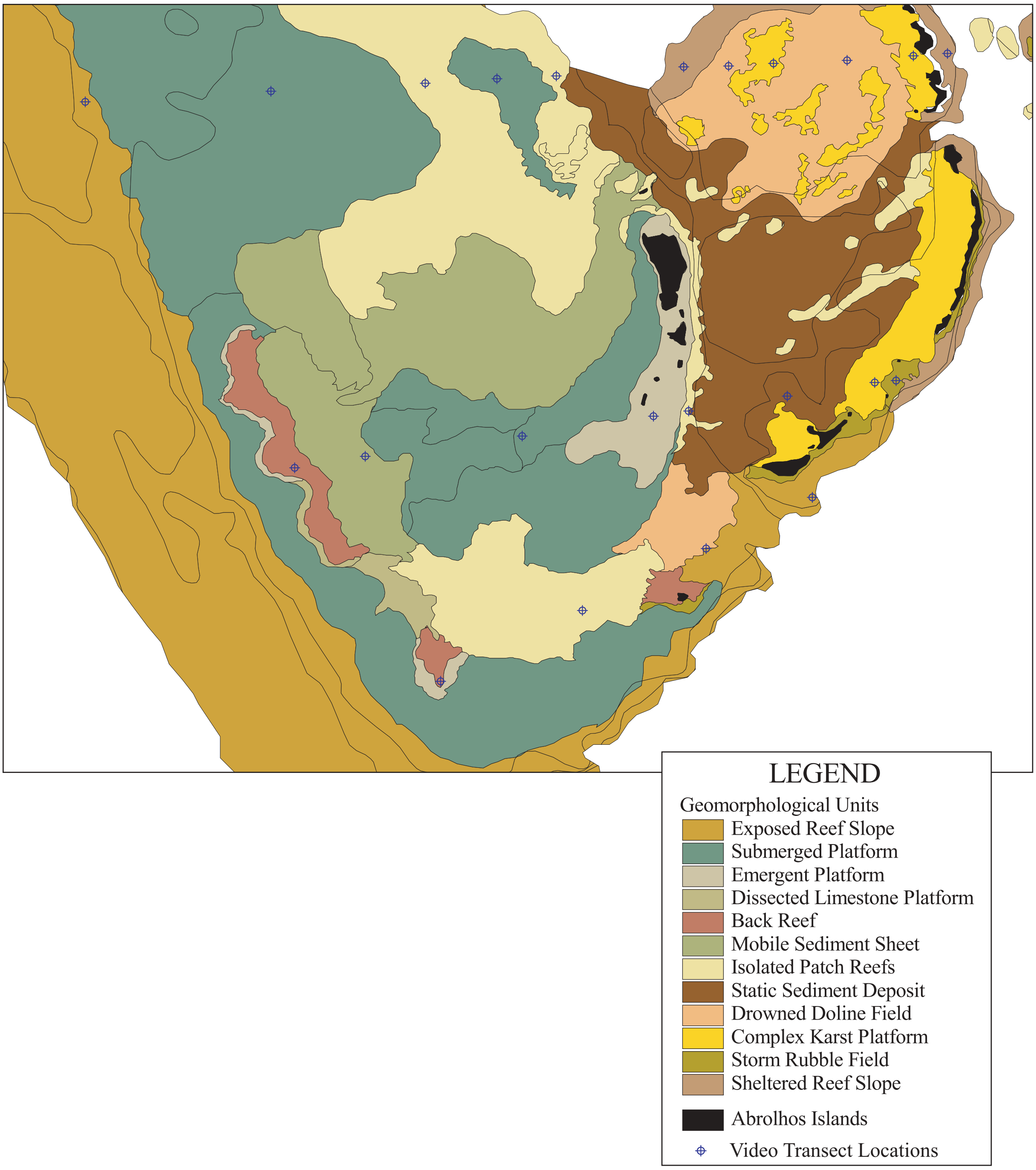


Figure 3.1e. Video transect locations in the Easter Group.

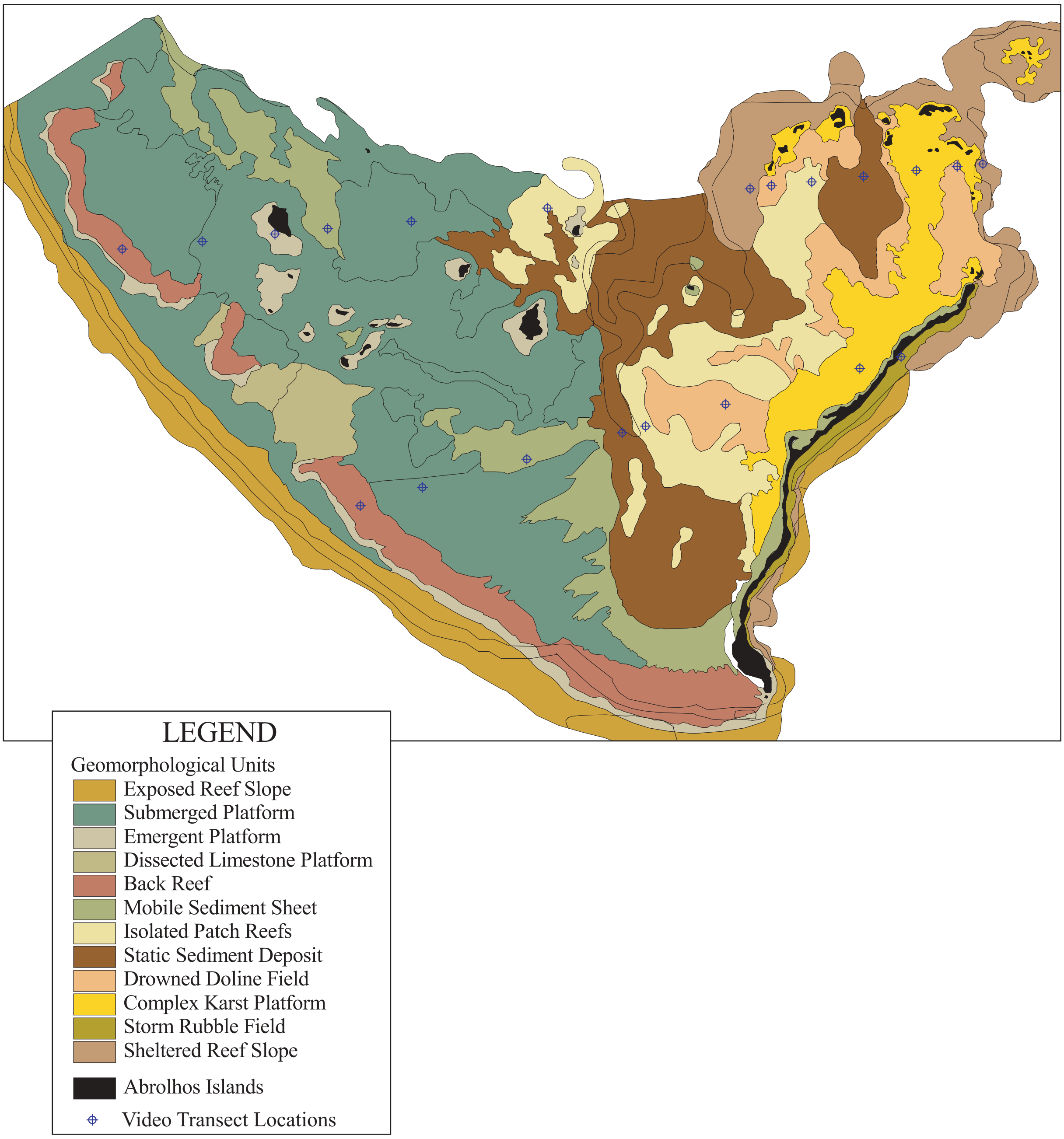


Figure 3.1f. Video transect locations in the Pelsaert Group.

9.4 to 19.5km with an average of twelve geomorphological units crossed by each track. A broad description and representative photograph of each habitat type is provided below. These habitats can be broadly categorized as occurring from east to west across each island group.

1. Exposed reef slope (Plate 3.1)

Exposed (windward) reef slopes occur on the western and southern margins of all three island groups. They consist of compacted and grooved ancient reef limestone to about 40m depth. They support rich, high biomass communities of algae and seagrasses with small numbers of scattered coral colonies. The coral communities tend to be the more robust forms; thick branched, tabulate or encrusting. The abundance and biomass of fish and invertebrates (particularly the western rock lobster) is high.

2. Submerged limestone platform (Plate 3.2)

Submerged limestone platforms with low to medium relief, are reefs with a thin overlay of sand and rubble (sediments). They are the dominant substratum in all three island groups comprising about 25% of the total submarine area in each. The communities of submerged limestone platforms are variable but generally can be described as having low biomass of meso-algae, sponges and occasional coral colonies with areas of unconsolidated sediments. In some areas in the Easter and Wallabi Groups, particularly at greater depths, submerged platforms support a richer biological community with *Sargassum sp*. and *Amphibolis sp.* beds and scattered kelps and corals. This is called the black and white bottom by fishermen.

The areas of submerged limestone platform at the edges of breakers support little plant biomass, however, rock lobsters are abundant.

3. Emergent limestone platform (Plate 3.3)

Low relief emergent platforms form the reef crests on the western side of the island groups and also the foreshores (intertidal pavements) eg. between the Wallabi Islands, which are exposed at very low tide. In the more exposed areas, such as the western and southern areas, wave action prevents the intertidal communities from desiccation. In these areas there are dense turfs of fleshy and calcareous algae and encrusting invertebrates. In depressions and deeper areas, larger algae and corals occur. Corals are thick robust forms. In the more sheltered areas (eg. such as between the Wallabi Islands) emergent limestone platforms collect sediment and dry at low tide. The fauna associated with these areas is impoverished.

4. Dissected limestone platforms (Plate 3.4)

Small gaps in the south-western reef perimeters occur where channels have been cut into the reef platform by strong, unidirectional water currents. These formations are characterised by moderate relief and rapid flushing. They may be dominated by rich coral, algae, or mixed coral and macroalgal communities. Corals include both robust and delicate forms.

5. Back Reefs (Plate 3.5a and b)

Back reefs develop immediately behind reef crests on windward (exposed) reef perimeters and are most pronounced in the Pelsaert Group and least developed in the

Wallabi Group. They are the transition from the emergent reef crests to the lagoons, and are variable in their composition of biological communities both within and between groups. All are characterised by strong water flow due to their proximity to the high energy exposed reef slopes and crests. There is a progression from the consolidated coralline algal pavements of the crest to the unconsolidated sediments of the lagoon floor. Meso- and macroalgae predominate in back reef communities, with some small isolated colonies of massive corals (Plate 3.5a). In the Pelsaert Group, dense stands of branching *Acropora* may reach 100% cover in certain areas of the back reef (Plate 3.5b).

6. Mobile sediment sheets (Plate 3.6)

At some poorly defined point the hard substrate of the back reef gives way to the mobile sediments consisting of coralline sands which extend downstream of the reef perimeters. Mobile sediments occur extensively throughout the Abrolhos in shallow areas where there is substantial water movement. The constant reworking of the sediments by physical processes limits the development of fauna and most areas are bare. However, in some isolated patches, seagrasses have colonised the sediments.

7. Isolated patch reefs (Plate 3.7a and b)

Isolated patch reefs are discrete but variable, both in size and in the biological communities they support. In all cases they are surrounded by unconsolidated sediments (sand). Patch reefs range in size from a few cubic metres to several thousand cubic metres and have a variable mix of coral and macroalgae. Patch reefs are present throughout each island group and, therefore, broad generalisation about their biological communities is difficult. The western areas tend to be dominated by algal/coral mixtures (Plate 3.7a), whereas the eastern areas are dominated by corals (Plate 3.7b). They exist as natural replicates across a gradient of coral/macroalgal abundance. The most common mixtures are branching *Acropora* species and algae of the genera *Sargassum*, *Lobophora* or *Eucheuma*.

8. Static sediments (Plate 3.8)

In more protected areas, such as the deep lagoon basins, static sediment deposits accumulate with little physical disturbance. The gradation from mobile to static sediments can be continuous and the distinction can become arbitrary. The sediments contain rich infaunal communities.

9. Drowned doline field (Plate 3.9a and b)

Doline fields are characterised by limestone platforms interspersed with deep pot holes (dolines) and characterised by high coral cover. The coral communities are very rich. In the shallower margins branching corals dominate, often reaching 100% cover (Plate 3.9a). Coral diversity tends to increase with depth in the dolines, with more foliose, encrusting and massive forms closer to the bottom (Plate 3.9b). The dolines may reach 25m in depth and are the "blue holes" referred to in section 4.2.

10. Complex karst platform (Plate 3.10 a and b)

The eastern sides of the Abrolhos feature a typically shallow limestone platform with a veneer of sediments, rubble, coralline and mesoalgae (Plate 3.10a). The complex karst platforms include shallow dolines, or circular pot holes, which have a thin margin of live coral. Complex karst differs from the drowned doline fields in the depths of the dolines and extent of coral cover. Some isolated areas have coral formations which can reach 100% cover and include more delicate forms that are thin and branching (Plate 3.10b).

Hatcher *et al.,* (1988) used the term complex karst platforms for this habitat. Technically this is an incorrect term, as karst is a structure formed by dissolution of limestone to form holes, whereas the reef platforms and circular holes at the Abrolhos have developed from reef growth. For consistency, however, the term karst has been retained for this report.

11. Storm rubble field (Plate 3.11)

The top of most sheltered (leeward) reef slopes terminate in a narrow reef flat leading to the foreshore of an elongated island. These reef crests and flats are characterised by unconsolidated storm rubble fields generated during relatively rare events when massive quantities of tabulate coral colonies are detached, fractured and deposited in the shallows. The biological communities of these habitats are variable, but typically have an algal coating on dead corals, algae growing in between coral rubble and sessile invertebrates on the underside of large coral plates. The extensive banks of tabulate and branching coral rubble indicate a continual source of material from reef slopes during the Holocene. This rubble contributes to the formation of the islands in the eastern part of each group.

12. Sheltered reef slope (Plate 3.12)

The leeward, sheltered reef slopes are protected from extensive wave action. They form a continuum with exposed reef slopes as one progresses from western and southern to eastern and northern reef margins. Steep slopes exhibit a depth zonation with plating corals and seasonal *Sargassum* cover near the surface. Branching corals (often with 100% cover) occur in mid-depths while high diversity coral (eg. foliose) and filter-feeding assemblages dominate the slope bases to depths of about 40m. Sheltered reef slopes are vulnerable to storms which produce wave shock from unusual directions. As a consequence, live coral cover alternates with coral rubble and macroalgae in patches.

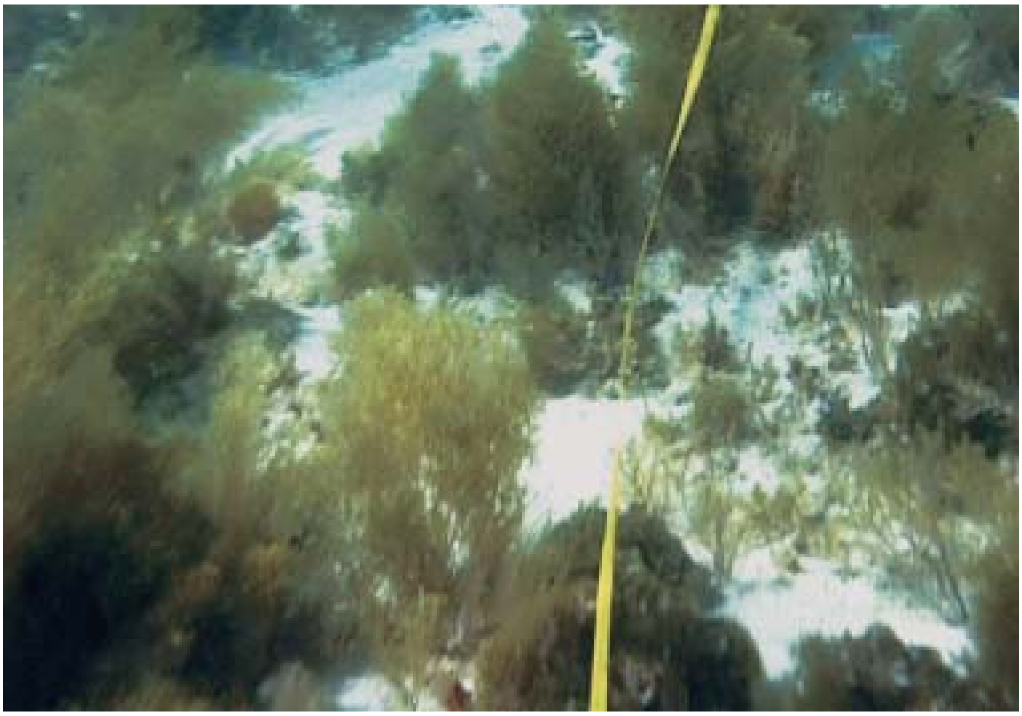
Plate 3.1. Exposed reef slope: windward, compacted, grooved, to approx 40m.

Plate 3.2. Submerged platform: low to medium relief pavements with sediments.

Plate 3.3. Emergent platform: limestone, low relief, intertidal pavements & reef crests.

Plate 3.4. Dissected limestone platform: gaps in windward reef perimeters; moderate relief; rapid flushing.

a)



b)

Plate 3.5a&b. Back reef: a) typical - unconsolidated rubble & sediments behind reef crests & flats, dominated by meso- and macroalgae; b) atypical - dense stands of branching *Acropora* - Pelsaert Group.

Plate 3.6. Mobile sediment sheet: coarse sands in shallows.

a)

b)

Plate 3.7a&b. Isolated patch reefs: discrete reefs surrounded by sediments; a) macroalgal dominant; b) coral dominant.

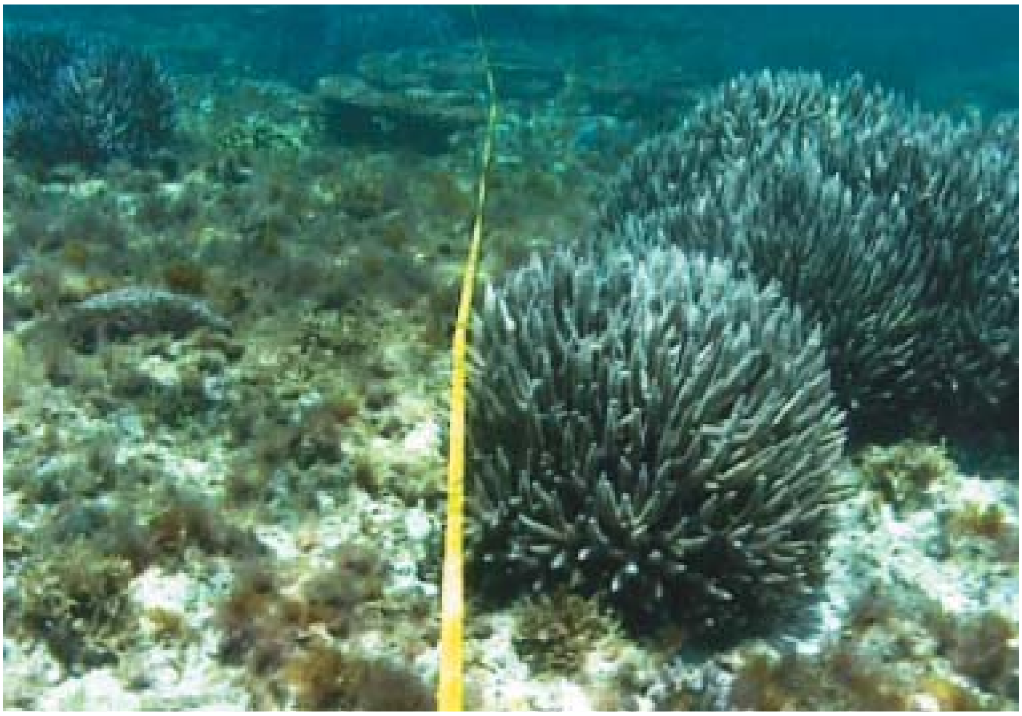
Plate 3.8. Static sediment deposit: fine sands in sheltered & deep lagoons.

a)

b)

Plate 3.9a&b. Drowned doline field: reef platforms interspersed with deep potholes (dolines) and characterised by high coral cover; a) shallow reef platform areas; b) bottom of deep pothole.

a)



b)

Plate 3.10a&b. Complex karst platform: shallow limestone platform with a veneer of sediment with shallow dolines with a thin coral margin; a) algal dominated platform; b) coral in shallow doline.

Plate 3.11. Storm rubble field leeward reef crests & flats, composed of unconsolidated coral fragments.

Plate 3.12. Sheltered reef slope: leeward, steep, to approximately 40m, coral zonation apparent.

3.1.1 Sensitivity of geomorphological units

The sensitivity of the various geomorphological units to physical damage was defined by Hatcher *et al.,* (1988) as "the susceptibility of the habitat to physical damage caused by rock lobster pots and hauling ropes, impact from jet boat hulls and the deployment of anchors" (Table 3.2). The geomorphological units were also ranked for sensitivity to damage with some classifications having equal rank. The drowned doline fields with abundant corals were classified as the most sensitive and the static and mobile sediment sheets as the least sensitive.

Table 3.2. Ranking of Geomorphological classes from west to east and sensitivity index

Geomorphological Class	Sensitivity	Rank
Exposed reef slope	Moderate	5
Submerged limestone platform	Moderate	5
Emergent limestone platform	Low	6
Dissected limestone platform	High	3
Back reef	Moderate	4
Mobile sediment sheet	Low	7
Isolated patch reefs	High	2
Static sediment deposit	Low	7
Drowned doline fields	High	1
Complex karst platform	High	2
Storm rubble field	Low	7
Sheltered reef slope	High	2

Hatcher *et al.,* (1988) specifically considered only the rock lobster fishing activity in their report. This report deals with human use impacts over a very much broader range of activities, nevertheless, the sensitivity indices remain relevant. The sensitivity indices were based upon a consideration of the species diversity, relative fragility and the ability of the dominant organisms in each geomorphological unit to regenerate (Table 3.2).

3.1.2 Biological sensitivity (fragility) within geomorphological units

Each geomorphological unit can be subdivided further into biological communities of varying sensitivity (fragility) to physical disturbance. For example, the karst complex is composed of limestone platforms with sand and algae covering and circular pot holes with fragile coral structures on the slopes. This geomorphological unit is classified by Hatcher *et al.,* (1988) as sensitive because of the presence of fragile coral, however, the coral is not uniformly spread throughout the unit. Thus, the platform communities would have a low sensitivity to disturbance but the branching corals would be highly sensitive. Therefore, this report relates physical disturbance to the sensitivity of the dominant biological communities in each geomorphological unit. See Appendix 1 for a description of the sensitivity of biological units.

3.2 Collection of data on human activities

Information about human activities at the islands was obtained through a series of interviews with the various professional and recreational user groups but was supplemented by quantitative data where possible. Aerial surveys of rock lobster pot distributions also were conducted. The study was restricted to depths of less than 20m because these are the areas most susceptible to the impacts from human activities. Furthermore, there are increased logistical constraints of habitat identification, mapping and assessment at greater depths.

The information obtained from interviews was based partly on written records and partly on interviewees' memory of fishing and recreational effort for the past five years. However, the information was assumed to be reasonably accurate. Due to the nature of these data, no attempt was made to quantify the uncertainty around the estimates presented in this report. The interview data represent the total fishing or recreational effort on an annual basis averaged over five years (1996-2000). Seasonal and annual variations generally were not captured during the interviews.

3.2.1 Western rock lobster fishing

The primary potential physical impacts caused by rock lobster fishing is damage caused by deployment and retrieval of rock lobster pots and from jetboat disturbance when operating in very shallow water i.e <1m. Information on the intensity of rock lobster fishing effort at the islands was collated from aerial surveys, interviews, and existing catch and fishing effort data bases (research log-book, monthly fishing returns) held at the Department of Fisheries.

3.2.1.1 Aerial surveys

Aerial surveys were conducted at the Abrolhos at the beginning and middle of the season to observe seasonal changes in fishing effort during a single season. Flights were conducted on March 15 and 16 (start of the season) and May 11 (middle of the season) in 2001. Surveys involved flying over each island group with two observers recording the number of pots spotted in areas readily identified from aerial photos (to an estimated depth of around 20m). The numbers of pots were recorded onto aerial photographs during the flights and later entered into the Geographical Information System (GIS). This "snap shot" of daily effort was related to geomorphological units. Potting densities calculated for aerial surveys only relate to the information collected on the day of the survey.

3.2.1.2 Interviews with rock lobster fishers

During April 2001, fishers were interviewed at their camps on each island group and asked about their fishing effort. Fishers were interviewed randomly and a total of 80 out of 149 fishers (53.7%) were interviewed. Whilst this study was restricted to consider activities in less than 20 metres, both deep and shallow water fishers were interviewed, as a proportion of pots set by the deeper water fishers were within the shallow areas.

Fishers were asked to mark on 1:40,000 aerial photographs, areas where they set pots and assign a proportion of their fishing effort associated with each area during a season. The proportions were averages over the previous five seasons. The number of working pots and seasonal changes in fishing patterns were also noted. An example of the interview is provided in Appendix 2. The proportions were scaled up to equal the number of pot lifts recorded in the logbook/monthly return data sets.

An objective of determining individual fishing efforts was to calculate the total number of pots set per hectare of seabed per fishing season. The areas of habitat were the estimated surface areas from the GIS maps. This two-dimensional approach is biased somewhat given the habitat is three-dimensional and not all of the area would be available for potting. Nevertheless, the surface area is considered a useful approximation of the extent of each habitat type.

3.2.2 Scallop fishing

Potential impacts from trawling activities include structural damage to the habitat from nets, anchors and scallop shells from "shucking". Members of the West Coast Trawl Association were interviewed to determine scallop trawling grounds and locations where boats anchor and shuck shells at the Abrolhos. Fishers agreed to mark on a series of marine charts, grounds where they have frequently fished in the last five years and previously in the last twenty years. The fishers claimed that they were unable to identify the frequency that different areas are fished during each season. However, some summary information was available from scallop log books from 1999 and 2000.

Information about scallop fishing grounds was then related to a study of bottom types in current and historically trawled areas at the Abrolhos Islands (Dibden and Joll 1998).

3.2.3 Wetline fishing

The term wetfish refers to cartilaginous fish (e.g shark) and scale- or fin-fish (e.g dhufish and snapper). The usual methods of wetline fishing are hand lining, drop lining, beach seining and hand hauled netting. At the Abrolhos Islands, gill net, long line and set line are prohibited at all times (Abrolhos Islands Fishing Methods Notice 1994).

Any commercial fishing boat can wetline and therefore the composition of the wetline fleet is extremely complex and difficult to both describe and quantify (Crow *et al.,* 1999). This study examined the 'wetline only' fleet, which are commercial fishermen targeting wetfish exclusively and were not licensed to operate in any other managed or interim managed fishery e.g rock lobster, scallop etc.

Potential impacts from wetline fishers are mainly from anchor deployment and possibly from fishing gear (snagged monofilament fishing line), which may interfere with the benthic habitat.

Information about the activities of 'wetline only' fleet at the Abrolhos was obtained from the monthly catch and effort data submitted to the Department of Fisheries. These data are recorded in grided fishing blocks, a series of geographical blocks covering Western Australian fishing waters, used for management purposes. The Abrolhos Islands are covered by three of these blocks (see Map 1 Crowe *et al.,* 1996). The Abrolhos fishing blocks extend well beyond the Fish Habitat Protection Area (FHPA), and so a judgement has to be made about the proportion of the catch originating the Abrolhos FHPA.

Information relating to commercial wetline fishing in the Abrolhos FHPA was obtained from Mr Mal McCrae, President of the Geraldton/Abrolhos Mid West Wetliners Association. Mr McCrae was able to recollect information for only the last two years. Each 'wetline only' fisher has over 500 locations within the Fish Habitat Protection Area where they drop anchor and fish. On the advice of the Mr McCrae, individual fishers within the FHPA were not interviewed to determine fishing locations or frequency of visits. This is because the individual wetline fishers operating within the FHPA vary from year to year, and it would be difficult to identify and locate these fishers, and even if all fishers were interviewed, it would be unlikely that they would be able to recollect their fishing locations and frequency of visits.

3.2.4 Recreational activities

The potential physical impacts associated with recreational activities at the Abrolhos are damage from anchors and SCUBA divers. There is little information available about the number of recreational visitors to the islands or their activities. To gain an understanding, interviews were conducted with various recreational user groups. In December 2000, an informal workshop and general discussions were held with Geraldton Charter Boat Association members. Members from yacht clubs and marinas throughout the state also were interviewed. However, many yacht clubs and marinas claimed that their members do not visit the Abrolhos, or perhaps only one or two visit occasionally but they were unable to identify these people for interview. Information about recreational activities of rock lobster fishers and visiting family and friends was not collected. Capturing information about the activities of these visitors was difficult due to the dispersed nature and infrequency of their visits.

Interviews comprised of a series of questions designed to determine the number of visitors per year, frequency of visits and the different recreational activities which they undertake. An example of the interview is provided in Appendix 3. The interview information was used to determine the frequency of anchor drops and number of SCUBA divers, both which have the potential to physically impact the environment. Calculation of numbers of anchor drops was related only to the number of times an anchor was deployed or retrieved at a location. For example, anchoring would be counted as occurring only once when a boat was in one position for several days and different activities such as diving or fishing were conducted from that site. Alternatively, a boat may return to the same location each night and, in this case, anchoring would be counted each time the anchor was deployed.

Information about recreational activities was related to habitat using the GIS.

3.3 Collection of data on natural source impacts

3.3.1 Weather

Potential impacts on the physical environment at the Abrolhos from events associated with the weather potentially are immense. In particular, the damage caused to sensitive environments by heavy wave activity is likely to be significant. The Bureau of Meteorology provided historical records on cyclones which have occurred in the region since 1915. The Bureau also provided data on wind speed recorded at North Island since 1990; including average monthly and average monthly maximum; wind direction/frequency analysis; and rainfall (recording commenced in December 2000). Wind roses for the Abrolhos are provided in Appendix 4.

The Department of Planning and Infrastructure provided data on swell height at Jurien (42m depth, 30° 17' 30" S, 114° 54' 52" E, data from 1998-2000) and Rottnest (48 m depth, 32° 06' 41" S, 115° 24' 07" E, data from 1994-2000), the closest open water wave rider locations to the Abrolhos. The data included average swell, average maximum swell and frequency of swell greater than a certain height (3m for Jurien, 4 m for Rottnest).

3.3.2 Natural perturbations

Natural perturbations refer to natural process imbalances within a system. For example massive increases in natural predators such as *Drupella cornus* and *Acanthaster planci*, deoxygenation from coral spawning and coral bleaching.

A literature search was conducted to determine if there have been any recorded imbalances in the marine system at the Abrolhos Islands. Scientific journals and books, fisheries and nature magazines and newspaper articles were examined. Scientists, historians and photographers from various institutions who have conducted research at the Abrolhos were also approached for published and unpublished material. Anecdotal information was sought from commercial fishers.

3.4 GIS and digital data generation

Geographical Information System (GIS) was considered to be an important tool to assist with the analysis of both the historical data and this study's survey data. It was necessary to convert some of the historical data, (eg. Hatcher *et al.,* (1988) habitat and pot effort data) into a digital form that would allow incorporation into a digital database. The data collected during the various surveys conducted for this study were a mix of textual files, photos and charts. Where GPS coordinates were provided, these were used to position activities. A technique called "Heads Up Digitizing" was used to enter most of the historical and survey data. Arcview 3.2 was the GIS software used for this study. This software has tools that enabled the manipulation of the various data sets to generate a series of combined data sets such as aerial survey pot distributions with Hatcher *et al's.* (1988) benthic habitats.

4.0 Description of the marine environment

4.1 Oceanography and the Leeuwin current

The dominant physical oceanographic event affecting the waters of the Abrolhos Islands is a southwards flowing current referred to as the Leeuwin Current. The Leeuwin Current is predominantly a geostrophic current (flowing down a gradient of sea level height) which is generated from an increased sea level height off Western Australia's north coast as Pacific Ocean trade winds push low salinity tropical water between Papua New Guinea and the Indonesian archipelago and Australia. To the south the sea level is lower, a gradient is established and consequently the amassed tropical water flows south (Pearce and Walker 1991). The strength of the flow is related directly to the volume of water shunted by the trade winds which, in turn, are affected by major climatic events. El Nino-Southern Oscillation (ENSO) events in the Pacific mean weak trade winds and consequently a weak Leeuwin Current. The opposite is true for La Nina conditions (Pearce and Walker 1991).

The Leeuwin Current tends to follow the continental shelf break from North West Cape south along the west coast of Western Australia, with the flow of the current generally at a maximum during winter. With continued La Nina events in the Pacific, the Leeuwin Current may persist throughout the year over a number of years. Large eddies and meanders often occur in the region of the Abrolhos Islands as the Leeuwin Current flows south (Pearce 1997). The warm Leeuwin Current flows around and through the Abrolhos Islands generally during autumn, winter and spring. The flow is greatest and most consistently south along the shelf break, a relatively short distance to the west of the Abrolhos. The currents through and inshore of the islands vary spatially and temporally. During the late spring and summer months, the current through and inshore of the islands tends to set to the north, driven by the prevailing southerly winds with occasional current direction reversal to the west along the shelf break. Summer easterly winds also affect the summer current patterns around the Abrolhos. Winter winds (westerlies and north-westerlies) generate southward setting currents inshore of the Abrolhos Islands (Pearce 1997).

4.1.1 Sea temperatures

The sea-surface temperatures around the islands tend to be stable, with the mean monthly maximum of 23.7°C in March and the minimum of 20.0°C occurring in September (Pearce 1997).

Water temperatures in relatively shallow or sheltered waters around the islands can follow the variation in air temperature, particularly during very hot and still, or, very windy conditions. This results in water temperatures that can rise above 23.7°C or drop below 20.0°C. The water temperature and salinity data gathered by Pearce (1997) in the vicinity of Rat Island, showed little thermal stratification, with minor differences between surface and bottom temperatures and salinities.

The diurnal water temperature pattern in the vicinity of Rat Island is similar to that at the coast (Pearce *et al.,* 1999), with the water temperatures tending to be lowest between 0600 and 0800 hours and highest in the early afternoon.

4.1.2 Chlorophyll

A number of water samples (44) were taken at 12 sites in the Abrolhos Islands area, on 12 occasions between September 1982 and September 1983 by Dr Bruce Hatcher (Hellerin and Pearce 2000). The samples were analysed for chlorophyll-a concentration. The highest concentrations of chlorophyll-a were from samples taken from the lagoon of the Easter Group on three separate occasions, April 7, 1983 (0.14 µg/L), April 21, 1983 (0.11 µg/L) and July 24, 1983 (0.14 µg/L) (unpublished data). The chlorophyll-a concentrations for all samples ranged from zero to 0.14 µg/L, the mean was 0.040 µg/L ± 0.032 µg/L and the median was 0.03 µg/L.

4.1.3 Climatological data

4.1.3.1 Wind

Dominant winds were from the southwest to southeast and exhibited both seasonal and diurnal patterns. Appendix 4 illustrates the frequency of winds by direction on a monthly basis since 1990. Winds are characterised in summer by consistently strong, south to south-easterlies in the morning with generally stronger south to south-westerlies in the afternoon. Winter winds tended to be weaker in the winter months and highly variable in terms of direction.

Over 40% of winds were from the south, and over 50% of strong winds (over 30 km/h) were from the south (Figure 4.1).

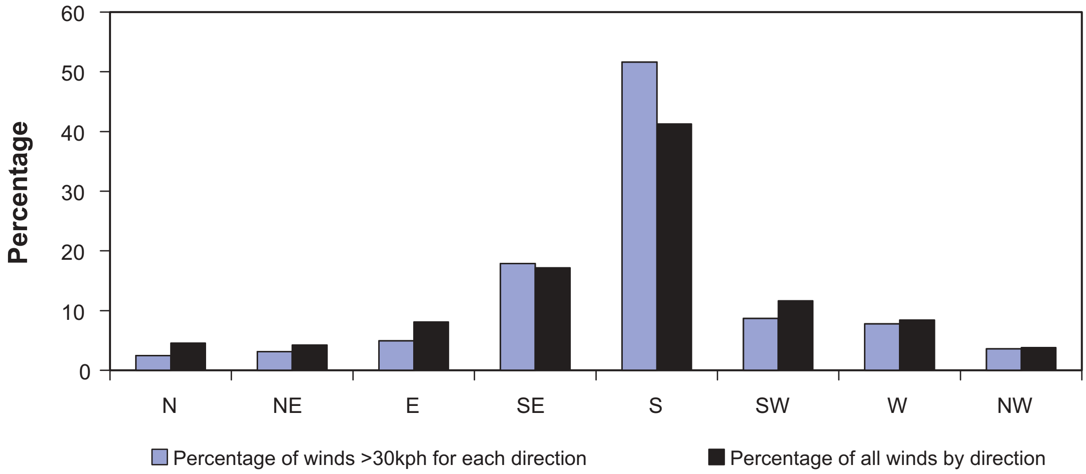


Figure 4.1. Wind direction relative frequencies at North Island since 1990. Data from Bureau of Meteorology.

Wind speeds in excess of 32 km/h occurred 44% of the time at the Islands (Anon. 1998). Calm conditions were rare and occurred mainly in winter (Anon. 1998). The average monthly maximum wind speed at the Abrolhos was 53.6 km/h. The average monthly wind speed was 26.4 km/h (Figure 4.2).

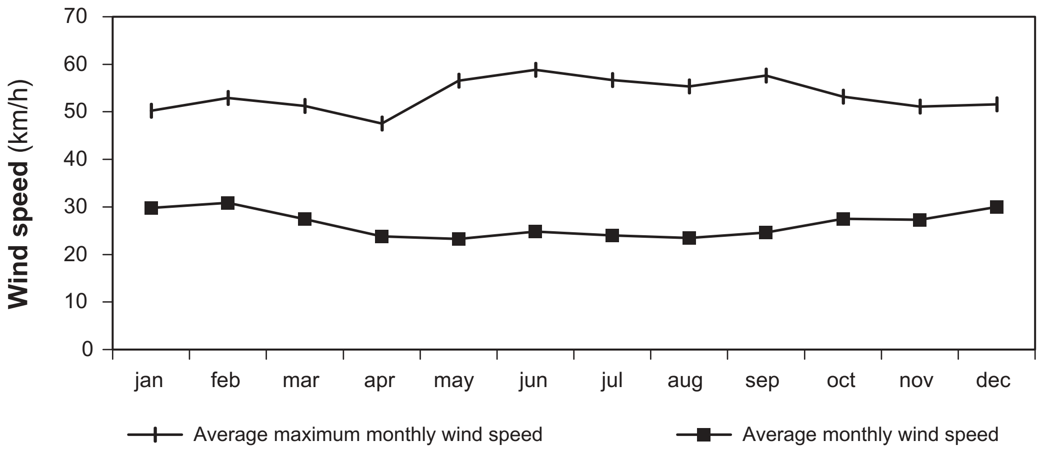


Figure 4.2. Average monthly wind speed at the Abrolhos Islands since 1990. Data from the Bureau of Meteorology.

4.1.3.2 Swell

The mean swell height throughout the year was 1.2m, approaching from the south and west 78% of the time (Steedman 1977). Wave impact energy was strongest on the southwesterly reef margins, forming the high energy, windward region of the platforms, whereas significant refracted swell and wind wave action impinged on southeast margins, forming medium energy leeward environments. This is consistent with the lack of well-developed coral communities on the western seaward section of the reef platforms. Here grows a mixture of macroalgae of temperate and tropical affinities (Hatcher *et al.,* 1988). In contrast, the eastern platform margins and lagoons support rich coral communities with high species diversity and high community production and calcification rates (Hatcher *et al.,* 1988).

The Department of Transport maintains records for swell height at various points along the coast of Western Australia. There is not a wave rider buoy positioned at the Abrolhos, however, data obtained from Jurien and Rottnest gives an indication of the swell affecting the west coast in that region. Records for swell height at Rottnest and Jurien commenced in 1994 and 1998 respectively (Figure 4.3).

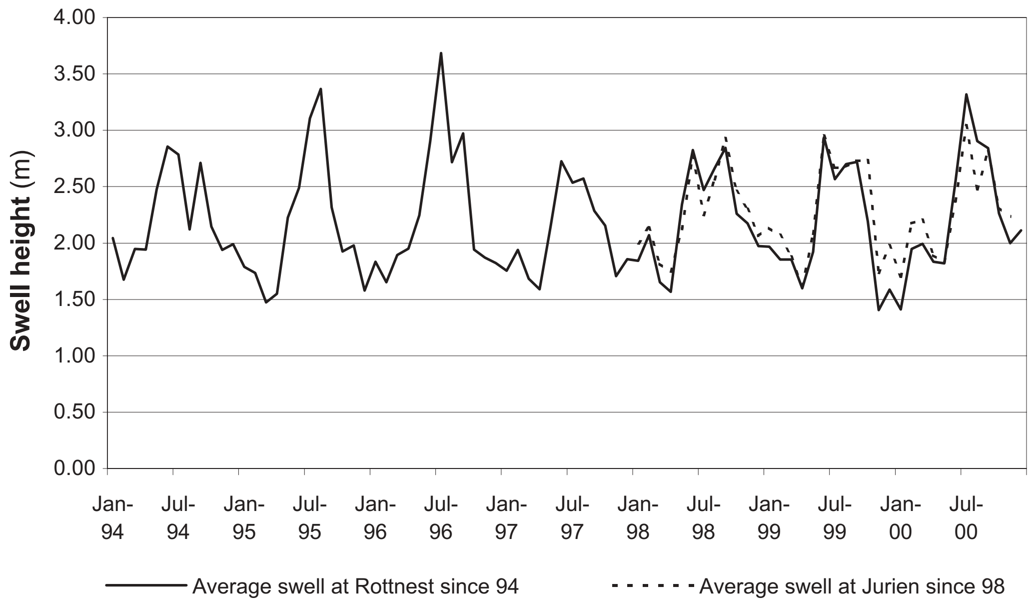


Figure 4.3. Average swell height over time (Rottnest and Jurien) demonstrating the pattern of significant winter swell and calmer summer months. Data from the Department of Transport.

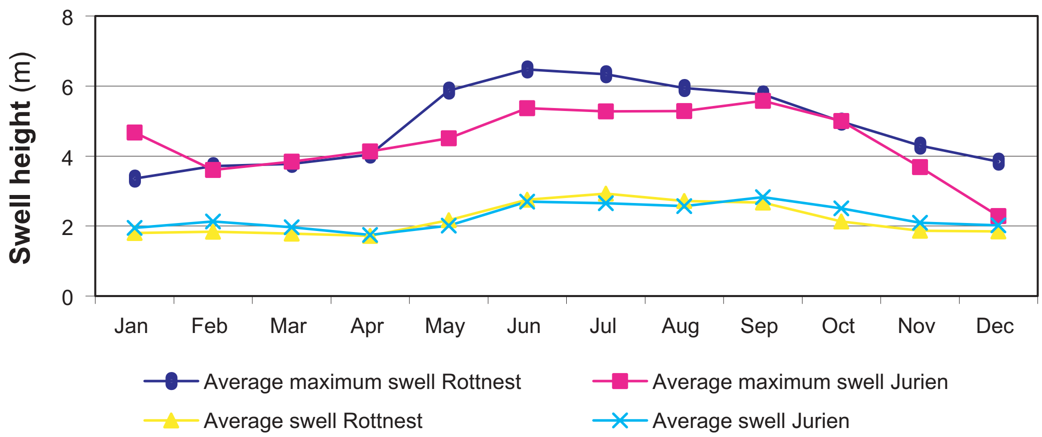


Figure 4.4. Average maximum swell height at Rottnest and Jurien. Data from the Department of Transport.

An obvious seasonal pattern is for swell to be generally low with an average height of 1.5 - 2.0 m during the summer and increasing during the winter months to an average height of about 2.5 - 3.5 m but it can reach an average maximum of about 5 - 6 m (Figure 4.4).

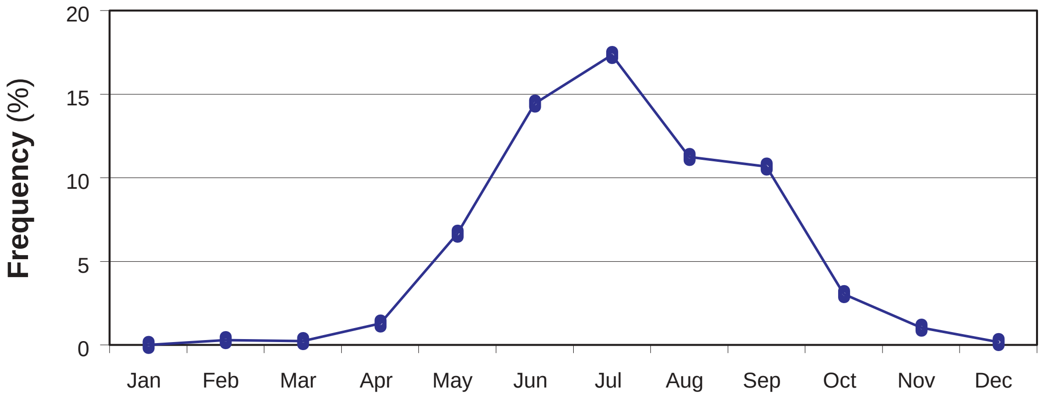


Figure 4.5. Frequency of swell at Rottnest greater than 4m.*

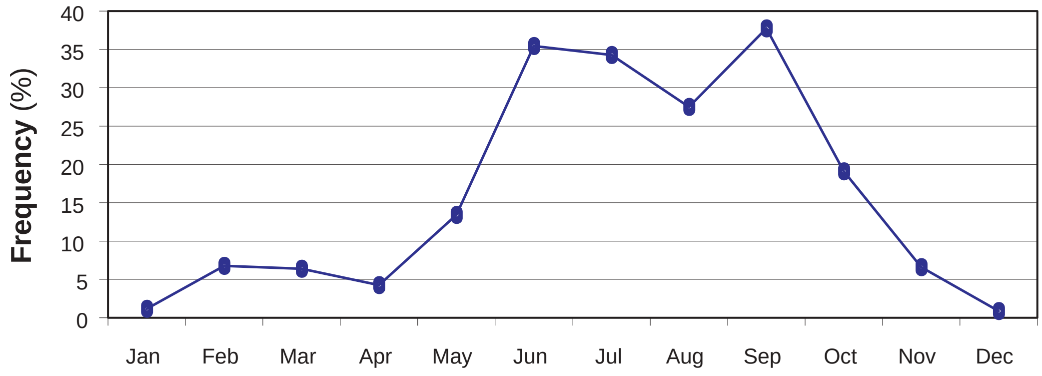


Figure 4.6. Frequency of swell at Jurien greater than 3m.*

* These figures represent the average frequency of waves recorded over 4m and 3m for Rottnest and Jurien respectively out of the total number of recordings for each month.

The Jurien buoy indicated that large swells (>3m) occurred in the region around 35% of the time during the period June to September, with the largest swells probably hitting the region in July or August (Figure 4.6).

4.1.3.3 Rainfall

Rainfall data for the Abrolhos are available only from December 2000 (Figure 4.7). The pattern clearly emerging from the data is consistent with anecdotal evidence that the Abrolhos Islands undergo a dry summer and wet winter.

Rainfall has been observed to cause runoff from the Islands (C. J. Dibden, Department of Fisheries, Western Australia, E. Toomey and H. Harmer, rock lobster fishers, pers. comm.) which could lead to sedimentation and, therefore, coral mortality.

4.1.3.4 Water temperature

Water temperature was logged by the Department of Fisheries at Cacka Flats (Easter Group) on a continuous basis. The average water temperature ranges between 20 - 25°C. The warm winter water temperatures being maintained by the presence of the Leeuwin Current.

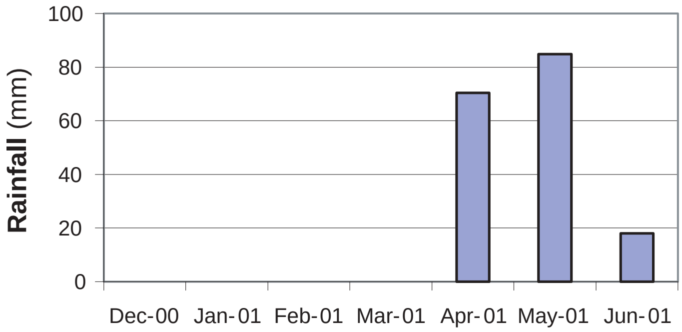


Figure 4.7. Rainfall at North Island since December 2000.

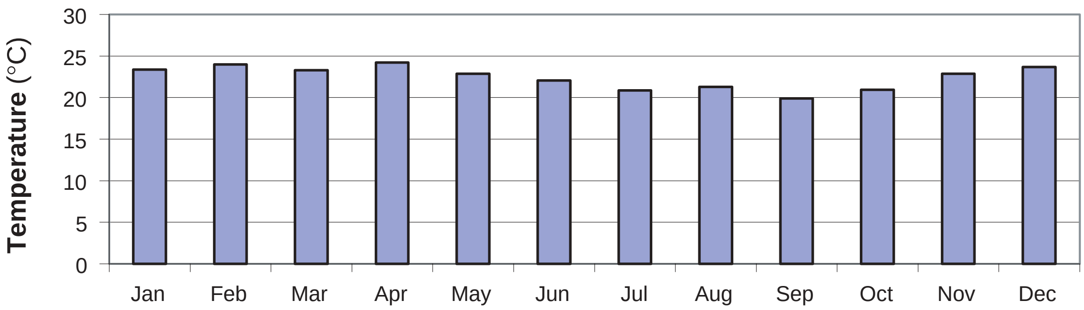


Figure 4.8. Average water temperature at Cacka Flats, Easter Group since 1996.

4.1.3.5 Cyclones

Winter storms are significant and summer tropical cyclones occur at an average frequency of once every 5 years. Up to 90% of cyclones approach from the northwest. The possibility of wind speeds reaching 165 km/h occurs once every 50 years, with 176 km/h winds possible once every 100 years (Anon. 1998). A winter storm which occurred around 1992 demolished a large patch of staghorn and tabular coral near Rat Island, Easter Group (H. Harmer, rock lobster fisher, pers. comm.). The area almost totally recovered three years after the storm.

Cyclones occurred in the Geraldton and Abrolhos area on the following dates (from Department of Meterology):

February 1915	March 1934	March 1975
January 1916	February 1937	February 1976
February 1921	February 1939	April 1978

January 1923	January 1949	March 1979
March 1923	March 1956	May 1988
March 1927	March 1960	

The effect of severe storm and cyclone damage on the Abrolhos habitats is likely to be significant, however, it is unquantified. Anecdotal observations indicate that storms or cyclones have potentially affected large patches of fragile corals such as branching and tabulate *Acropora* spp. The large storm rubble fields around the Abrolhos bear testament to the powerful physical impact of such events. It is not necessary for the cyclones or severe storms to pass directly over the Abrolhos, the impact may be from the strong winds and huge swells and seas generated by them.

4.2 Geomorphology

The Abrolhos chain comprises three island groups which differ geomorphologically becoming less organised to the north. Nevertheless, a windward reef, leeward reef and lagoon with a central platform are distinguishable in each group (Collins *et al.,* 1993a). Furthermore the eastern sectors of each island group contain a distinct "blue hole" terrain that is absent from the western and central parts (Figure 4.9). The "blue hole" terrain is submerged reef platform with steep-sided circular-shaped depressions, usually 15-25m deep with a sand floor (Collins *et al.,* 1996).

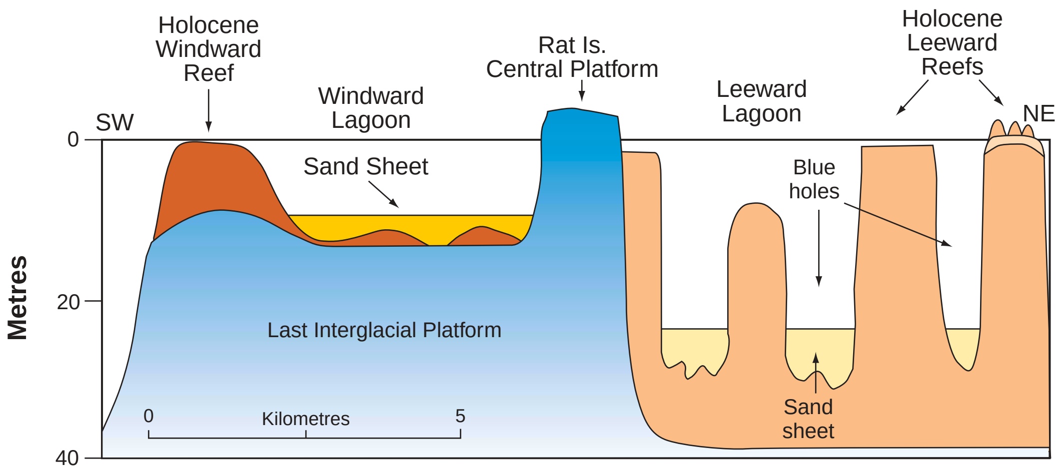


Figure 4.9. Generalised geomorphology of the Easter Group showing windward reef and lagoon, central platform and leeward lagoon and reefs including "blue hole" terrain (adapted from Collins *et al.,* 1998).

The Abrolhos are believed to have formed over three distinct geological periods; the Tertiary (65 million – 2 million years ago), the Pleistocene (2 million –10 thousand years ago) and the Holocene (last 10 thousand years). The geomorphological structures from the last two periods are present as ancient reef platforms which sit above the current sea level and form the central islands within each group, e.g Rat Island (Collins *et al.,* 1996).

The Abrolhos formation began during the Tertiary period during an era of cool water temperatures. Reef deposits were cool-water carbonate sediments dominated by bryozoans, molluscs and echinoids (forming calcarenites and calcitites) and lacked the warmer-water reef-building corals (Collins *et al.,* 1991, Hatcher 1991).

Reef formation continued during the late Pleistocene during an interglacial period when sea levels were higher due to the partial melting of glaciers (Figure 4.10; Collins *et al.,* 1998). During this interglacial period sea levels were up to 6m higher than present (Zhu *et al.,* 1993). Several researchers have attempted to refine the dates of this period of reef growth. A general consensus is that the highest sea levels occurred between 132 thousand – 117 thousand years before present and significant reef accretion would have occurred during this period (Collins *et al.,* 1991, 1993b, Zhu *et al.,* 1993). The growth of the Abrolhos reefs during this interglacial period was probably due to the Leeuwin Current which came into existence in the middle to late Pleistocene (Collins *et al.,* 1998, Kendrick *et al.,* 1991). The Leeuwin Current is believed to favour the maintenance of coral communities by influencing many factors essential for coral reef accretion such as temperature, larval delivery and nutrient concentrations (Collins *et al.,* 1993b). Evidence suggests that the Leeuwin Current activity was stronger during the Pleistocene period since the coral and mollusc fossil record deposited during this era shows a greater tropical affinity (Collins *et al.,* 1991).

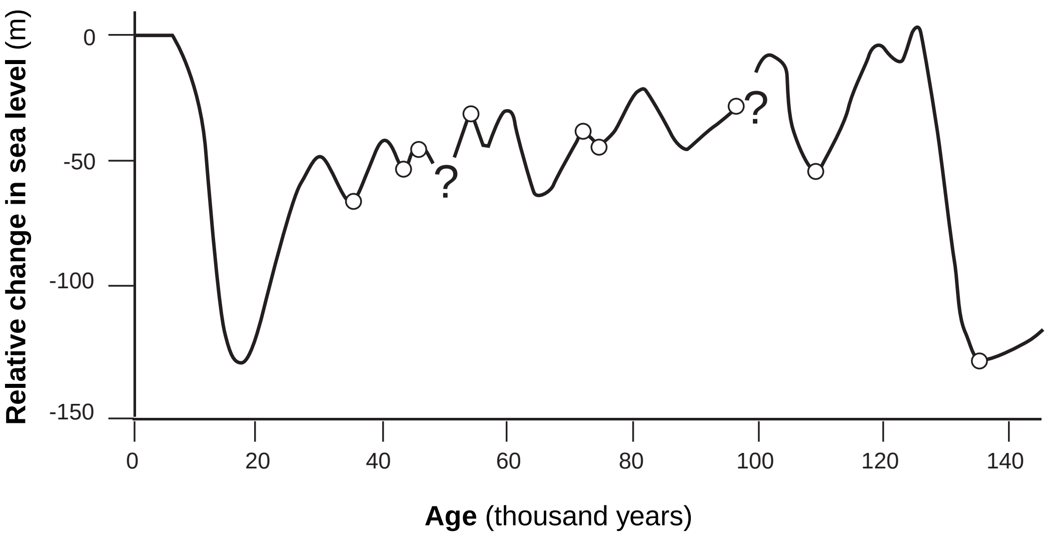


Figure 4.10. Changes in sea level over the past 140,000 years as measured at the Huon Peninsula, Papua New Guinea (adapted from Chapell and Shackleton 1986).

Reef development was interrupted during the last glacial period which occurred between approximately 110 thousand to 10 thousand years before present (Figure 4.10). During this period, sea levels were as much as 150m below present sea levels and reefs formed during the previous interglacial period were exposed (Collins *et al.,* 1991). Atmospheric exposure modified the morphology of the Pleistocene reefs and calcretes (conglomerate of sand and rubble cemented by calcium carbonate) were formed (Collins *et al.,* 1993a).

Around 9,800 years ago, during the Holocene, another interglacial period began and sea levels rose again, oscillating slightly before reaching current levels (Eisenhauer *et al.,* 1993).

Current sea levels are lower than previous interglacial sea levels and some of the reefs formed during previous periods are emergent and form the islands seen at the Abrolhos today. Modern reefs, formed during the last 9,800 years, occur over the top of ancient Pleistocene reefs. These modern reefs are strongly asymmetrical. On the windward (western) side of the Abrolhos, Holocene reef growth is only a thin veneer in comparison to the leeward (eastern) side Holocene reef which is up to 40m thick (Figure 4.9; Collins *et al.,* 1998). The most likely control of this asymmetry is the islands which form an energy shadow from the consistent south westerly wave regime.

Reefs on the western (windward) side of the Abrolhos are shallower and more exposed to wave action and are dominated by coralline algae and macroalgae. Here the macroalgae are able to outcompete corals (Collins *et al.,* 1998). In contrast, on the leeward (eastern) side of the islands, the water is deeper and more protected and branching corals have rapidly accumulated in this area. The "blue hole" terrain forms a part of the modern leeward reef, but the origin of its shape remains a mystery.

Islands formed on the eastern (leeward) side of the Abrolhos are much more modern than the central islands and have formed in the last 5000 years from coral rubble (Collins *et al.,* 1993b, 1996, Fairbridge 1948, Zhu *et al.,* 1993).

4.3 Marine biota

Biogeographic zones refer to areas having a similar biota, determined by long term hydrographic, geological and climatological processes. Western Australia has two biogeographic zones, the Northern Australian Tropical Province and the Southern Australian Warm Temperate Province (Figure 4.11; Morgan and Wells 1991). The two provinces overlap creating the West Coast Overlap Zone, a region of transition with gradual replacement of tropical biota by predominately temperate biota with increasing latitude. The Abrolhos is situated in the overlap zone but, essentially, is a tropical ecosystem (Morgan and Wells 1991).

The Abrolhos fauna is dominated by species of tropical origin, many existing at the southern limit of their range. However, algae and seagrasses are of predominately temperate origin, and the Abrolhos has the unusual mixture of tropical corals living in close association with temperate macroalgal species. Superimposed on the tropical-temperate mixture is a small number of species endemic to Western Australia. While these endemic species occur in all parts of Western Australia, they are concentrated in the West Coast Overlap Zone (Wells 1997). Certain endemic species maybe ecologically or economically important, for example, the western rock lobster (*Panulirus cygnus)*.

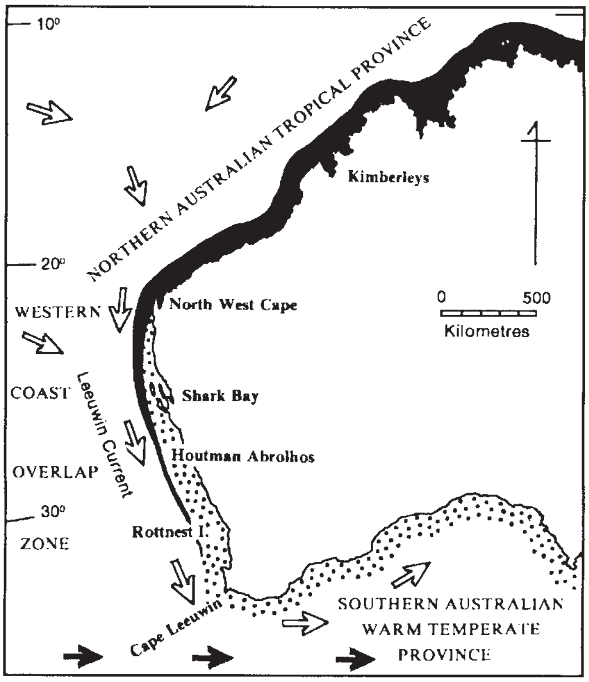


Figure 4.11. Zoogeographic provinces of Western Australia (reproduced with permission from Morgan and Wells 1991).

4.3.1 Algae

The marine benthic algae of the Abrolhos were reviewed by Huisman (1997). Two hundred and sixty species were identified, comprising 32 species of green algae (Chlorophyta), 50 species of brown algae (Phaeophyta) and 178 species of red algae (Rhodophyta). Fifty three species and 4 varieties were new records for the Indian Ocean off the coast of Western Australia.

Abrolhos algae are of predominately temperate origin intermixed with tropical species, many of which grow at the northern and southern limits of their respective ranges. Algal stands of *Turbinaria, Sargassum, Eucheuma*, and *Laurencia* can be found amongst corals on protected reefs (Crossland 1981) and the temperate kelp *Ecklonia radiata* on outer reef slopes where water turbulence is high (Johannes *et al.,* 1983).

Environmental conditions at the Abrolhos are favourable for algal growth (Crossland 1981). Nutrient concentrations are high in comparison to tropical reef counterparts and water temperatures are moderate. The absence of very warm or very cool water temperatures allow most tropical and temperate species to coexist at close to optimal conditions for both groups (Crossland 1981). However, for some species environmental conditions at certain times of the year are at the edge of their physiological tolerance. Growth of the kelp, *Ecklonia radiata*, was examined at the Abrolhos, the northern limit of its range. At certain times of the year, when water temperatures were greater than 23°C, kelp growth was retarded and mortality increased. However, significant variations in kelp growth and survivorship between study sites at the Abrolhos, suggest that factors other than temperature also have a role in the performance of this species at the Abrolhos (Hatcher *et al.,* 1987).

The algae contribute significantly to the total productivity of the Abrolhos system (Smith 1981). Algae are an important part of primary production in the food webs that support animal communities, including corals and those fish caught commercially. Algae may be consumed directly or be broken down to form detritus, which is consumed by bacteria and small invertebrates which in turn are eaten by larger carnivorous species (Anon. 1998). The lagoon waters of the Abrolhos carry high concentrations of particulate organic material, due in part to inputs of macroalgal detritus from the high-energy windward reef slopes (Crossland *et al.,* 1983, Hatcher 1983).

Measurements of grazing intensity on algae have been conducted at the Abrolhos (Hatcher and Rimmer 1985). Experiments involving the exclusion of grazing molluscs demonstrated that rates of grazing upon algae were significantly higher on the windward reef flat than at a lagoon patch reef. The difference in grazing rates between the two sites possibly may be related to the high levels of organic matter and detritus in the lagoons which molluscs may rely upon in preference to grazing.

The absolute grazing rates in coral reef habitats is lower at the Abrolhos compared to tropical counterparts (Hatcher and Rimmer 1985). This may be a consequence of the relative lack of herbivorous fish schools at the Abrolhos. Wilson and Marsh (1979) reported a noticeable absence of schooling siganids (rabbitfish), acanthurids (surgeonfish) and mugilids (mullet), dominant herbivores in tropical reef systems. The effect of grazing upon algal community structure also has been examined. It was found that macro-grazers such as parrot fish affect the abundance of small turf-forming algae, but do not have an effect on the larger forms which seasonally dominate the benthic community in terms of both biomass and cover (Hatcher and Rimmer 1985).

4.3.2 Flora

Ten species of seagrass have been recorded from the Abrolhos (Brearley 1997). These are mainly temperate species, seven of which are at or near the northern extent of their range and only three having tropical affinities. The seagrass communities at the Abrolhos are poor compared to Shark Bay (14 species) and Geraldton (13 species). The lack of extensive seagrass meadows at the Abrolhos and reduced species diversity may be related to a lack of suitable areas for seagrass establishment, the small amount of time to collect species and/or low winter water temperatures prohibiting the establishment of more tropical species (Brearley 1997).

Seagrasses play an important role in marine ecosystems. They are primary producers, reduce water movement, stablise sediments and provide habitats for a diverse assemblage of algae and invertebrates. Seagrass beds also provide nursery areas for many fish and invertebrates (Anon. 1998).

4.3.3 Fauna

4.3.3.1 Invertebrates

Coral Reefs

The Abrolhos coral reef system is the most southerly in the Indian Ocean. The presence of coral reefs at such high latitudes is attributed to the Leeuwin Current providing a source of warm water for coral function and survival and coral planulae from equatorial regions (Hatcher 1991, Pearce 1997, Wilson and Marsh 1979). The Abrolhos reefs have most of the structural habitats of tropical reef systems (Wilson and Marsh 1979).

Given the high latitudes, coral diversity is very high for the Abrolhos reefs. About 180 species of hermatypic corals in 40 genera and a further 10 species of ahermatypes in eight genera are found there. All but two coral species are tropical (Hatcher *et al.,* 1990, Wilson and Marsh 1979). *Acropora* species dominate both shallow leeward and lagoon reef habitats. At deeper, or more sheltered sites, genera including *Montipora, Echinopyllia, Oxypora, Mycedium, Pachyseris* and *Leptoseris* are common (Hatcher *et al.,* 1988).

The coral reef community at the Abrolhos is different to most coral reef systems due to the presence of fleshy macroalgae (Johannes *et al.,* 1983). Macroalgae at the Abrolhos are in direct competition with corals for light, space and nutrients (Hatcher *et al.,* 1990). Coral growth rates at the Abrolhos tended to be lower than those for tropical coral reefs (Crossland 1981, Harriot 1998). The depressed coral growth rates were attributed to the interaction of lower temperatures and light regimes during the winter, and the seasonal growth of and shading by algae. With favourable environmental conditions and an absence of large herbivores, macroalgae are able to overgrow live coral. Coral growth rates can be reduced by as much as 60% and survivorship by up to 50% in one year (Crossland 1981, Hatcher *et al.,* 1990).

Despite reduced coral growth, productivity of the reef community at the Abrolhos is high (Smith 1981). Measurements of calcium carbonate and organic carbon production found rates to be higher than for tropical reefs, a feature attributable to high levels of sunlight. The high rates of production demonstrate that coral reef communities are not stressed at latitudinal limits. However, production of organic carbon probably is directly attributed to the abundant fleshy and coralline algae within the community, not to the corals (Smith 1981).

There is anecdotal evidence from divers that branching corals at the Abrolhos are more susceptible to diver damage than in more tropical environments, however, scientific evidence is equivocal. Crossland (1981, 1984) reported slow growth and seasonally depressed calcification in one coral species at the Abrolhos and was concerned it could translate into corals possessing delicate structures and being more susceptible to physical damage. A more recent investigation (Harriot 1997) suggested that skeletal density of *Acropora formosa* (a branching coral) at the Abrolhos was higher than individuals of the same species at Ningaloo reef which is a more tropical environment.

Hariott (1997) also reported that branching *Acropora* species at the Abrolhos produced denser and thicker carbonate skeletons in areas where currents were strong but less dense and weaker skeletons in deeper areas where flow rates were much reduced.

Crustaceans

Crustaceans are a diverse group of animals which range in size from planktonic organisms such as copepods to macro-organisms like the western rock lobster, *Panulirus cygnus*.

A complete catalogue listing the crustaceans of the Abrolhos Islands is being developed and will be available from the Western Australian Museum in the near future. Lists of crustacean families have been published and include, barnacles, crabs, and lobsters. In the Western Australian Museum collection there are over 35 species of crustaceans, collected from the Abrolhos Islands (Dr D. Jones, Western Australian Museum, pers. comm.). These include a species of hermit crab, *Calcinus abrolhensis* (Morgan 1988). Previously, 44 species of Brachyura were identified at the Abrolhos (Montgomery 1929) and 9 species of Amphipods and 3 species of Isopods (Tattersall 1922).

Hydroids

Hydroids are small animals with a plant like appearance which grow attached to a substrate. A total of 137 species have been recorded at the Abrolhos with a mixture of tropical and temperate origins, the majority of which are attached to temperate algae (Watson 1997).

Molluscs

Intertidal and shallow water

A total of 492 species of marine molluscs are recorded from the Abrolhos in the vicinity of shallow water reefs. The dominance of tropical species found in other fauna groups also was encountered in shallow water molluscs. The percentage of tropical species was 68.6%, temperate 20.3% and species endemic to Western Australia 11.3%. For a comprehensive species list see Wells and Bryce (1997).

Drupella cornus is a coralivorous mollusc which has been recorded at the Abrolhos. At high densities it caused massive destruction along sections of the Ningaloo reef, however, at the Abrolhos it has not been observed in high concentrations or associated with large scale habitat destruction.

Deep water species

Little is known about the molluscan fauna from the Western Australian continental shelf. A study around the Wallabi Group at the Abrolhos revealed 135 species including the commercially dredged species *Amusium balloti* (southern saucer scallop) (Glover and Taylor 1997). The subtidal mollusc assemblage at the Abrolhos has both tropical and temperate affinities with some groups, such as the bivalves, tending to be more tropical in origin and others, such as archaeogastropods, more typical of temperate distributions. The molluscan fauna was identified as species rich, though in most habitats not very abundant, and extremely sparse on the sponge dominated and coralline algal substrates. The scallop grounds were found to have a diverse and distinct marine fauna dominated by *A.balloti* (Glover and Taylor 1997).

Worms

The majority of worms identified at the Abrolhos (22 species) are polychaete worms from the family Terellidae (Hutchings 1997). Sixteen oligochaete species have been identified from the order Tubifida (Erseus 1997).

Sponges

One hundred and nine demosponges (the largest class of sponge species) have been recorded from the Abrolhos, the majority of which are of temperate origin. The number of species recorded at the islands is likely to represent only a proportion of the total species due to restrictions on the sampling location. However, despite these restrictions it appears that in comparison to other areas the sponge fauna at the islands is rich (Fromont 1999).

Echinoderms

Echinoderms include Crinoidea (sea lillies and feather stars), Asteroidea (star fish), Ophiouroidea (brittle stars), Echinoidea (sea urchins) and Holothuroidea (sea cucumbers).

The echinoderm fauna of the Abrolhos is extremely rich and dominated by tropical species. Sixty three percent of the 172 species of echinoderms were tropical species, 14% were southern Australian temperate species and 21% were endemic to Western Australia but no species is confined to the islands. The richness of echinoderms is attributed to the presence of both tropical and temperate species in the West Coast Overlap Zone, due to the warm Leeuwin Current, and the Abrolhos habitat complexity which provides niches for a wide diversity of echinoderm life styles (Marsh 1994).

The crown of thorns starfish *Acanthaster planci* was not included in Marsh's (1994) summary of echinoderms. This species is a coral predator and has caused massive reef destruction at the Great Barrier Reef. However, only the occassional individual has been observed at the Abrolhos (Dr. J. Stoddart, Marine Science and Associates-Environmental Consultants, pers. comm.).

4.3.3.2 Vertebrates

Fish

The recorded fish fauna of the Abrolhos currently totals 389 species, 66% of which are tropical, 19% warm temperate and 13% subtropical. Several species are commercially important including the pink snapper, *Pagrus auratus*, baldchin groper *Choerodon rubescens*, Westralian dhufish *Glaucosoma hebraicum* and coral trout *Plectropomus leopardus*. Over 70% of the tropical fish species are very low in abundance suggesting that many are not maintaining breeding populations at the Abrolhos (Hutchins 1997). The Abrolhos has extensive coral reef systems and why fish populations are not more abundant is unknown. One hypothesis is that the dominance of a few types of coral such as *Acropora* (branching coral) limits the presence of coral specific fish species (Hutchins 1997). Furthermore, areas with high coral cover tend to be on the eastern side of the island groups away from the flow of the Leeuwin Current and may receive only low numbers of tropical fish recruits (Hutchins 1997).

Marine mammals

No direct research has been undertaken to identify marine mammals at the Abrolhos. However, Australian sealion *(Neophoca cinerea)*, humpback whale *(Megaptera novaeangliae)*, bryde's whale *(Balaenoptera acutorostrata)*, bottle nose dolphin (*Tursiops* spp), striped dolphin (*Stenella coeruleoalba*) have been sighted at the Abrolhos Islands. Dolphin species are present all year round in Abrolhos waters (Anon. 1998). The following anecdotal information is available (Gales 1984):

Australian sealion (*Neophoca cinerea*)
Individuals are commonly seen basking on the shores or swimming in the waters surrounding the Abrolhos. Gales (Department of Conservation and Land Management, Western Australia pers. comm.) has indicated that an average of about 20 sealion pups are born near the Abrolhos Islands (mainly the Easter Group) every 18 months.

humpback whale (*Megaptera novaeangliae*)
Sightings of humpback whales are common in the Abrolhos waters between April and October each year, during their northward breeding migration and the return journey to Antarctica (Anon. 1998).

Marine reptiles

The green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles are resident in low numbers in the waters off the Abrolhos Islands. Both of these species are towards the southern extent of their range, and do not breed at the Abrolhos because water temperatures are too low (Dr. R Prince, Department of Conservation and Land Management, Western Australia, pers. comm.).

5.0 Description of natural impacts on the environment

This section provides summary of the potential natural impacts on the marine environment.

5.1 Water movement

The Abrolhos Islands, situated on the edge of Western Australia's continental shelf are subjected throughout the year to generally high levels of water movement resulting from the presence of the Leeuwin Current, occasional cyclonic and severe storm events and other movement driven by tidal flux and the normal strong wind patterns. It is rare that the waters of the Abrolhos are still but such events do occur occasionally. The water movement in this region is responsible for a considerable level of erosion resulting in the spur and groove formation of the windward exposed reef slopes, for dissecting the emergent reef crest and for the movement of unconsolidated sediments. At the biological level, the distribution of animal larvae by the water movements and the strength of water flow determines how sessile organisms grow; for example, Harriott (1997) reported changes in *Acropora formosa* skeletal density in reef slope habitats compared to sheltered lagoon habitats.

5.2 Accretion and erosion

Changes in the physical environment are continual but often not noticed due to their slow pace over a long time period. Such processes can be seen at the Abrolhos using Beacon Island (Wallabi Group) as an example. Aerial photographs are available from 1966, 1986, 1998 and 1999. The period between 1966 and 1986 showed a noticeable change in the shape of the island where the northern tip of Beacon Island curved from a more straight western coastline towards an arc shaped outline (Plate 5.1a, b). In addition, the imagery showed a widening of the tip where a distinctive amount of broken coral material was deposited over time, a process which continued into 1999 (J. Franke, Curtin University, Western Australia pers. comm.).

a)

b)

Plate 5.1. Changes in the shape of the northern tip of Beacon Island between (a) 1966 and (b) 1998.

5.3 Storm impacts

The physical impacts of storms and cyclones on reef systems like the Abrolhos can be enormous. Also it is not necessary for cyclones, for example, to pass directly over the islands to affect them. All that is required is for the strong winds and large swells to encounter the islands and their reefs. Catastrophic impacts have been experienced by coral reef structures throughout the world. In the Caribbean, for example, it is not unknown for shallow, fringing reefs literally to be turned upside down by the wind and waves produced by hurricanes with effects noted down to 50m (Bonem 1988). Wind reversal from the normal pattern in Bonaire, resulting from the nearby passage of a hurricane, decimated shallow coral reef structures and dumped tonnes of coral rubble on normally sandy beaches (Dr C. F. Chubb, Department of Fisheries, Western Australia, pers. comm.).

The Abrolhos Islands are affected infrequently by cyclones (see Section 4.1.3) but only one cyclone is necessary for severe physical damage to be inflicted. However, severe storms are a frequent occurrence on Western Australia's west coast and these are likely to affect the Abrolhos marine habitats to a lesser or greater extent depending upon the severity of the storm. Storm surge and wave activity can break branching corals and upturn branching and small massive coral colonies. The presence of significant storm rubble deposits throughout the islands is evidence of the effects of storms and cyclones on the Abrolhos marine habitats (Plate 5.2 a and b).

5.4 Biological perturbations

Two coral predators, the crown of thorns starfish, *Acanthaster planci*, and the snail, *Drupella cornus*, have been observed at the Abrolhos but not in the plague proportions observed in other parts of Australia, such as the Great Barrier Reef or Ningaloo Reef.

In the past, concentrations of *D. cornus* were observed close to Big Rat and Beacon Islands. Whilst comprising several hundred individuals, these concentrations were not considered to be plague proportions and are no longer present. *D. cornus* currently is observed only as a few scattered individuals throughout the Abrolhos (Mr K. Nardi, Department of Fisheries, Western Australia, pers. comm.).

Only a few individuals of *A. planci* have ever been observed at the Abrolhos Islands (Dr. J. Stoddart, Marine Science and Associates-Environmental Consultants, pers. comm.).

5.5 Coral bleaching

Coral bleaching is the phenomenon where the individual polyp expels its symbiotic algae in response to stress, such as elevated water temperatures, and the coral turns white (Veron 1986). If the coral polyps do not die, they can recover from such stress. Prior to 2001, coral bleaching had not been observed at the Abrolhos, even during spring tides when large areas of reef are exposed. However, a single observation of apparent bleaching was observed in the blue hole terrain at the Easter Group in December 2001 (Associate Professor L. Collins, Curtin University, Western Australia pers. comm.). The general absence of coral bleaching probably is due to Abrolhos water temperatures not reaching the upper critical levels for coral mortality. Evidence for this hypothesis comes from the 1998 warm water event which caused extensive coral bleaching and decimated tropical coral reefs worldwide (Hoegh-Guldberg 1999), but had no discernable impact at the Abrolhos.

Plate 5.2a&b. Wooded Island, Easter Group, is composed of coral rubble, generated through storms, (photos C. Chubb).

5.6 Coral spawning

Coral spawning occurs when corals release eggs and sperm into the water in a massive synchronous event and fertilisation occurs producing coral larvae. At the Abrolhos Islands the major coral spawning event occurs over a 6-8 day period after the full moon in March or April, depending upon when the full moon occurs (Dr. C. Simpson, Department of Conservation and Land Management, Western Australia pers. comm.). If warm weather and calm conditions occur, the dense swarms of gametes and larvae may not disperse and the larval concentrations can severely deplete oxygen levels to below critical levels for survival. At the Ningaloo reef in 1989 coral spawning caused massive fish kills and coral death because the gametes and larvae did not disperse and oxygen levels became critically low (Hamilton 1990).

At the Abrolhos Islands, constant winds usually ensure that eggs and sperm are well mixed and larvae well dispersed. Oxygen depletion has occurred on a very localised scale, such as in some lagoons, causing some marine organisms such as fish and crustaceans to die (Dr C. F. Chubb, Department of Fisheries, Western Australia pers. comm.). However, a massive event such as that observed at Ningaloo in 1989 (Hamilton 1990), has not been observed at the Abrolhos.

6.0 Description of human use activities and their impacts on the marine environment

This section provides a background summary of current commercial and recreational human activities considered at the scientific workshop conducted to develop a strategic research plan. Potential issues associated with each human activity were identified.

6.1 Commercial fishing

6.1.1 Western rock lobster fishery

6.1.1.1 History

A rock lobster fishery has operated at the Abrolhos Islands since the 1880s when guano miners caught crayfish as a recreational pursuit (Gray 1999). By the mid to late 1940s the Abrolhos was the principle source of supply of rock lobster tails being canned for the armed forces (Sheard 1962). At this time, the majority of vessels were sailing craft (some fitted with auxiliary engines) and all pots were pulled by hand. Consequently the fishery was restricted to the shallow water reef areas within the Abrolhos. By the mid 1950s powerful engines, pot winches and echo sounders had been fitted to rock lobster vessels and the deep water areas outside the Abrolhos were being fished with the product marketed as frozen lobster tails in the United States (Sheard 1962). Since then technological advances in boat design and construction, navigation and fish-finding electronics and computers and the development of the lucrative Asian market for live and whole boiled lobsters, has seen the fleet evolve to a highly sophisticated level. In the Abrolhos larger vessels, in general, work the deeper waters whilst the purpose-built “jet boats” fish the shallows and moderately deep water within and around the reef margins of the island groups. In 1999/2000, 149 vessels were authorised to fish for rock lobsters in the Abrolhos region (A Zone), a number that has remained virtually static since 1993/94.

6.1.1.2 Economic value

Season 1999/2000 produced a catch of about 1750 tonnes (t) which was valued ex-vessel at $47 million and contributed about 12 percent of the total Western Australian landings. In the past 36 seasons, with the single exception of the 1985/86 catch of 1290 tonnes, landings from the Abrolhos have not fallen below 1500 t. The record catch of 1970 t was landed in 1998/99. Over the past 20 years catches have averaged 1700 t per season. Over the past 10 years the ex-vessel value of rock lobsters from the Abrolhos has ranged between $30 and $50 million.

6.1.1.3 Levels of fishing effort

The number of pots allocated to A Zone concessions was about 16,800 at the end of June 2000, however, under current management arrangements, only 13,800 were allowed to be fished. This led to 1.09 million pot lifts (= pot deployments) in A Zone in the 1999/2000 season. In 1993/94 a new management regime was introduced throughout the western rock lobster fishery to rebuild a severely depleted breeding stock. Amongst the package of regulations was a temporary reduction in pot usage of 18%. In the seven years since the management initiative was introduced, Abrolhos rock lobster fishers performed between 1.1 and 1.2 million pot lifts per season. In the seven years prior to 1993/94, pots were lifted between 1.4 and 1.5 million times. The management package was responsible for a decline in pot lifts of about 20% between the averages from the two time periods. Furthermore, the management arrangements forced current nominal fishing effort back to levels recorded for the mid 1960s (Figure 6.1). It is interesting to note that a similar temporary pot reduction of 10% in 1986/87 and the subsequent removal of those pots at 2% per year over the following five years, did nothing to reduce effort at the Abrolhos (Figure 6.1).The reason for this was simply that, as a reaction to pot losses, the fleet realised the considerable latent capacity to fish that existed then, and fishers worked more days of the season. Since the early 1990s, the fleet has fished almost the maximum number of days possible, so pot reductions now are an effective means of reducing fishing effort.

Rock lobster potting is the dominant human activity at the Abrolhos Islands. Superficially, the potential of this activity to cause physical disturbance to the Abrolhos marine habitats seems considerable. However, it is important to place this activity into proper context by first examining the proportion of total fishing effort expended in the shallow waters within and on the reef perimeters of the Abrolhos, then by examining the distribution of fishing effort within the geomorphological units in each of the island groups. This allows the effects of potting on fragile habitats to be assessed.

The average total A Zone fishing effort over the past five years was about 1.2 million pot lifts. The proportion of pot lifts made each Abrolhos season in waters less than 20m (approx. 10 fathoms) ranged between 48.6% and 58.9%, with an average of 52.0% or ≅568,000 pot lifts (Table 6.1) the remainder (48%) were set in waters deeper than 20m. The 0-20m depth category includes all geomorphological units in all island groups. On average 25%, 18% and 9% of the total A Zone effort was undertaken in the Wallabi/North Island Group, the Easter Group and the Pelsaert Group respectively. This equated to an average of 273,000 pot lifts in the Wallabi/North Island Group and 196,600 and 98,300 pot lifts respectively in the Easter and Pelsaert Groups. The distribution of effort across geomorphological units was given by the interview data.

Table 6.1. The average monthly percentages of total A Zone rock lobster potting effort undertaken in 0-20m of each island group.

		March	April	May	June	%
1995/96	Wallabi/North Is	5.5	6.9	6.5	5.5	24.5
	Easter	3.0	3.9	4.3	5.0	16.2
	Pelsaert	1.4	2.2	2.6	1.7	7.9
	Total	**10.0**	**13.0**	**13.4**	**12.2**	**48.6**
1996/97	Wallabi/North Is	4.7	8.7	7.5	6.7	27.5
	Easter	3.7	5.0	5.1	5.0	18.8
	Pelsaert	1.1	2.2	2.7	1.8	7.9
	Total	**9.5**	**15.9**	**15.2**	**13.5**	**54.2**
1997/98	Wallabi/North Is	4.5	7.1	7.4	6.7	25.8
	Easter	3.3	5.0	5.3	3.8	17.4
	Pelsaert	1.8	2.3	2.6	1.8	8.6
	Total	**9.6**	**14.5**	**15.3**	**12.4**	**51.8**
1998/99	Wallabi/North Is	4.2	7.1	5.9	4.3	21.5
	Easter	3.8	5.8	5.4	4.2	19.2
	Pelsaert	1.7	3.0	2.7	1.6	9.1
	Total	**9.7**	**16.0**	**13.9**	**10.2**	**49.8**
1999/00	Wallabi/North Is	5.1	9.3	6.8	6.1	27.3
	Easter	3.9	6.9	6.4	3.7	21.0
	Pelsaert	1.8	3.5	3.1	2.2	10.5
	Total	**10.8**	**19.7**	**16.4**	**12.0**	**58.9**
Average	Wallabi/North Is	4.9	7.7	6.8	5.8	25.2
	Easter	3.4	5.1	5.1	4.4	18.1
	Pelsaert	1.6	2.6	2.7	1.8	8.7
	Total	**9.9**	**15.4**	**14.6**	**12.1**	**52.0**

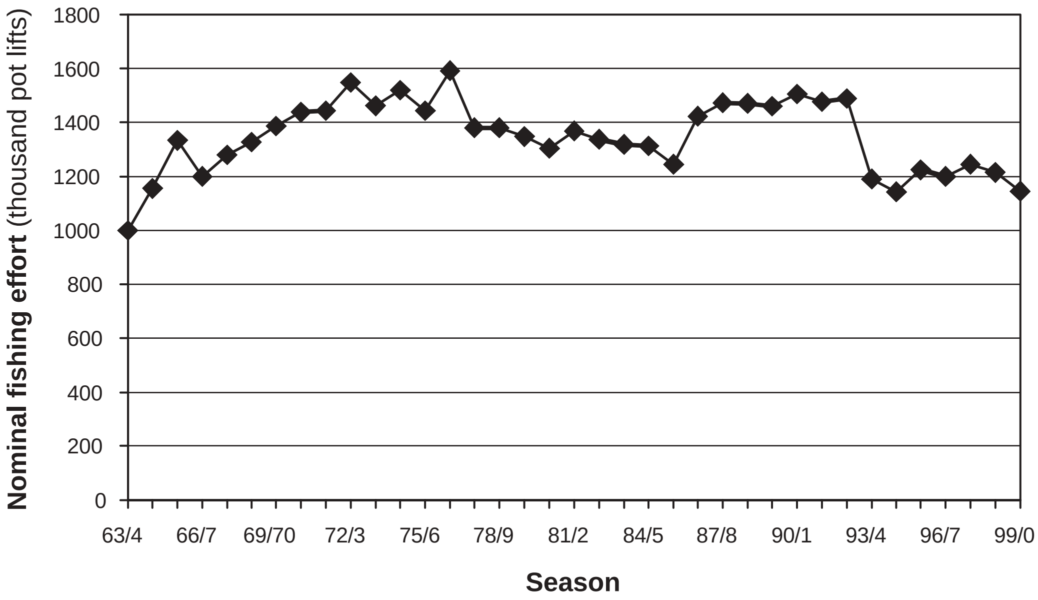


Figure 6.1. The time series of nominal fishing effort levels (pot lifts) at the Abrolhos Islands from 1963/64 until 1999/2000.

Interview data

Potting data from commercial fishers' interviews were combined over geomorphological units in each island group to relate rock lobster potting to the sensitivity (= fragility) of biological communities within those units to physical damage. The most heavily fished units through all island groups were the submerged limestone platforms and exposed reef slopes. Isolated patch reefs were important fishing areas in the Easter Group and the Wallabi/North Island Group (Table 6.2 Figure 6.2). In general, these three geomorphological units form the western and central parts of these island groups (Figure 3.1a, b). Sheltered reef slopes replaced isolated patch reefs as the third important fishing area in the Pelsaert Group (Table 6.2, Figure 6.2). The three most heavily fished geomorphological units in the Wallabi/North Island Group, Easter Group and Pelsaert Group respectively contributed 82.7%, 72.2% and 62.5% of all potting in depths of less than 20m.

Other relatively important units were the mobile sediment sheet in the Easter Group and the back reef in the Pelsaert Group (Table 6.2, Figure 6.2b). The high sensitivity eastern parts of the island groups, comprising the drowned doline fields, complex Karst platforms and sheltered reef slopes (Figure 6.3d-f), were little fished, attracting between 1.0-5.3% of the shallow water effort in each group (Table 6.2). The exception was the sheltered reef slopes of the Pelsaert Group which were fished with 17.8% of the shallow water effort expended in that group.

Table 6.2. The distributions of percentage of fishing effort (pot lifts) in 0-20m between geomorphological units within each island group during a season. Data are averaged over the five seasons 1995/96 to 1999/00. (W/NIG – Wallabi/North Island Group; EG – Easter Group; PG – Pelsaert Group).

Geomorphological Units	Total	W/NIG	EG	PG
Exposed reef slope	16.7	18.0	15.8	14.8
Submerged limestone platform	39.2	47.5	32.5	30.0
Emergent platform	2.0	1.9	1.5	3.3
Dissected limestone platform	3.3	2.9	2.8	5.3
Back reef	2.7	1.0	2.5	7.8
Mobile sediment sheet	4.2	0.2	9.8	4.1
Isolated patch reefs	16.9	17.2	24.0	1.9
Static sediment deposit	2.8	2.4	1.7	5.8
Drowned doline field	3.0	2.9	3.4	2.6
Complex karst platform	3.6	4.4	1.8	5.3
Storm rubble field	0.7	0.3	0.9	1.4
Sheltered reef slope	4.8	1.1	3.4	17.8

It should be noted that potting intensity across a geomorphological unit in any island group was not uniform. For example, varying levels of potting were noted in sections of the submerged platforms to the west of North Island and in the Easter and Pelsaert Groups; the sheltered reef slopes in the eastern region of the Wallabi Group; and the isolated patch reefs of the central and eastern parts of the Easter Group (Figure 6.3a-c). Recognizing these variations do exist, the potting data within each geomorphological unit were correlated with levels of sensitivity (fragility) relating to the differing biological communities within those units (Figures 6.3d-f, 6.4). Potting activity on biological communities having a low

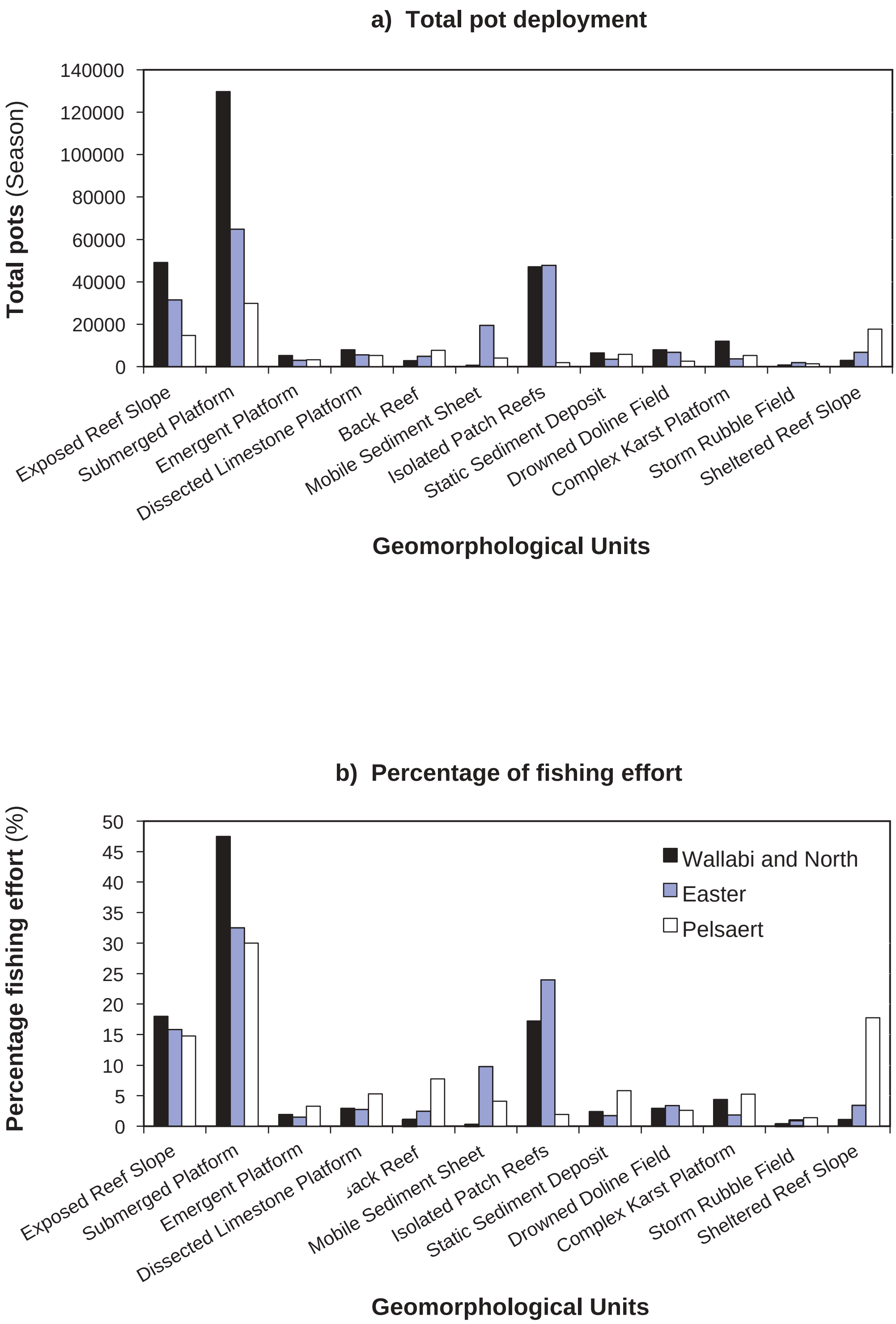


Figure 6.2. Total number of pots deployed (a) and percentage of fishing effort (b), in 0-20m per season in each geomorphological unit across the Island Groups.

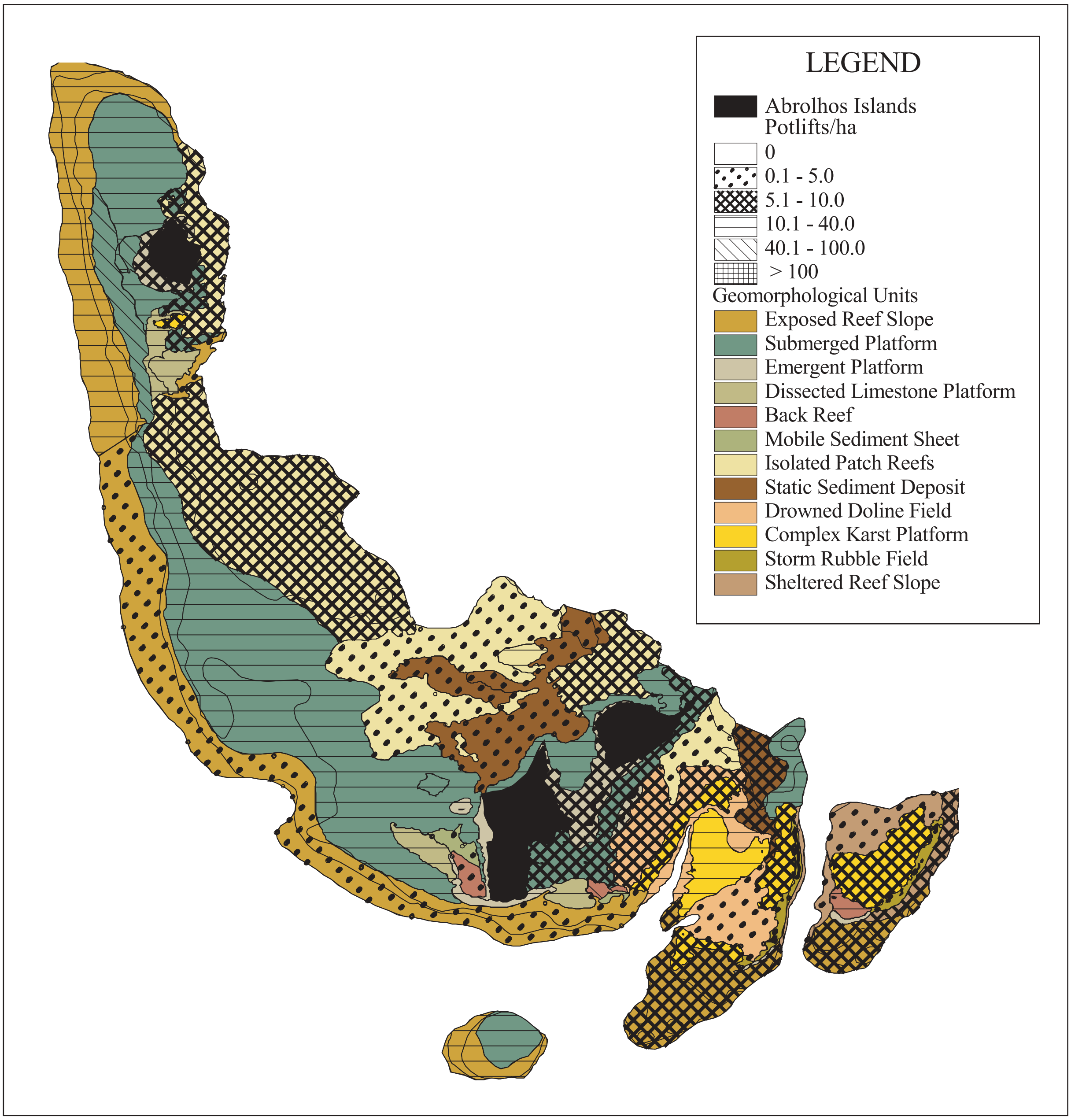


Figure 6.3a. Geomorphological units mapped at North Island and Wallabi Group (after Hatcher *et al.,* 1988) and pot densities per hectare per season.

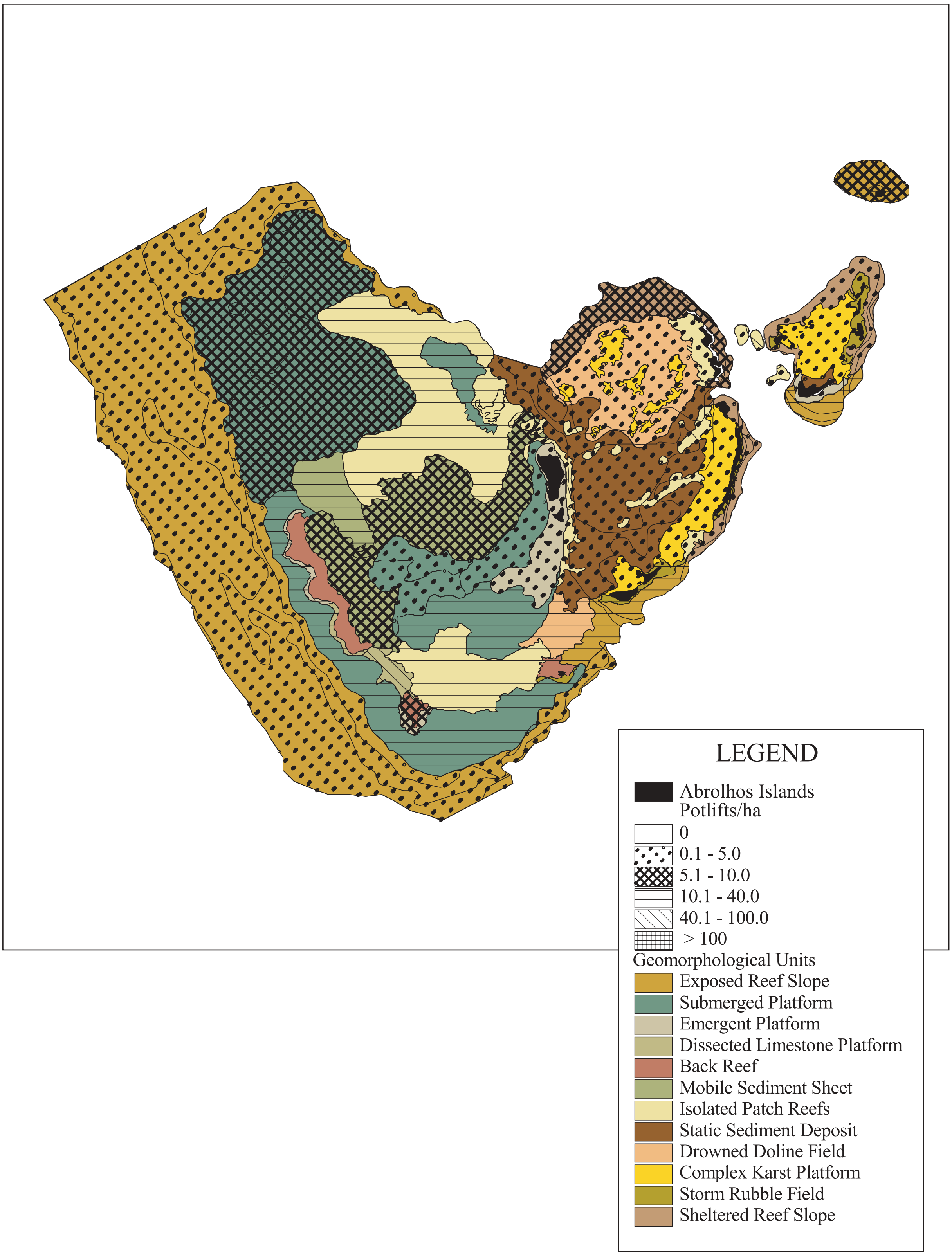


Figure 6.3b. Geomorphological units mapped at Easter Group (after Hatcher *et al.*, 1988) and pot densities per hectare per season.

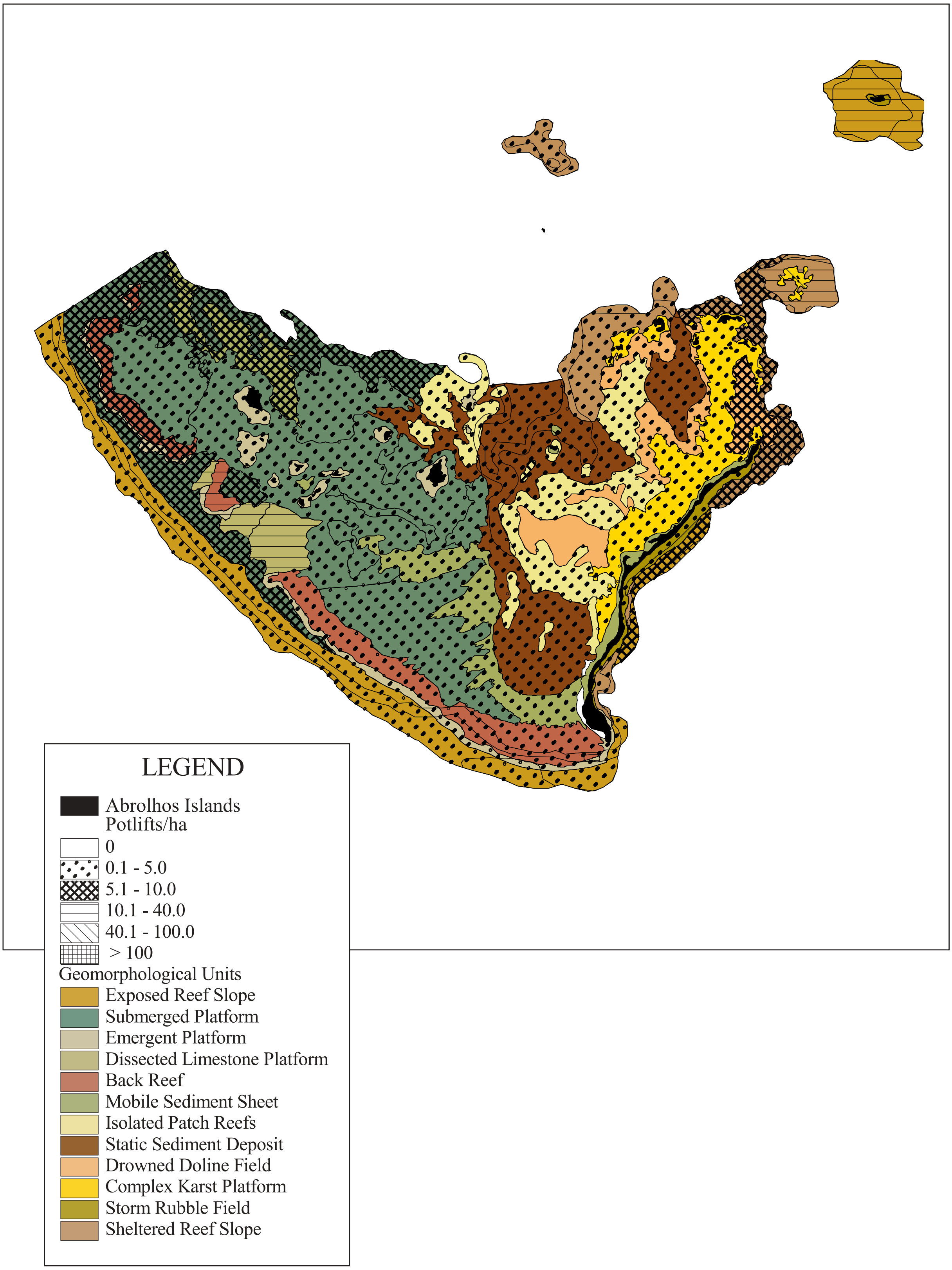


Figure 6.3c. Geomorphological units mapped at Pelsaert Group (after Hatcher *et al.*, 1988) and pot densities per hectare per season.

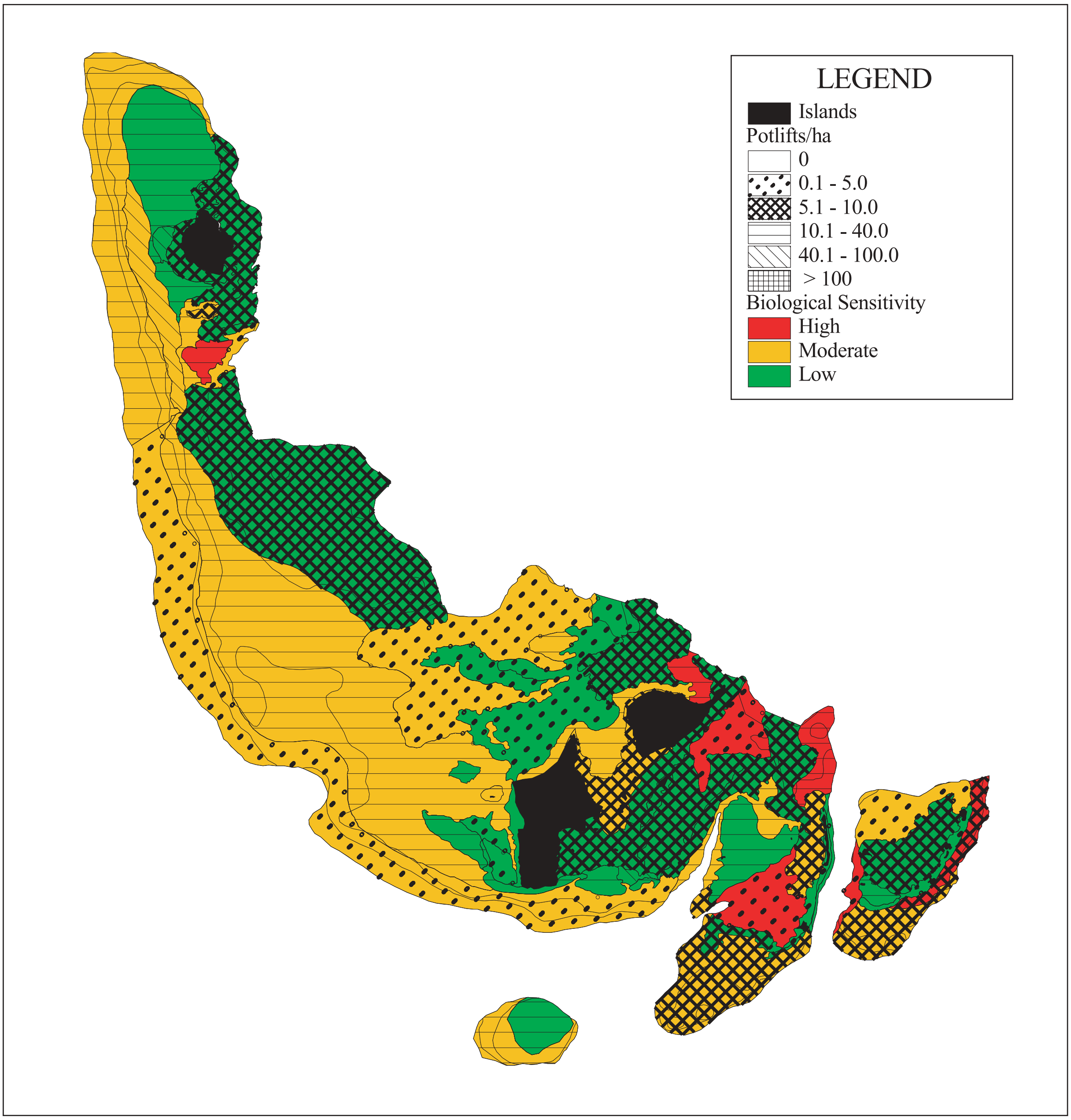


Figure 6.3d. Distribution of potlifts per hectare per season in relation to biological sensitivity at North Island and the Wallabi Group.

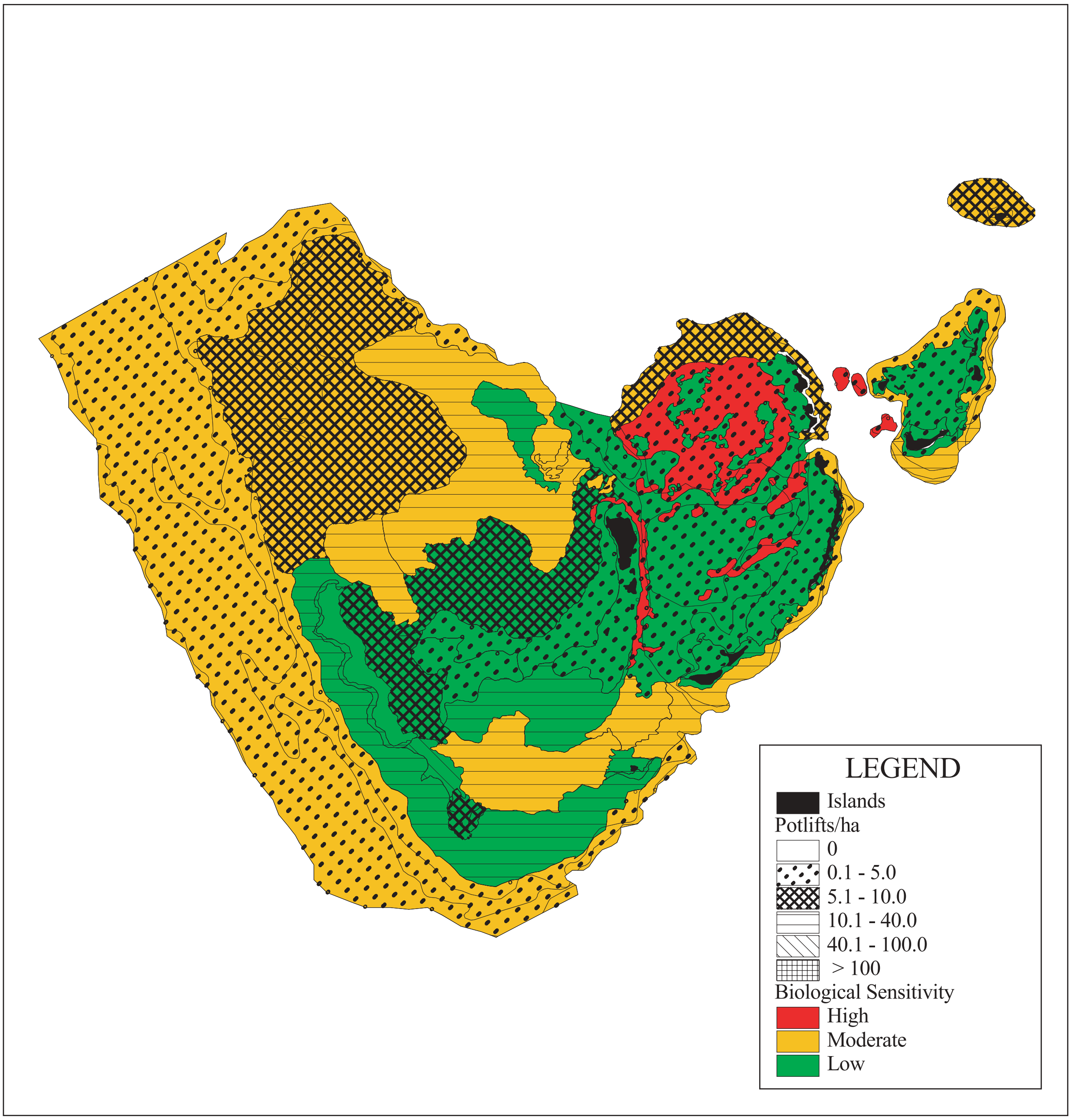


Figure 6.3e. Distribution of potlifts per hectare per season in relation to biological sensitivity at the Easter Group.

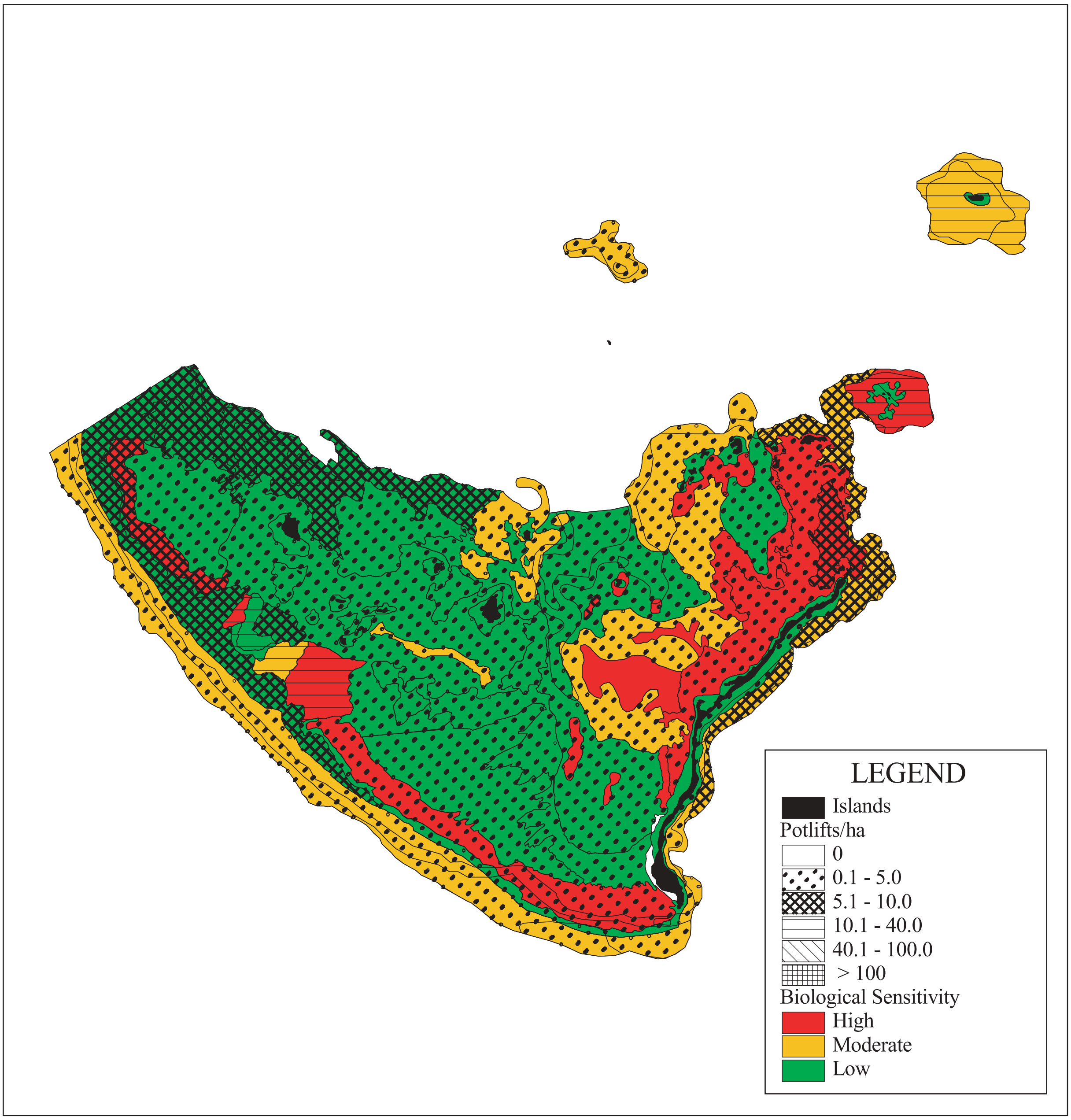


Figure 6.3f. Distribution of potlifts per hectare per season in relation to biological sensitivity at the Pelsaert Group.

sensitivity accounted for between 37.1% and 48.5% of fishing effort in each of the island groups (Table 6.3a). A majority of pot lifts occurred over substrates of moderate biological sensitivity in the Wallabi and Easter Groups (53.7% and 60.6% respectively) (Table 6.3a). In the Pelsaert Group only 27.6% of effort was in moderately sensitive substrates with an equivalent effort (23.8%) expended in fragile biological communities. In the other two groups, minimal effort (2.4%-5.4%) was centred upon fragile habitat (Table 6.3a).

The sensitivities of biological communities comprising the geomorphological units in each island group are detailed in Appendix 1. Exposed reef slopes principally are mixed macrophyte assemblages with some coral-macroalgal assemblages. These slopes are the high-energy windward slopes of the Abrolhos and the biological communities are moulded by their ability to withstand wave action from open ocean swells.

In the Pelsaert Group, the submerged limestone platforms are lower energy environments and contain depauperate sediments, coral-macroalgal assemblages and stands of *Sargassum sp*. The same geomorphological unit in the Easter Group also has *Sargassum sp.* cover in addition to coral-algal pavement and meso-macroalgal assemblages. However, the submerged platforms in the Wallabi/North Island Group harbour a varied set of communities. Here can be found coral-algal pavement, meso-macroalgal stands, mixed macrophytes, filter-feeding communities, infaunal sediments, seagrasses and low-energy coral assemblages.

The fishing in the isolated patch reefs of the Wallabi/North Island Group occurs around coral-macroalgal and meso-macroalgal assemblages, *Sargassum sp.* stands, with filter-feeding communities and depauperate sediments between the reefs. The patch reefs of the Easter Group are more sensitive with high-energy and high-diversity coral assemblages, stands of mixed macrophytes and *Sargassum sp.* and coral-macroalgal assemblages.

Of all the biological communities represented in exposed reef slopes, submerged limestone pavements and isolated patch reefs, only the low-energy coral assemblages of the Wallabi/North Island Group, and the high-energy and high-diversity coral communities of the Easter Group have a high sensitivity to physical damage (Appendix 1). The remaining biological communities in these units are tolerant to the effects of rock lobster potting, with the habitats appearing more like temperate limestone reef structures.

Important fishing areas in the Pelsaert Group are the leeward sheltered reef slopes. Here fragile, high-energy coral assemblages occur together with mixed macrophyte stands.

The back reef of the Pelsaert Group and mobile sediment sheets of the Easter Group each received 7.8% and 9.8% of the fishing effort in their respective groups (Table 6.2). For the most part the back reefs, the areas directly behind reef crests on exposed perimeters, are dominated by low stands of meso- and macroalgae and small isolated colonies of massive corals due to the strong water flow, but in some more protected areas of the Pelsaert Group, dense stands of branching *Acropora* have developed. The mobile sediment sheets of the Easter Group generally comprise depauperate and infaunal sediments but, in some areas, seagrass beds have formed.

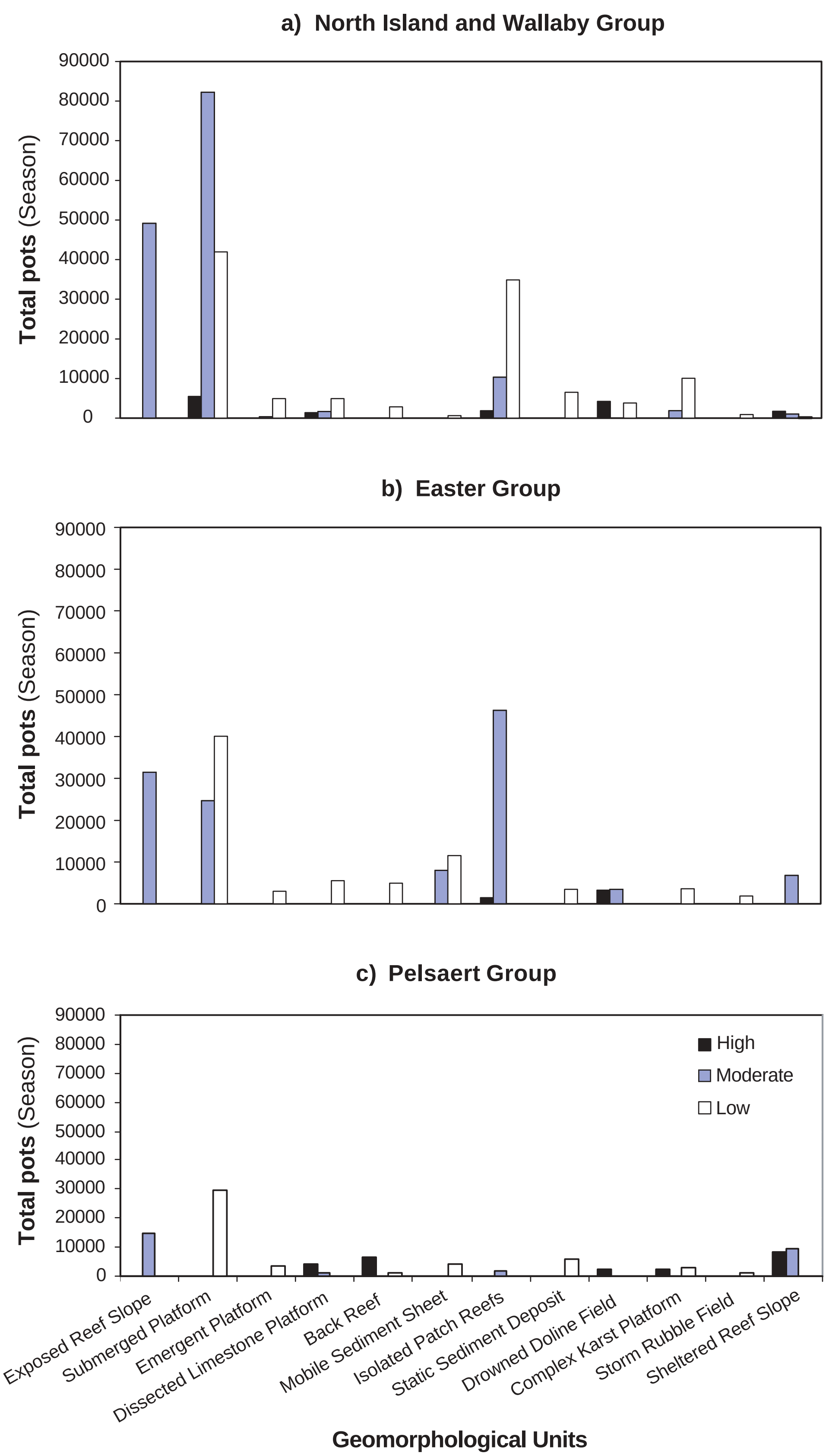


Figure 6.4a,b & c. Total number of pots deployed per season in relation to biological sensitivity within each geomorphological unit at each island group.

Table 6.3a. The average percentage of total pot lifts in 0-20m in each island group occurring on low, moderate and high sensitivity biological communities in a season.

Group	Low	Moderate	High
Wallabi/North Is	40.9	53.7	5.4
Easter	37.1	60.6	2.4
Pelsaert	48.5	27.6	23.8

Table 6.3b. The average percentage of total pots counted in the March and May 2001 aerial surveys in each island group occurring on low, moderate and high sensitivity biological communities

Group	Low		Moderate		High	
	March	May	March	May	March	May
Wallabi/North Is	52.2	47.7	40.4	40.8	7.4	11.4
Easter	52.5	35.9	47.2	60.5	0.3	3.6
Pelsaert	49.0	49.7	27.8	22.9	23.2	27.4

The complex karst platforms and drowned doline field comprise a significant proportion of the eastern parts of the island groups (Figures 3.1a-c). These are low energy areas with good water flow. The karst platforms principally have coral-macroalgal and meso-macroalgal assemblages and depauperate and infaunal sediments with occasional assemblages of low-energy coral. They attract between 1.8% and 5.3% of the shallow water effort (Table 6.2). More sensitive are the drowned doline fields, which receive 2.5% to 3.5% of the effort (Table 6.2). This "blue hole" terrain consists of low-energy coral and high-diversity coral communities with areas of meso-macroalgae and coral-macroalgal assemblages. The drowned doline fields often have visually spectacular stands of corals.

The dissected limestone platforms are categorised as high sensitivity. This is due to the presence in these units of rich coral, algal or mixed coral-macroalgal communities. Nevertheless these dissected platforms occur as small gaps in the south-western reef perimeters where strong, unidirectional water flow has eroded the windward reef platform and crest. The extent of this geomorphological unit is very small. Other areas of the Abrolhos containing high sensitivity biological communities have little fishing effort expended in them (Table 6.2).

Aerial surveys

The aerial surveys conducted in March and May of 2001 provide data important for two reasons. Firstly they were spot counts of pots in actual areas of fishing and as such may be used to validate data from the interview process. Secondly, they provide an indication of the spatial movement of effort across island groups during the season.

The total number of pots counted on both flights was 1992 and 1978 in March and May respectively. This number of pots equates to about 214,000 pot lifts per season (calculated multiplying the number of days per season (108) by the average number of pots observed for both days (1985)). This is not enough to provide the average of 52% of effort in the shallows for a season (equivalent to ≅568,000 pot lifts, calculated from log book returns). Whilst there may be some ambiguity in fishers' allocation of pot effort to the upper end of the 0-10 fathom (0-20m) depth category in the research log books when fishing across that depth, it is obvious that the aerial surveys did not extend to the 20m contour. The pots immediately seaward of the surf zone on the exposed reef slopes were counted but the considerable level of fishing activity immediately to the west (i.e. probably still within the 20m contour) was not included in the pot counts. Delineation of pots within 20m contour from an aircraft is difficult. Nevertheless, the pots counted represented the total number being fished on and within the reef perimeters of the island groups, or in other terms, the areas where habitats have been mapped. The number of pots (approx. 2000) counted in the shallows in the Abrolhos was consistent between flights and thus, possibly reflects the real number of pots used in the mapped area. Furthermore, the densities of pots seen during the flights is considered to be indicative of the real fishing pressure various areas would be subjected to on a daily basis.

The distributions of pots across geomorphological units in each island group derived from the aerial surveys (Figures 6.5, 6.6) show a very similar pattern to that derived from fishers' interviews (Figure 6.2b). This confirms that the major geomorphological units for fishing are the exposed reef slopes and submerged limestone platforms in all groups; the isolated patch reefs in the Wallabi/North Island and Easter Groups; the mobile sediment sheets of the Easter Group and the sheltered reef slopes and back reefs of the Pelsaert Group. In addition, the actual positions of pots recorded in the aerial surveys, pot frequency distributions (related to biological sensitivity) were consistent with that derived from the interview data (Table 6.3a, b). These results give confidence in the use of the interview data to describe average seasonal fishing effort levels across geomorphological and biological units in the Abrolhos.

The aerial survey data also indicate how fishing effort varies across each geomorphological unit in each island group during a season (Figures 6.5b, 6.6b). The "core" units remain as described above for the whole season, but at the commencement of the season (March 15) a greater proportion of the effort is centred on the known high-abundance rock lobster habitats of the Abrolhos such as the exposed reef slopes, submerged platforms and isolated patch reefs, or sheltered reef slopes in the Pelsaert Group. Later in the season, when catch rates of lobsters are declining in those areas, fishing effort is reduced in the western parts of the island groups (eg. submerged platforms) and redistributed more into the central and eastern parts. Thus the isolated patch reefs in the two northern groups and the drowned doline fields and karst platforms in all groups receive more effort and speculative fishing at this time (Figures 6.5b, 6.6b). The differences in the effort distributions with time discussed here are unlikely to be statistically significant given the level of uncertainty around the estimates. However, the trends described are consistent with anecdotal information from the fishers. The decline in effort levels in June (Table 6.1) as the season draws to a close (June 30), depends upon three things: fishers' catches prior to the Abrolhos season (March 15); the lobster densities remaining on the Abrolhos grounds; and the price paid to fishers for their product at that time.

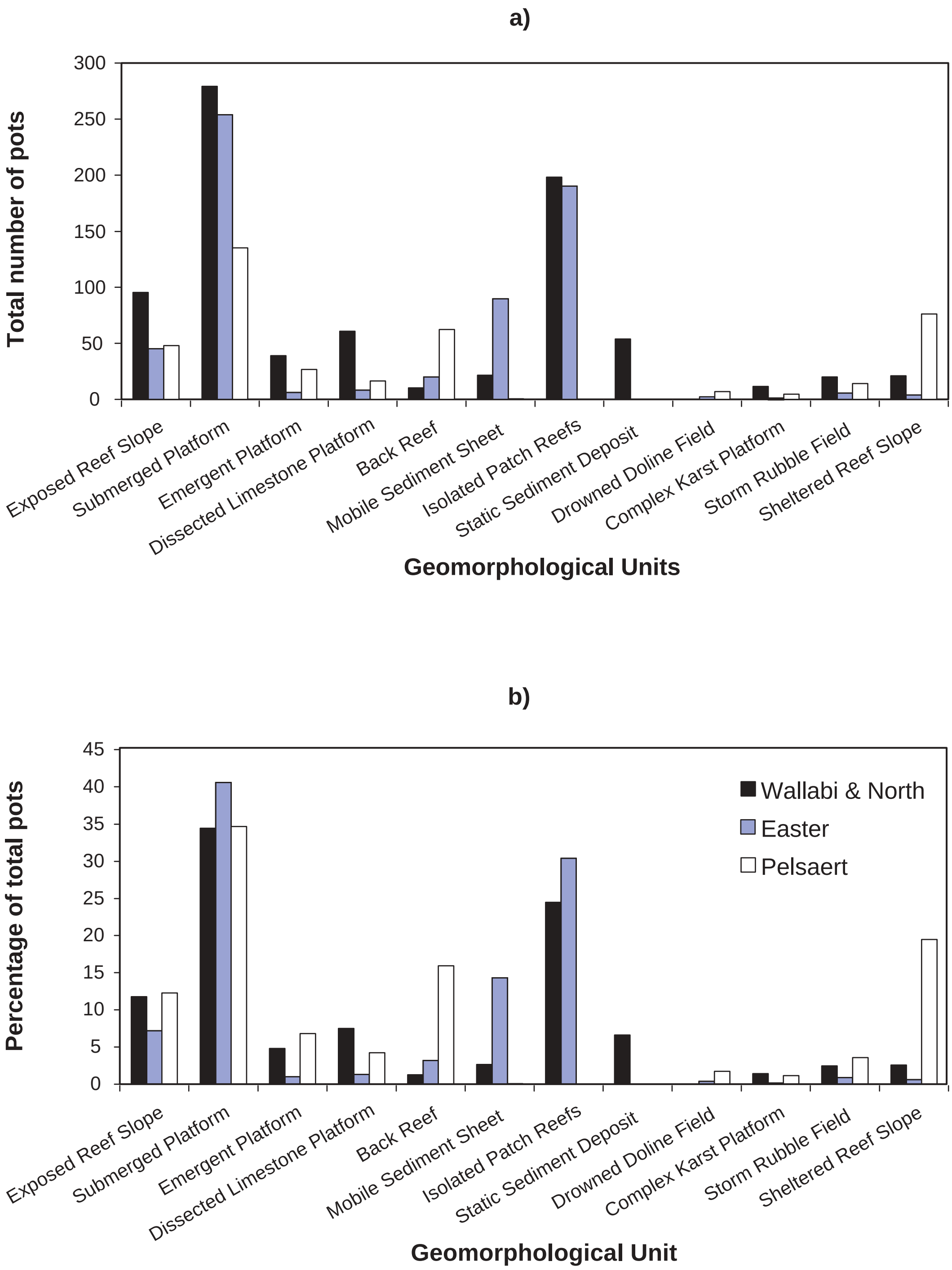


Figure 6.5. Total number (a) and percentage (b) of pots in each geomorphological unit as observed during the March 2001 aerial survey at all of the island groups.

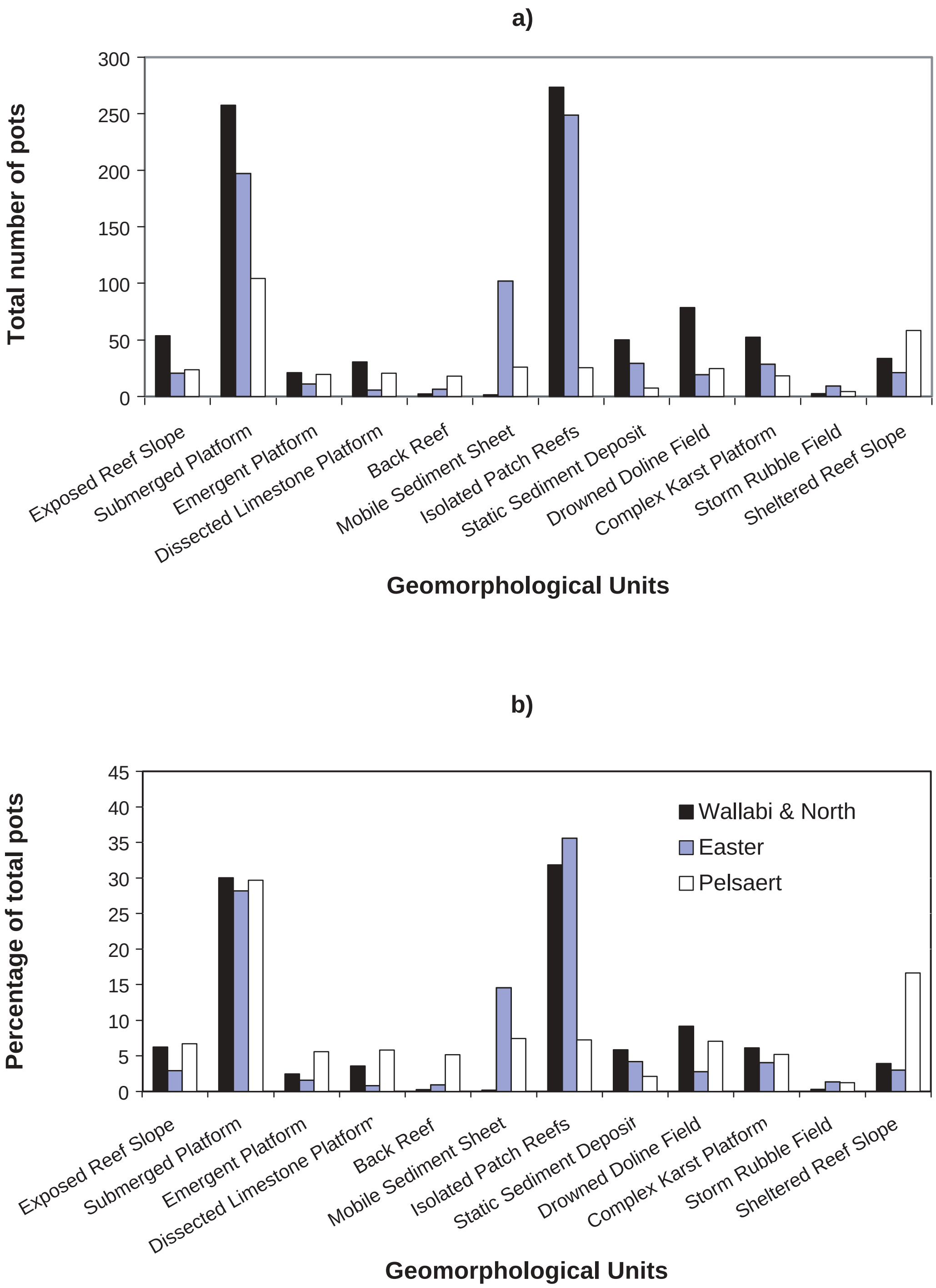


Figure 6.6. Total number (a) and percentage (b) of pots in each geomorphological unit as observed during the May 2001 aerial survey at all of the island groups.

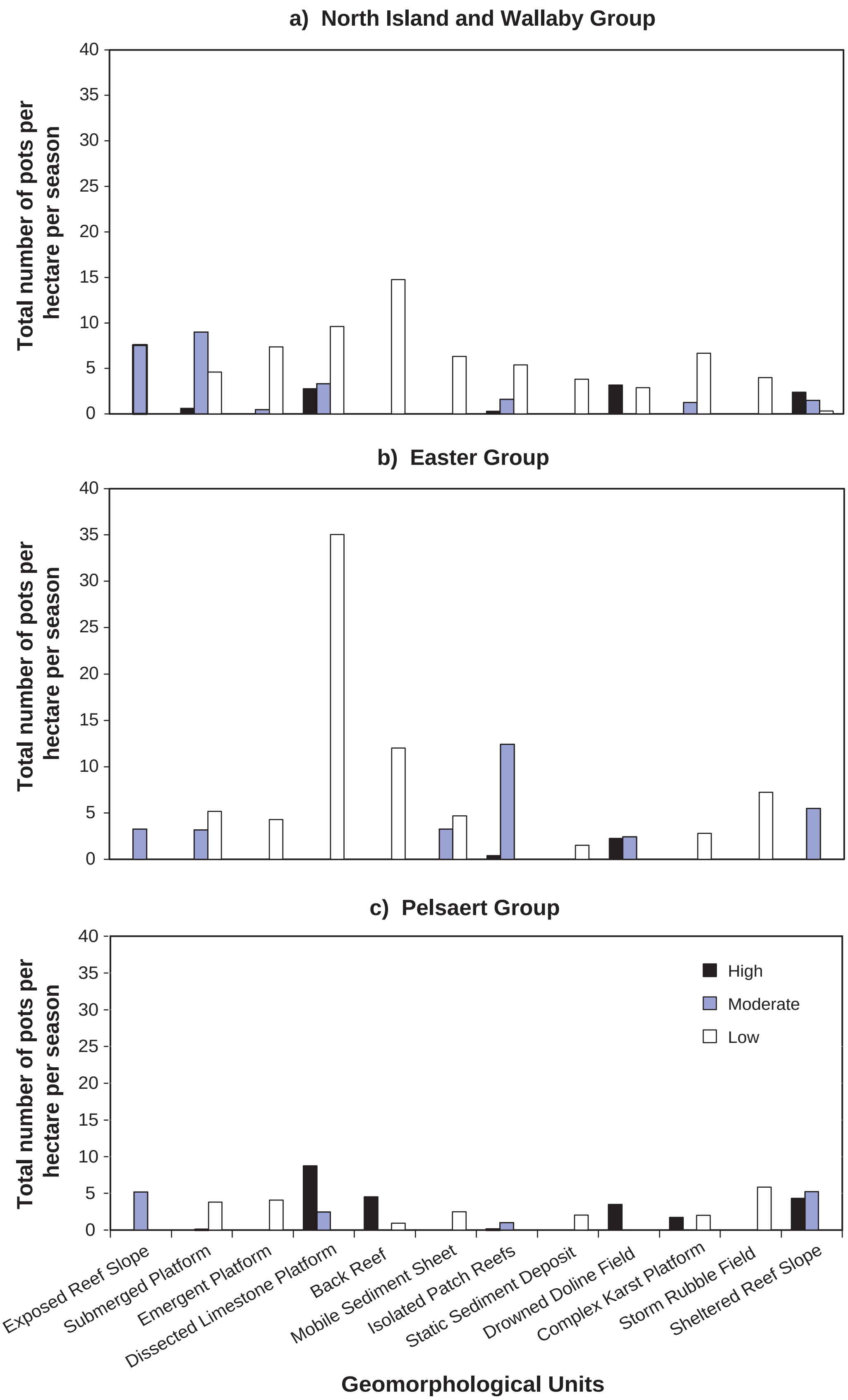


Figure 6.7a, b&c. Pot density per season in relation to areas of biological sensitivity within each geomorphological unit at each island group as determined from interview data.

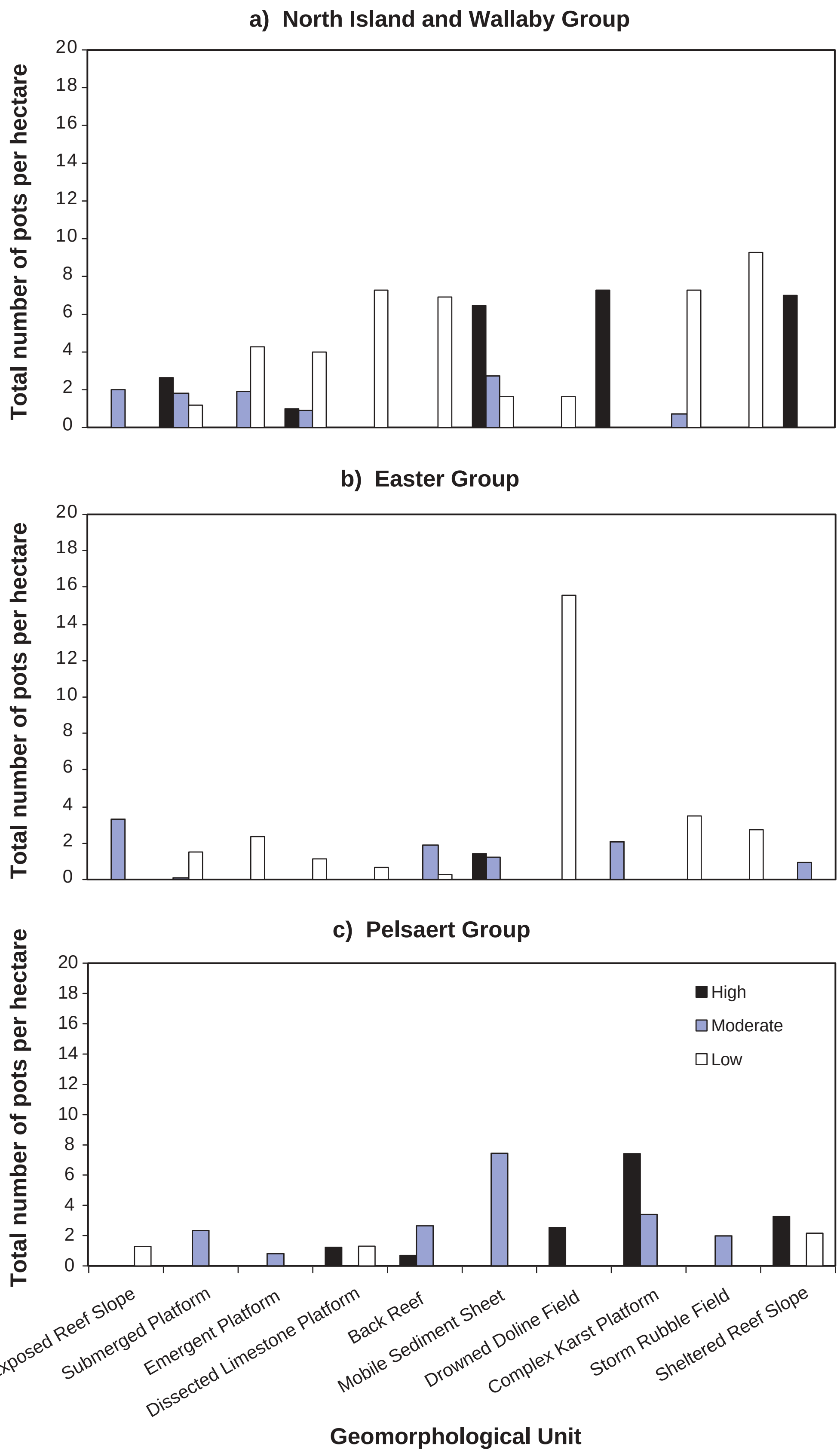


Figure 6.8a, b&c. Pot density identified during March 2001 aerial survey in relation to areas of biological sensitivity within each geomorphological unit at each island group.

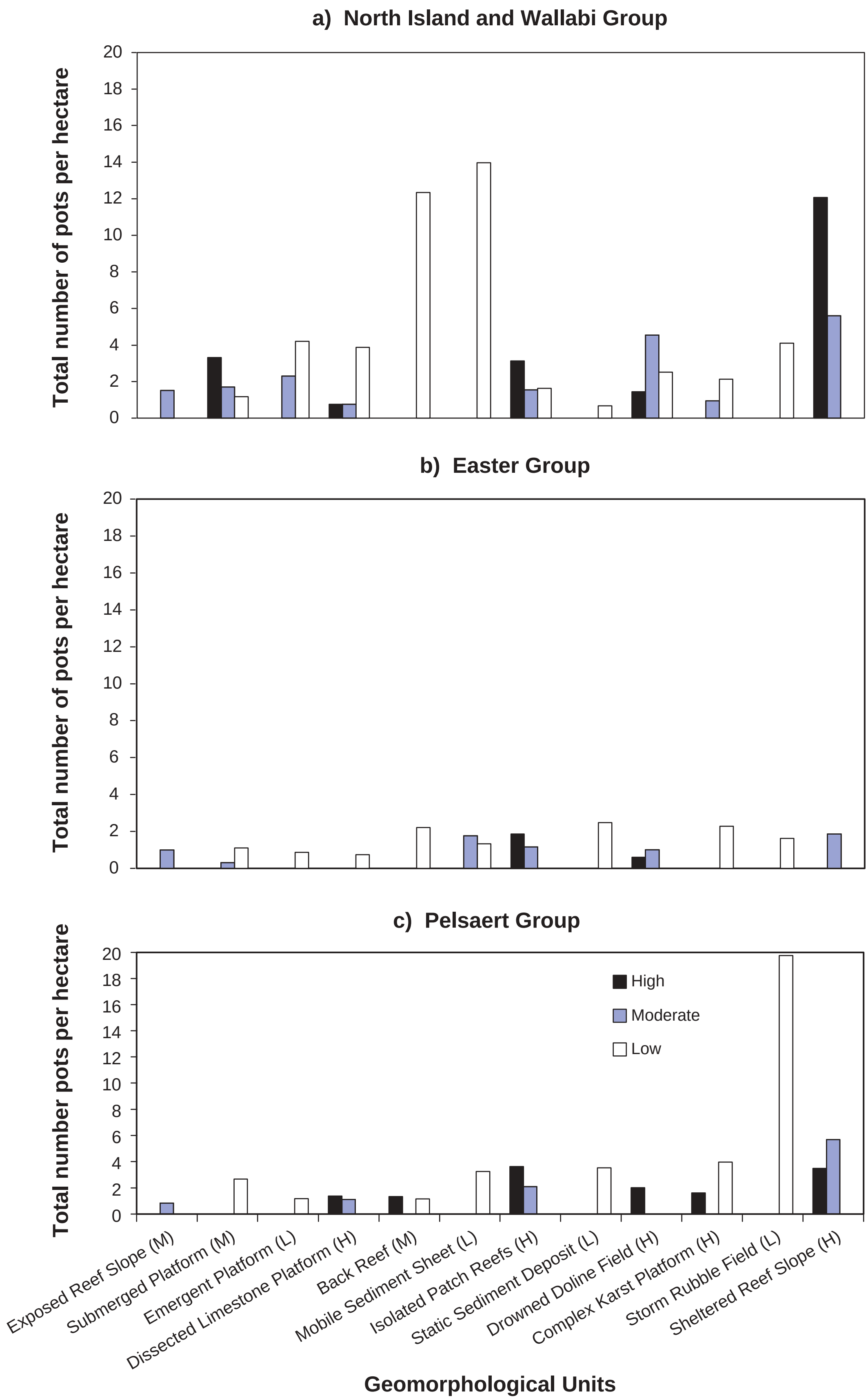


Figure 6.9a, b&c. Pot density identified during May aerial survey in relation to areas of biological sensitivity within each gemorphological unit at each island group.

The density of pots (number per hectare) over geomorphological units from fishers' interviews was calculated on the assumption that pots were uniformly distributed across those units in each island group (Figure 6.7). Furthermore, the densities represent an average for a season. The high density of pots (35 per ha) in the dissected limestone platforms of the Easter Group (Figure 6.7b) is an artefact of the very small area this geomorphological unit comprises in this group. Whilst recognising the limitations of both the aerial survey and interview data sets, and those of the area estimates of the geomorphological and biological units (see section 3.3.3), the aerial survey data provide a more realistic picture of the likely daily potting densities across the sensitive biological communities in each geomorphological unit (Figures 6.8, 6.9).

The patterns shown in all three data sets are generally consistent. The difference appears to be that for the Wallabi/North Island and Easter Groups, the aerial survey data show a higher proportion of the effort being targeted on the high sensitivity coral formations than is apparent in the interview data. This is due to the averaging process in the interview data where pots were allocated to a geomorphological/biological unit, compared to the determination of the actual locations of groups of pots in the aerial surveys. The latter data reflect the targeting by fishers on areas of plate corals and the like, which provide den habitat for the western rock lobster. This notwithstanding, the fishing effort on these high sensitivity communities was less than 10 pots per hectare on a daily basis but with 12 pots per ha recorded for the high sensitivity components of the sheltered reef slopes in the Wallabi/North Island Group in May (Figures. 6.8, 6.9). The interview data suggests that virtually all types of habitat around and within the reef perimeters of the islands are fished with a relatively low intensity of generally much less than 15 pots per hectare per day during the three and a half month season.

Comparison with historical data

Hatcher *et al.,* (1988) produced pot density estimates for the Abrolhos rock lobster fishery. These data also were gathered from interviews with fishers in 1987 but a much smaller sample size was used than in the present study. A comparison of the two interview data sets (Figure 6.10a-c) reveals little, because in each island group some areas have increased potting densities, some have similar and some have reduced densities, however, there is no consistent pattern of change. Only in the Wallabi/North Island Group does there appear to be a trend away from highly concentrated effort (>100 pots/ha) around the northern edges of West and East Wallabi Islands and the Eastern edge of Long Island to the more evenly distributed densities seen in this study. These high densities were not noted by Hatcher *et al.,* (1988) in either of the other groups. In the Wallabi/North Island and Pelsaert Groups, areas of the eastern parts of both groups, indicated as having a low density of fishing effort by Hatcher *et al.,* (1988), were not indicated as current fishing grounds by the fishers interviewed in the study (Figure 6.10a-c). However, Hatcher *et al.,* (1990) did indicate that fishing effort intensity was generally lower in fishing zones containing a significant cover of coral or filter feeding communities than in those lacking these biological communities. The difference was statistically significant in the Easter Group only.

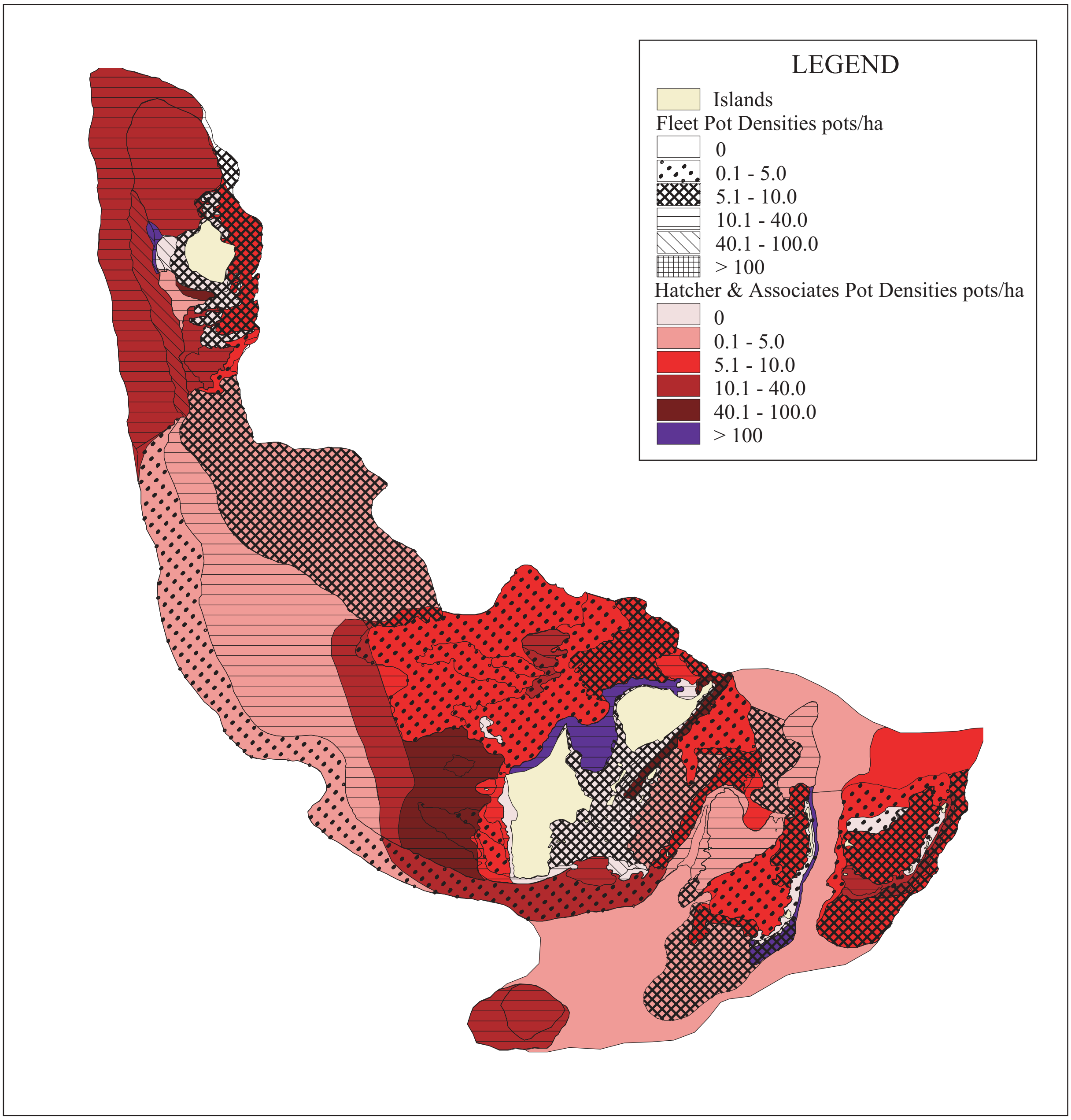


Figure 6.10a. Comparison of potting effort between Hatcher *et al.,* (1988) study and annual potting effort as determined from interviews conducted during the present study, at North Island and the Wallabi Group.

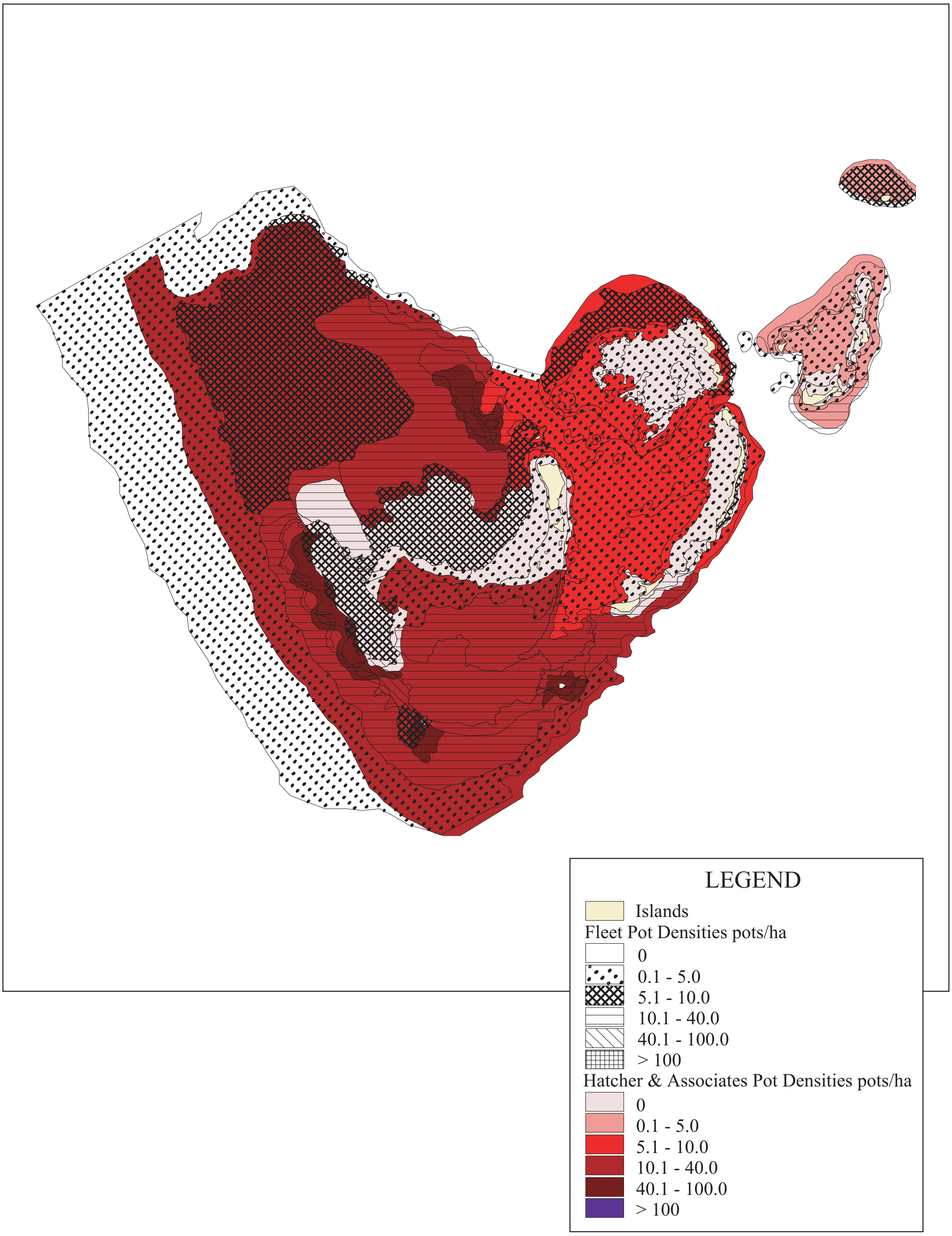


Figure 6.10b. Comparison of potting effort between Hatcher *et al.,* (1988) study and annual potting effort as determined from interviews conducted during the present study, at the Easter Group.

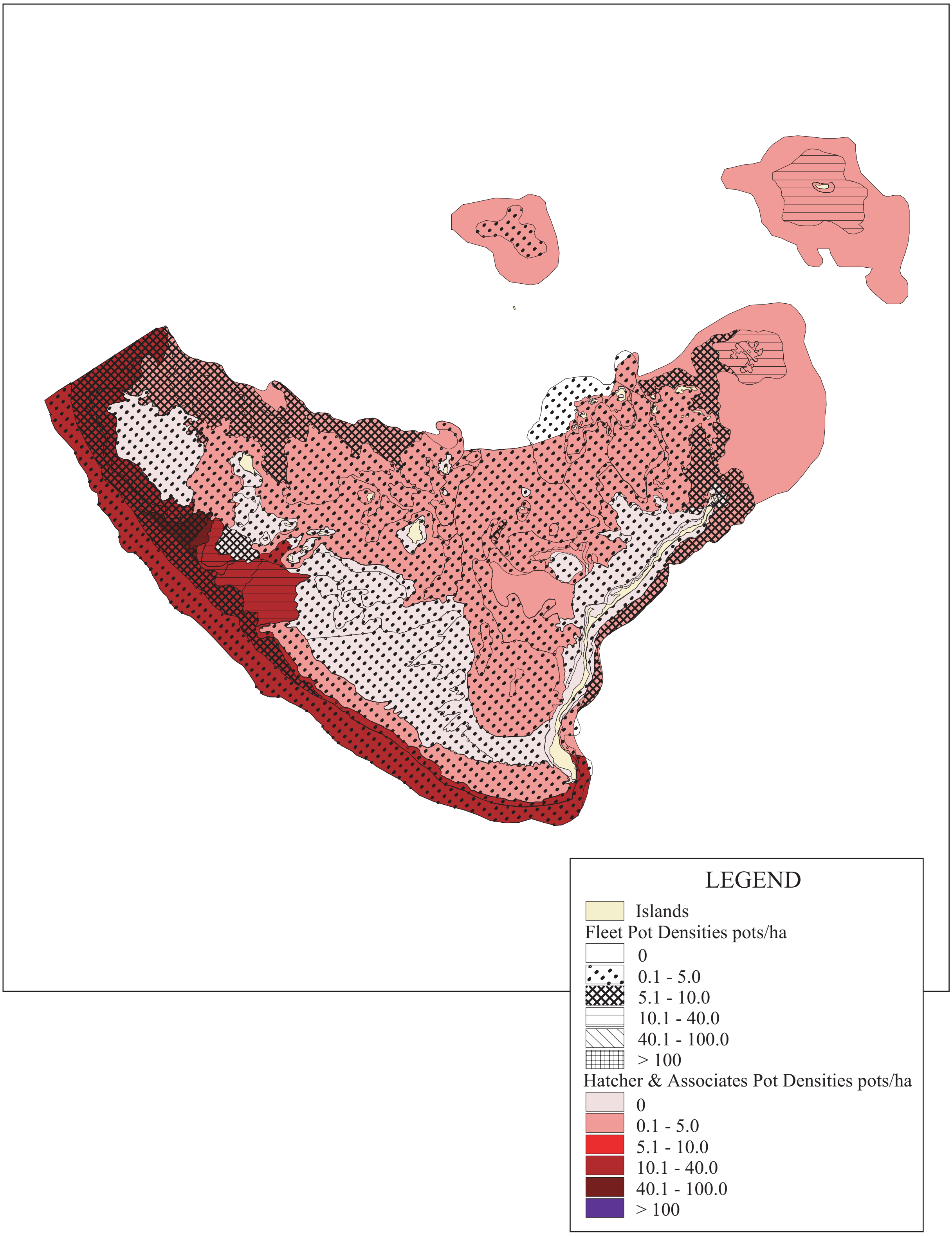


Figure 6.10c. Comparison of potting effort between Hatcher *et al.*, (1988) study and annual potting effort as determined from interviews conducted during the present study, at the Pelsaert Group.

A comparison of interview and aerial survey data from both studies, related to biological sensitivity, reveals consistently low pot densities on a seasonal basis (Table 6.4). While the upper limit for densities in low sensitivity habitats was greater in the current study, but lower in the moderately sensitive habitats compared to Hatcher *et al*'s (1988) findings, the range of pot densities in fragile communities was very similar across all data sets at between 2 and 12 pots per hectare (Table 6.4).

Table 6.4. Comparisons of the range of pot densities (pots per ha) in biological communities of low, moderate and high sensitivity between Hatcher *et al's* (1988) data and the current study.

Biological sensitivity	Hatcher *et al.,* (1988)	Interview 2001	Aerial March 2001	Aerial May 2001
Low	3-7	2-35	2-16	2-20
Moderate	5-22	2-13	2-7	1-6
High	5-10	2-9	2-8	2-12

6.1.1.4 Likely impacts

It is important to recognise that rock lobster fishing at the Abrolhos is undertaken for only three and a half months of the year, from March 15 to June 30. It is also important to note that on average 25%, 18% and 9% of the total potting effort at the Abrolhos occurred in depths of less than 20m at the Wallabi/North Island Group, the Easter Group and the Pelsaert Group respectively. Furthermore, much of that effort was directed at prime rock lobster habitats, most of which contain biological communities of low or moderate sensitivity (Figures 6.3d-f, Appendix 1). The moderately sensitive communities are the mixed macrophytes, stands of *Sargassum* and the coral-macroalgal assemblages, all of which are relatively resistant to the physical impacts of pot fishing.

Nevertheless, some effort was targeted at lobsters living in sensitive habitats where corals can have greater than 50% cover and comprise robust forms such as thick branching, tabulate and encrusting corals, delicate forms eg. thin branching, foliose and plating corals and species-rich mixtures including massive and solitary forms depending upon their position in the habitat and the strength of water flow. Even though rock lobster fishers generally set their pots on edges, i.e., on sand but adjacent to reefs, there is potential for damage in these biological communities each time a pot is deployed and lifted. The physical impact of such activity would be the fracturing of the fragile corals such as the branching and tabulate forms. Anecdotal evidence suggests that if damage occurs it happens where the pot settles after deployment. Pot ropes also may be tangled around fragile corals which may fracture when the pot is lifted.

From the habitat mapping and interview data, it was determined that the total area of high biological sensitivity (fragile) habitat, where there is significant potential for damage to the benthic biota from rock lobster pots, is approximately 9.2%. This is consistent with the findings of Hatcher *et al.,* (1988) and Wright *et al.,* (1988) who estimated that less than 10% was susceptible to damage. Fragile biological communities comprise 6.5%, 5.6% and 17.0% of the Wallabi/North Island, Easter and Pelsaert Groups respectively. An estimated impact of potting on fragile habitat can be calculated using the 2001 seasonal potting densities and an assumption that each rock lobster pot will disturb an area of coral or sponge (fragile) habitat equivalent to 4 sq. metres each and every time it is set. The percentage of fragile habitat so disturbed would be between about 0.1% and 0.3% of the surface area of such habitat in each island group (Table 6.5). Similar estimates of about 0.2 – 0.4% of the surface area of moderately sensitive habitat would be affected (Table 6.5).

Table 6.5. Estimates of the percentage surface area of low, moderate and high sensitivity biological communities impacted by rock lobster pots (see text for assumptions).

Group	Low	Moderate	High
Wallabi/North Is.	0.36	0.39	0.31
Easter	0.27	0.26	0.11
Pelsaert	0.14	0.18	0.23

Due to the low densities of pots set in fragile areas during a season, most of this habitat is unlikely to be disturbed. However, the actual extent to which damage is caused by pot fishing in these sensitive communities is unknown and is in need of investigation. The biological impact on the corals also needs to be quantified, given Harriot (1998) has recorded rapid rates of growth (mean of about 5-7cm/yr) for branching *Acropora formosa* and that the regeneration of coral colonies from fragments is possible (Dr A. Heyward, Australian Institute of Marine Science, pers. comm.). It also is important to note that rock lobster fishing is prohibited between July 1 and March 14, allowing a substantial recovery period of 8.5 months for any damaged habitat.

Rock lobster vessels do not move at night and are either tied alongside jetties or moored in well defined areas close to the jetties. Rarely do rock lobster vessels anchor at sea during the day. Boats that work the Abrolhos from the mainland may either return to port each day or anchor in appropriate places overnight. The larger boats with large pot allocations tend to operate in the deeper waters surrounding the Abrolhos reefs. Thus, not all of the 149 vessels that have Abrolhos concessions work in the shallow water areas. However, boat activity in shallow water can cause minor damage to reef structures when the hulls of vessels “ground” occasionally when manoeuvring to lift or set pots. The frequency with which this happens is unknown and this type of physical damage is not confined to the rock lobster fleet. Pleasure craft that do not know the waters similarly may impact on the marine habitats when underway. The physical impact of vessel “groundings” may be minimal when compared to the effects of violent storms on the marine habitats.

There is evidence that plastic banding used to hold bait cartons together and the cartons themselves are being thrown overboard by some industry members at the Abrolhos. For a number of years there has been an ongoing education programme and a code of practice has been developed to eliminate this polluting behaviour and, fortunately, this practice is not prevalent any more. Most Abrolhos fishers take all rubbish material back to their camps where it is either burnt or sent to the mainland to be disposed of in an appropriate manner, as is the case with engine oil for example. The impact of the discard of rubbish at sea is likely to be minimal.

The rock lobster industry’s considerable use of imported bait each season was cause for some concern following the pilchard mortalities of recent years. Bait remaining in pots is, in some cases, discarded at sea but it is very quickly recycled by all manner of organisms. A very thorough risk assessment conducted by Jones and Gibson (1997) concluded there was very little likelihood of disease introduction through the use of imported baits. Bait use has no impact on the Abrolhos marine habitats.

6.1.1.5 Issues for consideration

- Pot fishing in fragile areas: what is the extent of any disturbance? What is the response (growth and regeneration) of corals? What is the contribution of lobsters in these areas to catches.
- The frequency of groundings by rock lobster vessels and extent of damage caused. “Collateral damage”?
- Boat anchoring and moorings could also be a potential problem.

6.1.2 Scallop industry

6.1.2.1 History

The Abrolhos Islands scallop fleet targets the saucer scallop, *Amusium balloti*. The Islands were first fished commercially for scallops during the late 1960s, although no fishing occurred in the region between 1969-1972. The fishery then operated intermittently over the next five years, with catches ranging from 0.3 to 6.7 tonnes (t) of meat landed by between three and six vessels. After a poor season in 1977 (0.8 t meat), fishing for scallops again ceased during 1978 and 1979. In the early 80s landings increased significantly, mainly due to increased recruitment and fishing effort. Further advancements in processing methods and marketing strategies, and an associated increase in profitability, attracted even more vessels to the fishery and produced further increases in fishing effort. The Abrolhos fishery was declared a limited entry fishery in 1986, and currently, there are 16 licensed operators.

Saucer scallops tend to be restricted to areas of bare sand in the more sheltered environments found in the lee of islands and reef systems. The technology available to trawlers (i.e. Global Positioning Systems (GPS), Vessel Monitoring System (VMS) and coloured echo sounders) allows for fairly accurate targeting of areas suitable for trawling. Thus, it is generally accepted that scallop trawlers target bottom types which suffer minimal disturbance from the activity. However, some of the bottom-types which scallops recruit to contain sedentary organisms which are likely to suffer incidental damage from trawling (Dibden and Joll 1998).

From 1997, the Department of Fisheries commenced annual surveys of the Abrolhos area to identify grounds with good scallop concentrations and to provide a catch forecast for the following season. This has allowed the fleet to become more selective in choosing areas to operate (Figure 6.11). However, the settlement of scallops is variable from year to year and there is anecdotal evidence that fishers occasionally seek out new fertile fishing grounds, which might impact on some areas of fragile habitat.

The majority of the annual catch is exported as frozen scallop meat to Asia, Europe and the United States of America, while a small portion is marketed directly to the public via local retail outlets.

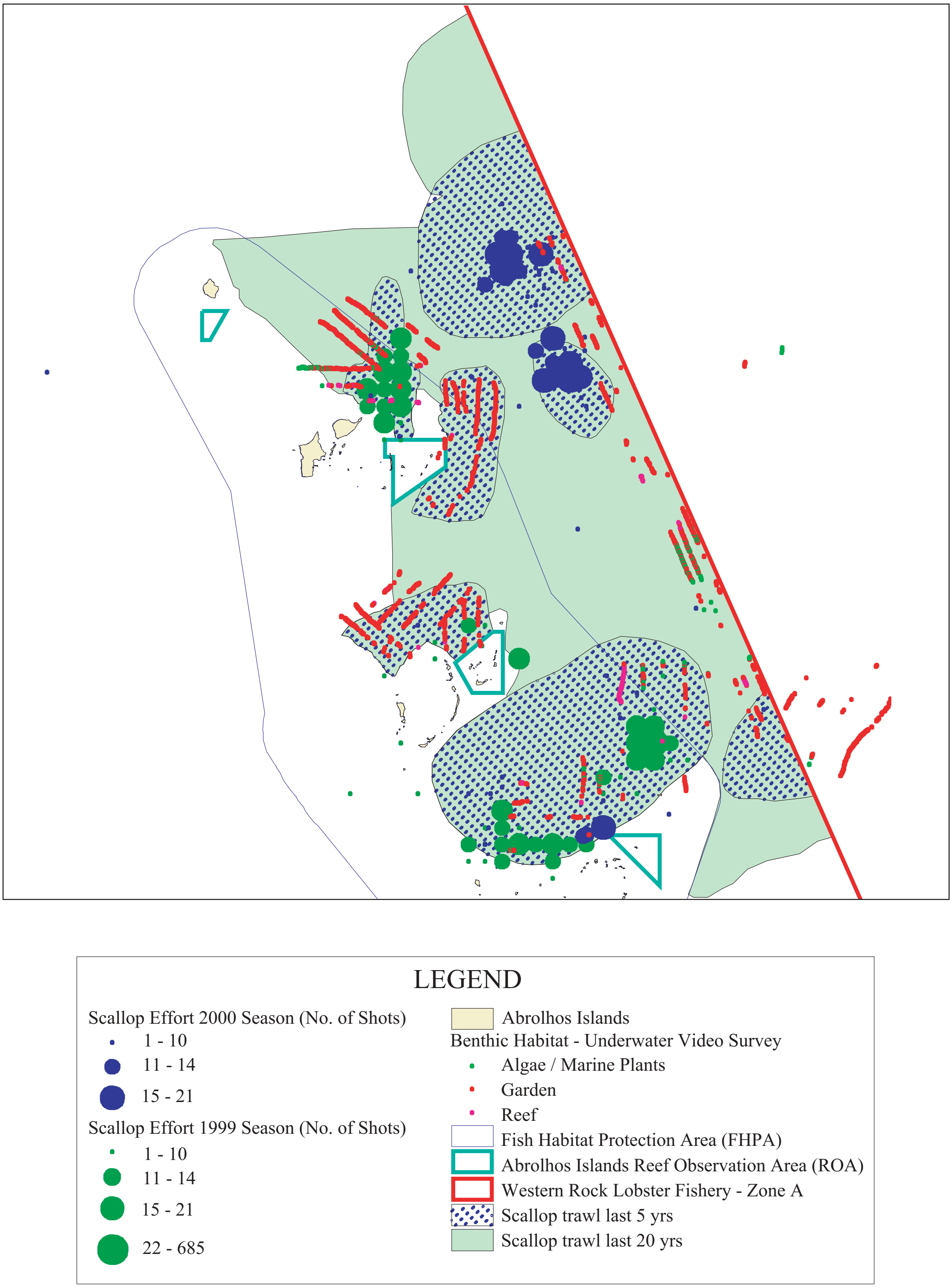


Figure 6.11. Areas of scallop trawling in the Abrolhos area as determined from research logbook data (years 1999, 2000) and interviews, with benthic habitat mapping from Department of Fisheries Western Australia video surveys (Dibden and Joll 1998).

6.1.2.2 Economic value

The average catch of the Abrolhos Islands and Mid-West Trawl Managed Scallop Fishery, is 121 t (meat weight) per year, but has varied from about 9 to 527 t (worth \$0.3–\$9.5 million) in the last 15 years. In 2000, the Abrolhos fishery produced 85.7 t, valued at \$2.3 million. The majority of catch and effort occurred in the central Geelvink Channel fishing ground (93%) which is immediately to the east of the Islands. Marginal catches were taken in the Southern (3.7%) and Wallabi Groups (0.9%). The majority of the total annual catch usually is taken during the first two to three weeks of the season which extends from the beginning of April until the end of May.

6.1.2.3 Levels of fishing effort

Scallop settlement is variable both temporally and spatially which is reflected in the distribution of fishing effort. The lowest catch recorded was in 1997 with 8.8 t of scallop meat landed from a nominal fishing effort of 1138 hours, compared to 1994, when a record catch of 527 t was taken with 17508 hours of trawling. On average, most boats fish only the first two to three weeks of the season, however, one or two boats in the fleet may stay until the end of May.

Log books were introduced to the fishery in 1998 and good records concerning fishing locations are available only for the 1999 and 2000 seasons. During 2000, 14 vessels actively fished within the Abrolhos Islands area, with the season running from April 4 to May 31. Most boats fished for between 7 to 10 days with fishing prohibited in a specified area after 1700 hours on April 13. The total catch for the 2000 season was 85.7 tonnes of scallop meat. The majority of the catch was from an area adjacent to the eastern boundary of the Abrolhos management area (Figure 6.11). The value of the catch was estimated to be approximately \$2 million. The 2001 season total catch was approximately 235 tonnes of scallop meat from 16 vessels.

The current licence holders were interviewed as a group, and asked to map onto marine charts their historical and current areas of trawl activity. This information was provided on two charts, which were then interpreted, and digital data generated for inclusion into the Abrolhos Habitat digital database. The trawl areas identified in the interviews were compared with the 1999 and 2000 logbook data held at Dept. of Fisheries which precisely document the start point of each trawl shot for the seasons. Trawl areas from the two information sources corresponded, indicating that the fishers' mapping was accurate (Figure 6.11).

The interview information provided by licence holders showed that, historically, the fishing activity was widely distributed, extending from the deeper water (greater than 30 metres) east of the island groups, to the eastern boundary of the A Zone of the western rock lobster fishery. Fishing also occured between the island groups (Figure 6.11). Fishing activity over the last 5 years was concentrated in 7 areas within these historical fishing grounds. These areas were:

a) to the north of the Pelsaert Group including the Zeewijk Channel, Gee Bank, Hummock Island and Snapper Bank;

b) the Mid Reef area;

c) to the north of the Easter Group, including Good Friday Bay;

d) to the east of North East Reef, Morning Reef and the Beacon Island Reef Observation Area;

e) from north of East Wallabi Island and east of Recruit Bay, including the northern section of Goss Passage, east of North East Reef and north beyond Beagle Knoll and Acute Bank;

f) north east of the Wallabi Group, adjacent to the eastern boundary of the Abrolhos Islands fishery in the Geelvink Channel;

g) east of North Island, adjacent to the eastern boundary of the Abrolhos Islands fishery in the Geelvink Channel and extending in a north-westerly direction.

6.1.2.4 Likely impacts

Since no habitat mapping was available for the trawl grounds, the underwater video survey data collected by Dibden and Joll (1998) was compared to the trawl activity areas provided by the scallop licence holders (Figure 6.11). The video survey transects and the scallop trawl areas were largely coincidental for trawl areas a, c, d, and e, with some coincidence for areas b, f and g. The comparison showed that within each of the trawl areas there were occurrences of algae/marine plants, sponge garden and reef habitats, which were considered vulnerable to trawling. Therefore, there is the potential for habitat damage in some areas currently subject to scallop trawling. However, it should be noted that hard reef habitats actively are avoided by trawlers since trawl gear cannot withstand direct contact. The comparison also showed that the habitat elsewhere was flat sand which is suitable for trawling.

6.1.2.5 Issues for consideration

- Incidental trawling occurs in sensitive habitats such as algal/marine plant, sponge garden and reef habitats.
- Different types of sponges are becoming increasingly important for their biochemical properties in the manufacture of pharmaceutical products (Dr A. Heyward, Australian Institute of Marine Science, pers.comm.). New and useful species are still being discovered and the Abrolhos may be an important source of sponges.

6.1.3 Wetline fishing

6.1.3.1 History

Commercial wetline fishing commenced in the Geraldton region (including the Abrolhos) in the late 1800's. In the first half of the 20th century it was a significant fishing industry and prior to 1939, 58 boats were known to fish in the region (Cooper 1996). However, with the growth of the rock lobster industry in the 1940's the wetline industry now is the third most important commercial fishery in the Abrolhos Islands region (Anon 1998).

6.1.3.2 Economic value

It is difficult to estimate the economic value of the wetline catch because it is based on a number of variable components including species composition and market/beach prices for product. Therefore, no current estimate of economic value of the Abrolhos wetline catch is available. However, in 1995 it was estimated that the value of the wetline catch within the Fish Habitat Protection Area was approximately $1 million (Anon 1998).

6.1.3.3 Fishing effort

As described in section 3.2.3, information about to fishing effort at the Abrolhos was collated from the 1995-2001 catch and effort data and a series of interviews with the President of the Geraldton/Abrolhos Mid West Wetliners Association.

Those data revealed that over the past six years, there has been a sporadic pattern of wetline fishing at the Abrolhos. The fleet was highly variable, usually composed of around 30 boats, although in 1996 and 1997, the number of boats fishing at the Abrolhos was greater with 50 and 40 respective vessels reporting wetling exclusively. Most boats tended to fish only for several weeks per year, although every year there were a small number of boats (around 5) which reported more than 100 days per year.

Between the years 1995 and 2001, the average number of days fished per boat per year by the 'wetline only' fleet was 39, while the range was 1-195 days. Most fishing occurred between March and October when the winds tend to be more moderate.

Within the FHPA, the number of boats fishing regularly also was variable, ranging between 2 and 10. In 2001, there were three wetline-only boats regularly fishing in the FHPA and in 2000 there were five. The number of days these boats fished was weather dependent but usually around 100-130 (Mr Mal McCrae, President of the Geraldton/Abrolhos Mid West Wetliners Association pers comm.).

Within the FHPA the location where the wetliners fish is dictated by weather. Most wetliners spend the majority of their time in the central part of the islands where they are more protected from the winds. Each fisher has around 500 locations where they fish. On average each fisher visits around 10-15 fishing locations per day and drops anchor at each location. Fishers tend to anchor away from the reef areas and drift back over the reef. Anchoring occurs on different bottom types and may occasionally include more delicate areas such as coral. Fishers tend to rotate the different areas where they operate so as to not exhaust the fish stocks in any given area. This would also serve to reduce the impacts to the benthic habitats where they anchor.

6.1.3.4 Issues for consideration

The locations where fishing, and associated anchoring, occurs were not identified.

The "Management of the Houtman Abrolhos System" paper of December 1998 recommended that immediate action be take to reduce wetline fishing in the Abrolhos Islands to limit total catch. As a part of reducing effort, the report recommended that negotiations should be undertaken with fishing boat license holders to prohibit commercial wetline activities within the shallows of the main island groups.

6.1.4 Purse seine fishery

The purse seine fishery commenced in the Geraldton region in 1991. Since then, three developmental licences have been issued for the fishery. Currently, only one purse seiner is operating with the majority of catch being scaly mackerel (*Sardinella lemuru*).

The boundaries of this fishery are all Western Australian waters between 31°00'S and 26°30'S, to the Economic Exclusion Zone (200 nautical miles from shore), but excluding the waters of Shark Bay. The majority of the catch of scaly mackerel is taken from waters around the Geraldton region, rather than around the Abrolhos Islands. The future of the fishery is uncertain.

The licensee currently fishing the region has advised that his fishing activities do not involve anchoring, leaving from Geraldton early in the morning and returning later that night with the day's catch. This fishery, therefore, has no impact on the marine habitats of the Abrolhos.

6.1.5 Aquaculture

6.1.5.1 History

Aquaculture is a relatively new entrant to the Abrolhos commercial sector. The first application for a licence to farm pearls in the region was received by the Department of Fisheries in 1993 with operations physically commencing in 1995. This application subsequently underwent a major variation in 1998. Since the industry's establishment, gear progressively has been installed over time with stock (shell) numbers increasing in 1997/98.

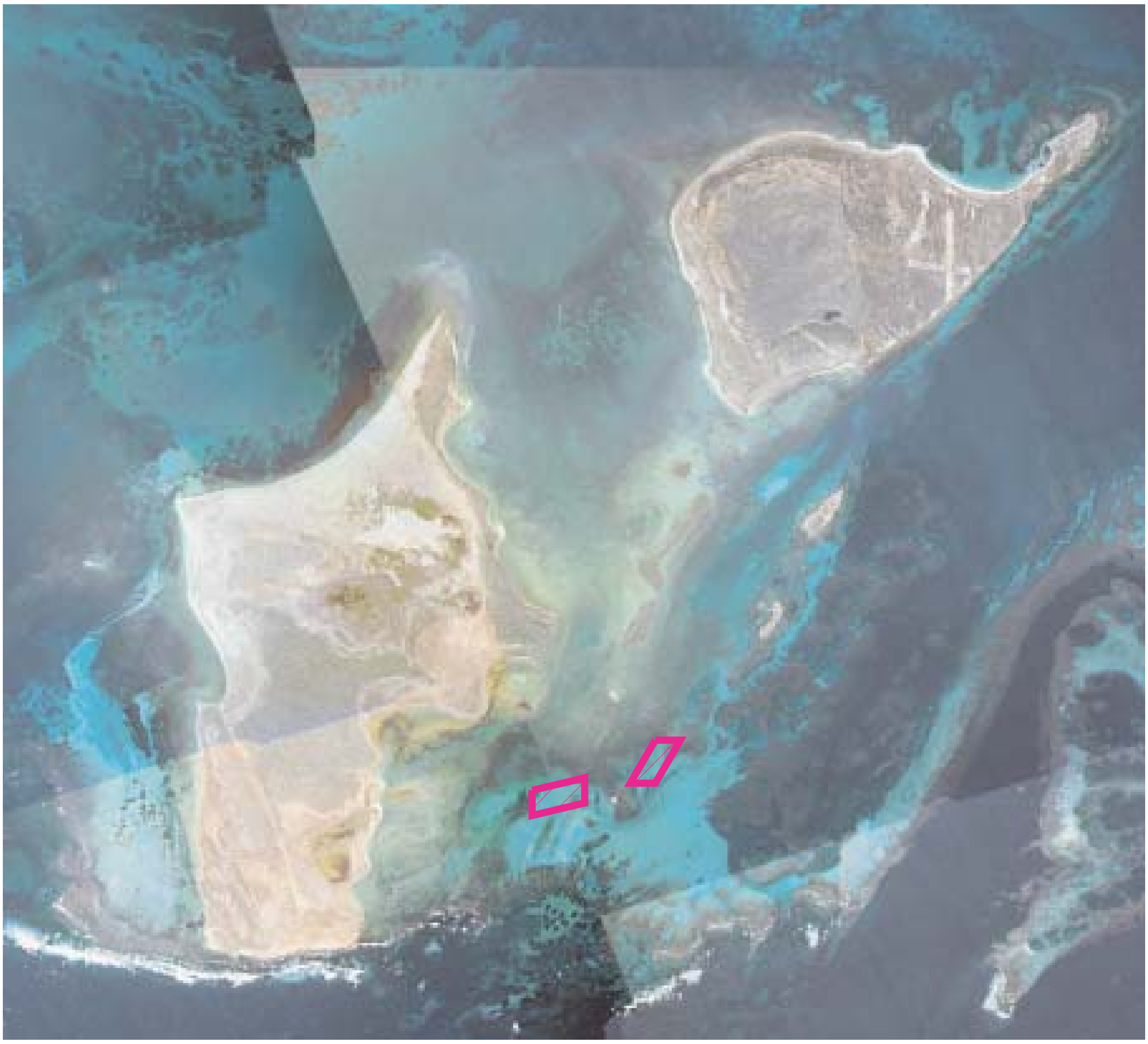
6.1.5.2 Economic value

Trial harvests in the last twelve months have produced several hundred black-lipped pearl oysters, *Pinctada margaratifera,* pearls which have been sold on the local market as value added pieces of jewellery. The product is sold at premium prices due to the "rarity" of the product. The value of production is not available for publication because there are less than three operators at present.

6.1.5.3 Growout effort

Currently there are six licensed aquaculture sites at the Abrolhos. Two other applications are under consideration (Figure 6.12). The oyster species listed on these licences are *Pinctada margaratifera*, *Pinctada albina* and *Pteria penguin,* although only *P. margaratifera* is under cultivation. The total size of the area licensed for aquaculture is around 1000 ha. Only 214 ha of the total licensed area currently is used for grow out, of which 95 percent is in the Pelsaert Group. The combined total number of shell used at the Islands is 210,000.

The Government recently released an "Aquaculture Plan for the Houtman Abrolhos Islands" (Anon. 2000) which aims to assist prospective aquaculturists in preparing proposals and guide the Department of Fisheries in the decision-making process for aquaculture licence applications. Aquaculture licence applications are evaluated through the licence assessment process.



LEGEND
Aquaculture Sites
AQUACULTURE SITE - LICENSED
AQUACULTURE SITE - APPLICATION
Abrolhos Islands Reef Observation Area (ROA)

Figure 6.12a. Aquaculture lease sites at the Wallabi Group.

b)

c)

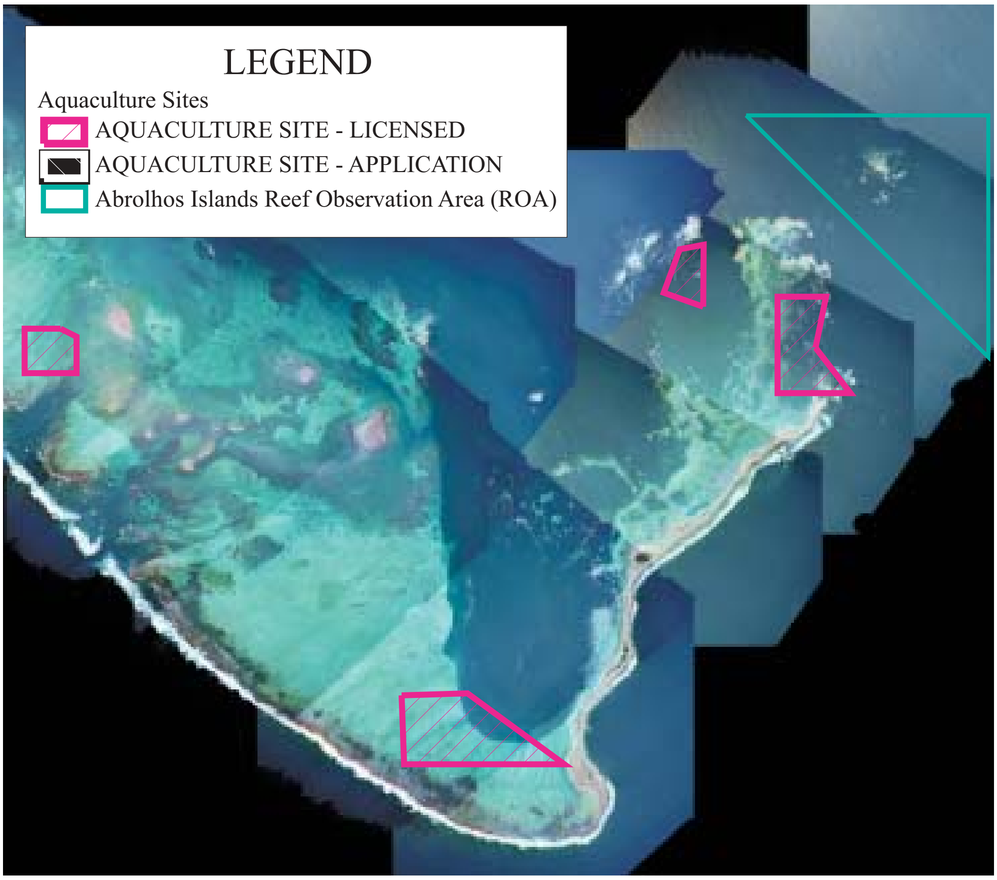


Figure 6.12b & c. Aquaculture lease sites at the Easter and Pelsaert Groups.

All aquaculture activities must take place within the context of the management plan for the Abrolhos Islands (Anon. 1998). The plan states that, “before further aquaculture is undertaken in the Abrolhos Islands, appropriate examination of potential impacts, both beneficial and adverse, must be undertaken”.

A rather broad spectrum of species is listed in the Aquaculture Plan as having potential for aquaculture in the Abrolhos Islands and includes molluscs such as, black-lipped pearl oyster (already under cultivation), the giant clam, and saucer scallop; western rock lobster; and finfish such as snapper, black bream, yellowfin tuna, mahi mahi and baldchin groper. The Plan describes areas which cannot be used for aquaculture, such as Reef Observation Areas and protected shipwreck sites. It also lists sites where approval of aquaculture is unlikely, such as areas of high conservation value; locations already extensively utilized by other interests, such as navigation areas; and locations extensively used by commercial fishermen, tourist operators or private visitors to the islands. High conservation areas are listed as including mangroves; significant seagrass meadows; coral reefs; major habitats of significant fauna, such as seabirds and marine mammals; and any other areas which might later be set aside for the protection of flora and fauna or habitats.

Sites located in areas adjacent to, or otherwise able to affect, areas of high conservation value are also unlikely to be approved, i.e. waters adjacent to important seabird nesting areas. Also, sites with significant social importance or high visual amenity values are unlikely to be approved for aquaculture operations.

For any other proposed area, a detailed habitat description is required as part of the aquaculture proposal. The application is also required to provide information on the existing uses of the proposed area, by people such as recreational fishers, tourism operators and private users.

The key goal listed in the Plan is to manage aquaculture developments so as to minimize their effect on the environmental and cultural values of the Abrolhos system.

6.1.5.4 Likely impacts

Although, a recent study of the environmental impacts of the pearl (*Pinctada maxima*) industry (Wells, 1998) examined a variety of potential impacts e.g.:

- waste disposal involving the removal of packaging wastes, biodegradable materials, old ropes, floats and other discarded items;
- discharged water from toilets and sinks, either on boats or from camps on shore;
- fuel, oil, and chemical storage and handling (presenting problems of handling and potential small scale spills and low levels of seepage from equipment);
- oil disposal after use; and
- boat paints (which have anti-foulant compounds embedded in their chemical composition);

these impacts were considered to be minimal in this fishery. In the Abrolhos context pearl culture operations are much smaller scale, are bound by strict management plans, and operators work positively to ensure such problems do not arise in this region.

One potential environmental impact of aquaculture at the Abrolhos is the impact of moorings and anchors. Permanent moorings are required for aquaculture cages or longlines.

Longlines are maintained in a constant position, with anchors at either end. In contrast to boats, longlines are maintained taut in the same position. This means they do not swing about on the tides or winds and their environmental effects, therefore, are minimized. However, there have been cases of longline anchors becoming dislodged and causing damage to surrounding reefs. This could be an issue where licences cover areas of fragile corals, e.g. in the Pelsaert Group.

An alternative anchoring system for pearl oysters is star pickets embedded in the substrate or sections of railway line placed in holes in the reef. Again, the effects are arguably minimal, as the same anchor is used for several years. In fact, the metal "anchors" develop an attached biota which attracts a number of fish species to the area (Wells 1998). Whilst the pin system is benign in some of the Abrolhos reefs, there is evidence that the star picket system has caused damage to coral in at least one site at the Abrolhos. In this instance, the pin was placed 7-10 m from the edge of the reef, and once the panels had been placed on the longline, the rope had come to rest over the coral colonies and abraded an area across the top of several *Acropora* colonies (Dr C. Chubb, Department of Fisheries, Western Australia, pers. comm.).

The environmental effects of culturing the proposed species of bivalve molluscs, pearl oysters, edible oysters, giant clams, and scallops, are all similar. The key feature is that they are all sedentary, filter-feeding species, requiring some form of infrastructure attached to the substrate. Single celled algae and other particles are filtered from large quantities of seawater that are moved through the animals. As the animals are not fed, there is little accumulation of wastes on the sea bottom or addition of nutrients to the water column in comparison to species that are fed. There is speculation that the introduction of large numbers of filter feeders, such as oysters, may reduce food availability for downstream wild filter feeders by "scrubbing" the water of food detritus and plankton.

6.1.5.5 Issues for consideration

Potential impacts could arise from the use of anchors for long lines and damage from dislodged longlines to reef structures. Boat anchors and moorings could also be a potential problem.

6.2 Recreational activities

6.2.1 History

While little is known of early recreational activities at the Abrolhos it is known that guano miners fished for recreation in the early 1880s (Gray 1999). The unique features of the Abrolhos make it an excellent destination for recreational pursuits with world class diving on the coral reefs, excellent fishing, good conditions for surfing and windsurfing, historic wreck sites of the Dutch ships Batavia (1629) and Zeewijk (1727) and an abundance of sea birds. Recreational activities at the islands are undertaken by tourists, rock lobster fishers and their immediate families and friends. Tourists are defined by the Western Australian Tourism Commission (WATC) as: "persons who have been away from their place of residence for any purpose except work for a period of at least one night, at a location of least 40km from their usual place of residence". Thus, visiting family and friends of fishers are considered tourists by the WATC. Presently only family and friends are allowed to stay at camps on the islands during the season. All other tourism is boat based. Other tourists either utilise charter boats or have their own vessels (Anon. 2001).

Activities currently undertaken at the islands include SCUBA diving and snorkelling; boating and sailing; windsurfing; fishing and spearfishing; birdwatching; historical tours; and surfing.

Most visitors to the islands undertook one or more of these activities per visit. The favourable time to visit the Abrolhos is during the autumn/early winter period, when the southerly winds, on average, are weaker and less persistent.

6.2.2 Economic value

There is no estimate of the economic value of tourism at the islands.

6.2.3 Recreational effort

Data about recreational activities at the islands were collected primarily from charter boat operators. Detailed information (where possible using GPS positions) about the type and locations of recreational activities was gathered. Charters were dominated by SCUBA diving with other recreational activities, such as sightseeing and fishing, conducted as secondary activities. Other charters for the purposes of surfing or birdwatching also were conducted at the islands, but less frequently.

The charter boat industry in Western Australia (including the Abrolhos) is under review. By the year 2002 operators will require a licence to conduct charters. Currently around 10 charter vessels operate at the Abrolhos Islands although only one vessel is dedicated exclusively to charter work. Most operators are either Abrolhos rock lobster fishermen (A Zone licencees) or carrier boat operators who conduct charters between July and February, outside of the rock lobster season. Carrier boats ferry supplies from, and rock lobster catches to the mainland. Charter operators not involved with the rock lobster fishing industry tend to concentrate their activities during the period March to June when weather conditions usually are more favourable. From the interviews it was estimated that the total annual number of charters to the islands was approximately 150 and the total annual number of visitors associated with this industry was about 1650. Charter boat operators tended to fall into two categories, those who conducted regular charters, around 33 per operator, per year, and those who conducted infrequent charters, averaging approximately 5 per operator, per year (Table 6.4). The average trip length for all charters was 3 days with a range of 1-7 days.

Table 6.4. The number of charter boat operators interviewed, frequency and length of charters and the estimated annual number of tourists over the last 5 years at the Abrolhos.

Type	No. charter operators interviewed	Average trip length (days)	Average No. of charters per year	Estimated No. of tourists per year
Regular	4	3	33	1584
Irregular	4	3	5	60

Private yachts and pleasure boats have visited the islands for many years and the number of visiting boats is increasing (Anon. 2001). During the rock lobster closed season, boats visiting the islands are required to register with Department of Fisheries for safety reasons. During a one year period from 25 January 1996 to 24 January 1997, a total of 28 boats and 252 people registered. However, most private vessels visit the Abrolhos during the rock lobster season when conditions are more suitable and therefore the total number of boats will be much higher than 28. The Abrolhos Islands tourism management plan proposes to introduce a fee for visits to the islands by tourists (Anon. 2001). This would provide a more accurate record of visitor numbers.

As a part of this study, every yacht club in Perth, Geraldton and Carnarvon was contacted to gather information about visitors to the Abrolhos Islands. However, the Commodores of each yacht club knew little about individual members' activities. Interviews were conducted with representatives from only two clubs; Geraldton Yacht Club and Hillaries yacht club.

The interview results enabled the tentative conclusion that yachts and power boats mainly visited the islands during long weekends, the Easter holiday period and school holidays, although boats did visit at other times. Most boats tended to anchor at a few safe anchorages or used moorings if available and did not move around much. Yachts usually have a tender (small dinghy) to access areas for fishing and diving and to go ashore. Power boats also may have a tender, however, fishing was conducted mainly from the large vessel in deeper water away from the islands. Information about tender activities and anchoring was not collected during the interviews.

Representatives from fishing and diving clubs were interviewed, with most clubs tending to utilise charter boats. However, the Geraldton Offshore Fishing Association conducts an annual game fishing competition involving approximately 23 boats, many from Perth. Most fishing is trolling for pelagic fish in the open water where fish are tagged and released. Overnight, these vessels utilise jetties or rock lobster vessel moorings, if available, or anchor in a few sheltered locations in the Easter Group.

Perth Diving Academy and the Australian SCUBA Centre conduct annual dive trips to the Abrolhos, usually over a two week period in the Autumn. Diving occurs throughout the island groups but only the latter club's representative was able to identify dive locations on a chart. Anchoring was associated with most of the dive sites.

Exact numbers of visiting family and friends of rock lobster fishers was not obtained as a part of this study. However, it is estimated that numbers increase to 2000-4000 over the Easter period alone and this group constitutes a major proportion of visitors to the islands (Mr K .Nardi, Department of Fisheries, Western Australia, pers. comm.). Interviews with some rock lobster fishers indicated that, as expected, most family and friends visited during long weekends, the Easter period and school holidays. The number of visitors to each individual camp during a season was highly variable with some rock lobster fishers having only their immediate family visit once or twice during the season and others having a constant flow of groups of visitors. Activities undertaken usually were cited as fishing, diving and visiting the islands with transport by dinghies and occasionally a rock lobster vessel.

The leisure activities of the deckhands also were considered as a part of recreational use at the Abrolhos. Rock lobster fishers tend to have 1-2 deckhands per vessel, occasionally more, and common activities appear to be fishing, diving and surfing, usually once or twice a week depending on the weather. Dinghies generally are used for these activities. Information about the locations or frequency of dinghy anchoring was not collected for the activities of deckhands or for visitors to rock lobster fishers' camps.

There was a good correlation between the recreational activities in the locations nominated by the interviewees and the habitat mapping. However, some incompatibility was noted e.g SCUBA diving in static sediment. This is likely to be a consequence of either:

- the interviewee marking the site inaccurately;
- anchoring could occur in one habitat but the activity in another e.g. anchor in static sediment but SCUBA diving occurs on adjacent sheltered reef slope;
- habitat mapping is too coarse; and
- slight variation between charts, habitat mapping and GPS information.

6.2.3.1 Recreational activities

SCUBA diving was identified as the most popular recreational activity, by charter boat participants in each of the island groups, both in terms of the number of sites identified and the frequency of activity (Table 6.5).

In the Wallaby Group, 15 sites were identified where SCUBA diving occurs. Here the total number of anchoring events associated with SCUBA diving was 135 per year and total number of divers was approximately 1620.

At the Easter Group, 17 SCUBA diving sites were identified during interviews. The annual total number of anchoring events for SCUBA diving was 221, and SCUBA divers 2652.

The number of dive sites was highest in the Pelsaert Group, where 40 locations were identified during interviews. The annual total number of anchoring events for diving at the Pelsaert Group was 200 and the annual total number of divers 2400.

Other activities such as surfing, historic site visits and birdwatching were undertaken less frequently at all of the island groups. The number of sites identified and frequency of boats anchoring in association with each activity was much lower. For example at the Wallabi Group, 9 visits were recorded annually to 3 historic sites.

Table 6.5. Total number of sites and annual frequency of visits for all individuals interviewed in different types of recreation at the islands (total annual number divers is also included).

Activity	Wallabi and North			Easter			Pelsaert		
	Sites	**Visits**	**SCUBA divers**	**Sites**	**Visits**	**SCUBA divers**	**Sites**	**Visits**	**SCUBA divers**
Birdwatching	-	-	-	3	24	-	-	-	-
Fish feeding	-	-	-	-	-	-	1	18	-
Fishing	-	-	-	3	-	-	3	9	-
Historic site	3	9	-	1	3	-	2	8	-
Overnight stops	4	-	-	10	-	-	5	15	-
SCUBA diving	15	135	1620	17	221	2652	40	200	2400
Surfing	4	-	-	4	50	-	3	6	-
Windsurfing	-	-	-	-	-	-	2	6	-
Yachting	2	28	-	1	29	-	1	41	-

6.2.3.2 Recreational activities in relation to habitat

SCUBA diving was concentrated in the eastern parts of the Wallabi and Easter Groups which are more protected from wind and swell (Figure 6.13 a, b). These areas are characterised by geomomorphological units such as sheltered reef slope, complex karst platform and isolated patch reef and contain biological communities more sensitive to damage such as:

- High energy assemblages of coral;
- Low energy assemblages of coral;
- Coral macro algal assemblages; and
- High diversity coral communities.

In the Wallabi Group, 5 dive sites were identified in sheltered reef slopes, with a total of 55 annual anchoring events for SCUBA diving in this habitat. Four sites were identified in complex karst platform with 45 anchoring events in this habitat per year (Figure 6.14a).

At the Easter Group, the annual total number of dive sites visited and frequency of anchoring events in association with diving in highly sensitive areas were: sheltered reef slope-3 sites and 45 anchoring events; complex karst platform-3 sites and 35 anchoring events; and isolated patch reef-2 sites and 33 anchoring events.

For both the Wallabi and Easter Groups, close examination of the locations where boats anchor in relation to SCUBA diving, indicated that within the sensitive habitats, boats selectively anchor in areas of sediment. Thus, the impacts from anchoring in relation to SCUBA diving are probably low, and the greatest risk of physical damage to fragile habitats may be from the SCUBA divers themselves.

Dive sites were identified mainly in the central part of the Pelsaert Group which, unlike the Wallabi and Easter Groups, is protected from swells and wind by the western fringing reef. Dive sites were identified in a range of habitats of varying sensitivities (Figure 6.13c) but it seemed unusual that in the Pelsaert Group, dive sites were identified in areas of sediment. However, it is likely, in these areas, that small reef outcrops with which diving was associated were not identified during the habitat mapping.

6.2.3.2 Popular areas for recreation

Certain locations in each island group were very popular (Table 6.6). These areas were either an attractive dive site and/or a safe anchorage from which a range of activities were conducted.

At the Wallabi Group the most popular areas were Long Island, Turtle Bay, Beacon Island, Fish Point and the historically significant Batavia wreck site on Morning Reef. Each of these locations and it’s habitat type is discussed below.

A dive trail has been installed at Long Island which makes it popular for diving. The geomorphological unit at Long Island is sheltered reef slope which is characterised by high and low energy coral assemblages. Most anchoring was identified in an area characterised by meso-macro algae, which has low sensitivity. Two permanent moorings have been installed at this site by Department of Fisheries with funding from Environment Australia.

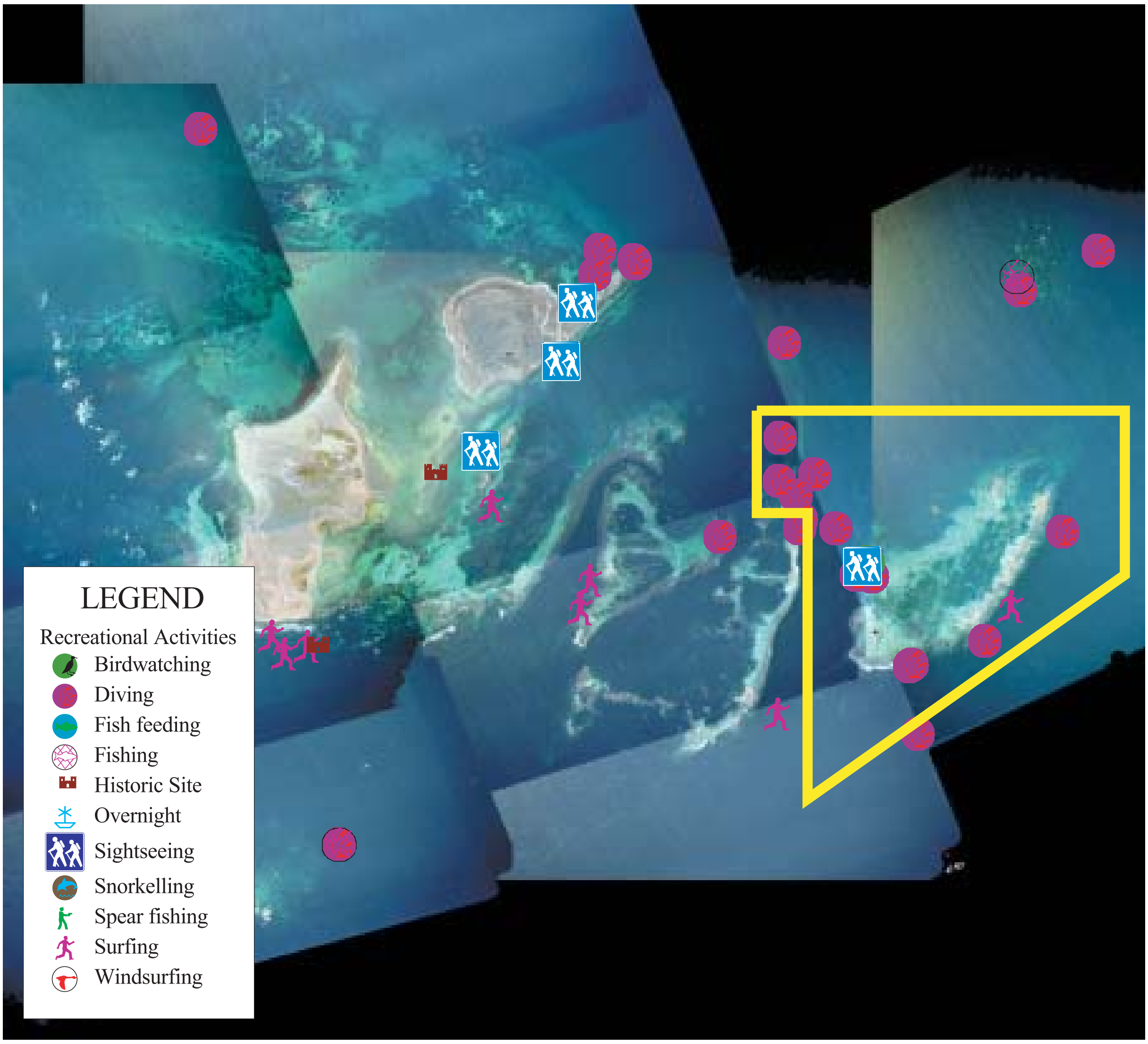


Figure 6.13a. Locations where recreational activities were conducted at the Wallabi Group as determined from interviews. Area enclosed by yellow line is a Reef Observation Area (ROA).

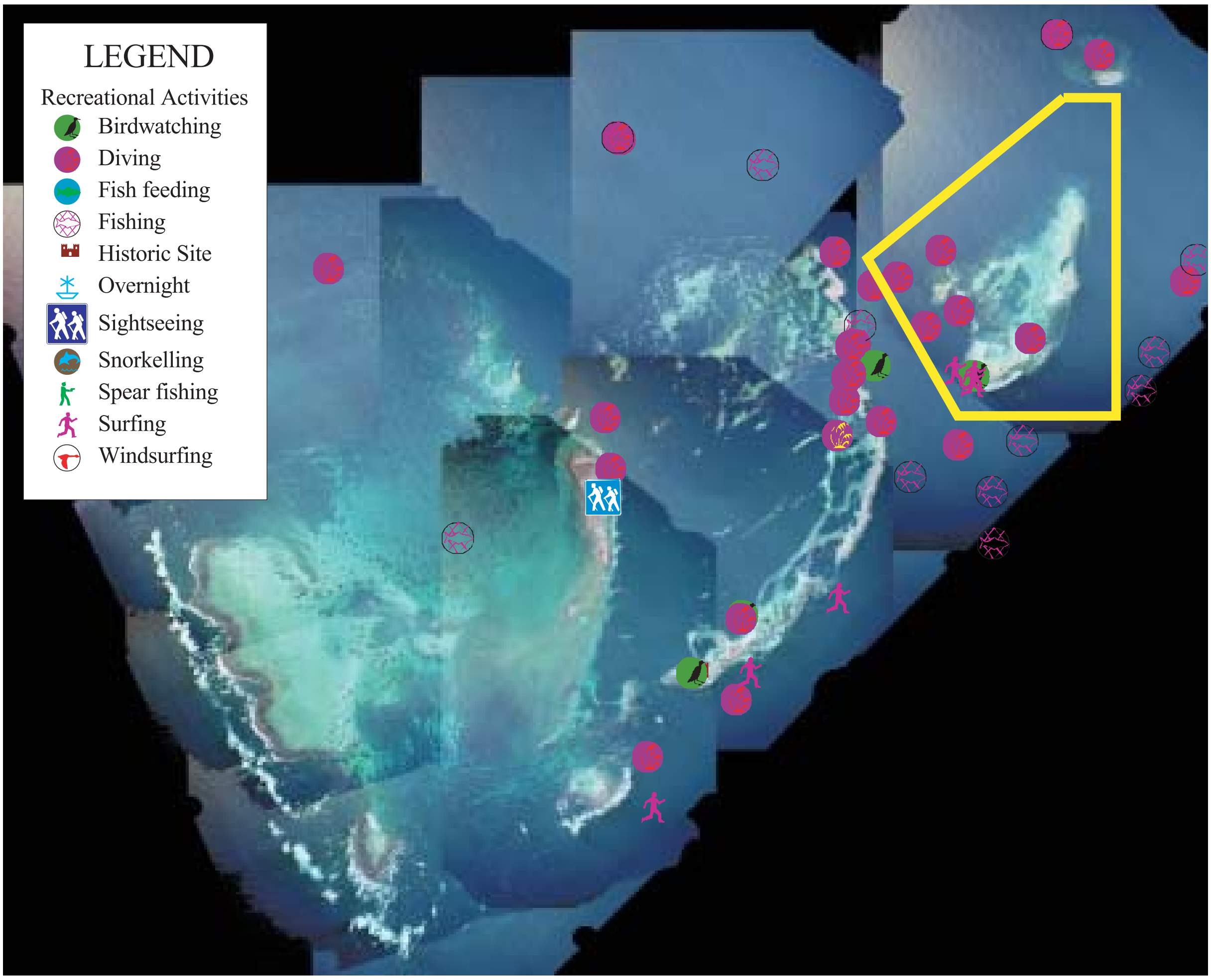


Figure 6.13b. Locations where recreational activities were conducted at the Easter Group as determined from interviews. Area enclosed by yellow line is a Reef Observation Area (ROA).

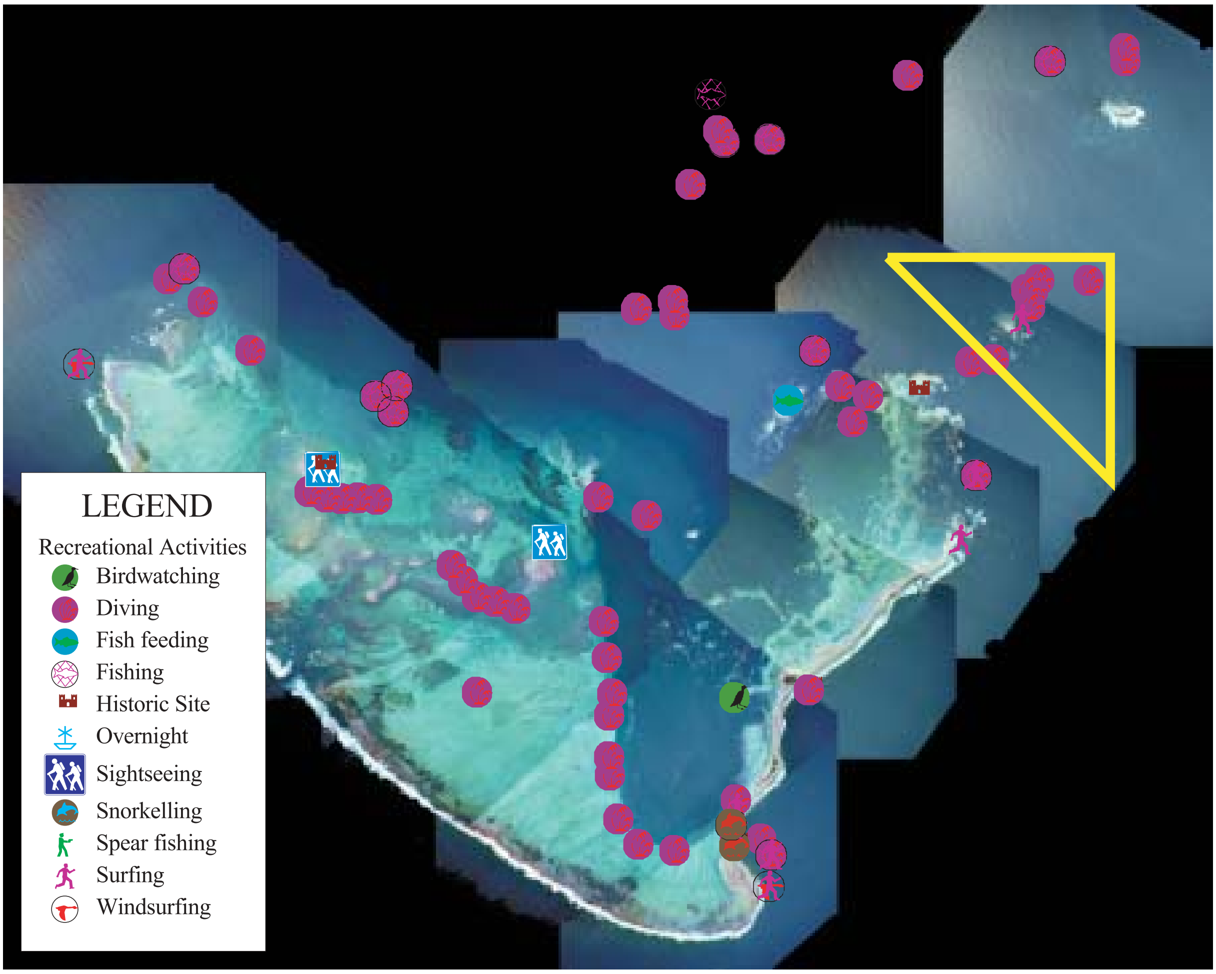


Figure 6.13c. Locations where recreational activities were conducted at the Pelsaert Group as determined from interviews. Area enclosed by yellow line is a Reef Observation Area (ROA).

Table 6.6. Popular locations where anchoring and diving occurred at the Wallabi, Easter and Pelsaert Groups. *Mooring or jetty present, only boats which anchored at this location were recorded.

Location	Habitat Type	Main biological community and sensitivity where anchoring locations were identified	Activity	Average number of anchor drops	Average number of divers	Number of moorings
Long Island (north end)	Sheltered Reef Slope	Meso-macro algea Low	Diving	51	639	2
Beacon Island	Complex Karst Platform	Infaunal sediments Low	Diving Historic Bird Overnight	40*	918	-
Turtle Bay	Submerged Limestone Platform	Low energy coral assemblage Low	Diving Overnight stop Sight Seeing Yacht club Spear fishing	48	108	4
Fish Point	Submerged Limstone Platform	Coral-algal pavment Low	Diving	19	226	2
Batavia Wreck Site	Exposed Reef Slope	Coral-algal pavement Low	Diving – wreck site	12	144	-

Table 6.6. Popular locations where anchoring and diving occurs at the Wallabi, Easter and Pelsaert Groups (cont.). *Mooring or jetty present, only boats which anchored at this location were recorded.

Location	Habitat Type	Main biological community and sensitivity where anchoring locations were identified	Activity	Average number of anchor drops	Average number of divers	Number of moorings
Easter Group						
Wooded Island	Complex karst platform	Infaunal sediments Low	Historic site Overnight stop Diving Birdwatching	36	120	-
Anemone Lump	Isolated patch reef	High diversity coral assemblage High	Diving	83	1050	2 proposed
Leo Island	Emergent limestone platform	Coral-algal pavement Low	Diving Surfing Fish feeding Birdwatching Surfing	32	144	1
North of Big Rat Is	Isolated patch reef	Infaunal sediments Low	Overnight stops – Fishing competition	92	-	2
Morley Island	Static sediment sheets	Infaunal sediments Low	Yachting Overnight stop Diving Birdwatching	128	270	-
Pelsaert Group						
Coral Patches	Sheltered reef slope	High energy coral assemblage High	Surfing Diving	44	386	2 proposed
The Hummock	Exposed reef slope	Mixed macro algae Moderate	Diving	51	666	
Pelsaert Island	Mobile/static sediment	Infaunal sediments Low	Overnight stop Historic site Birdwatching Snorkelling Diving Windsurfing Surfing Snorkelling Yachting Fishing	52*	40	

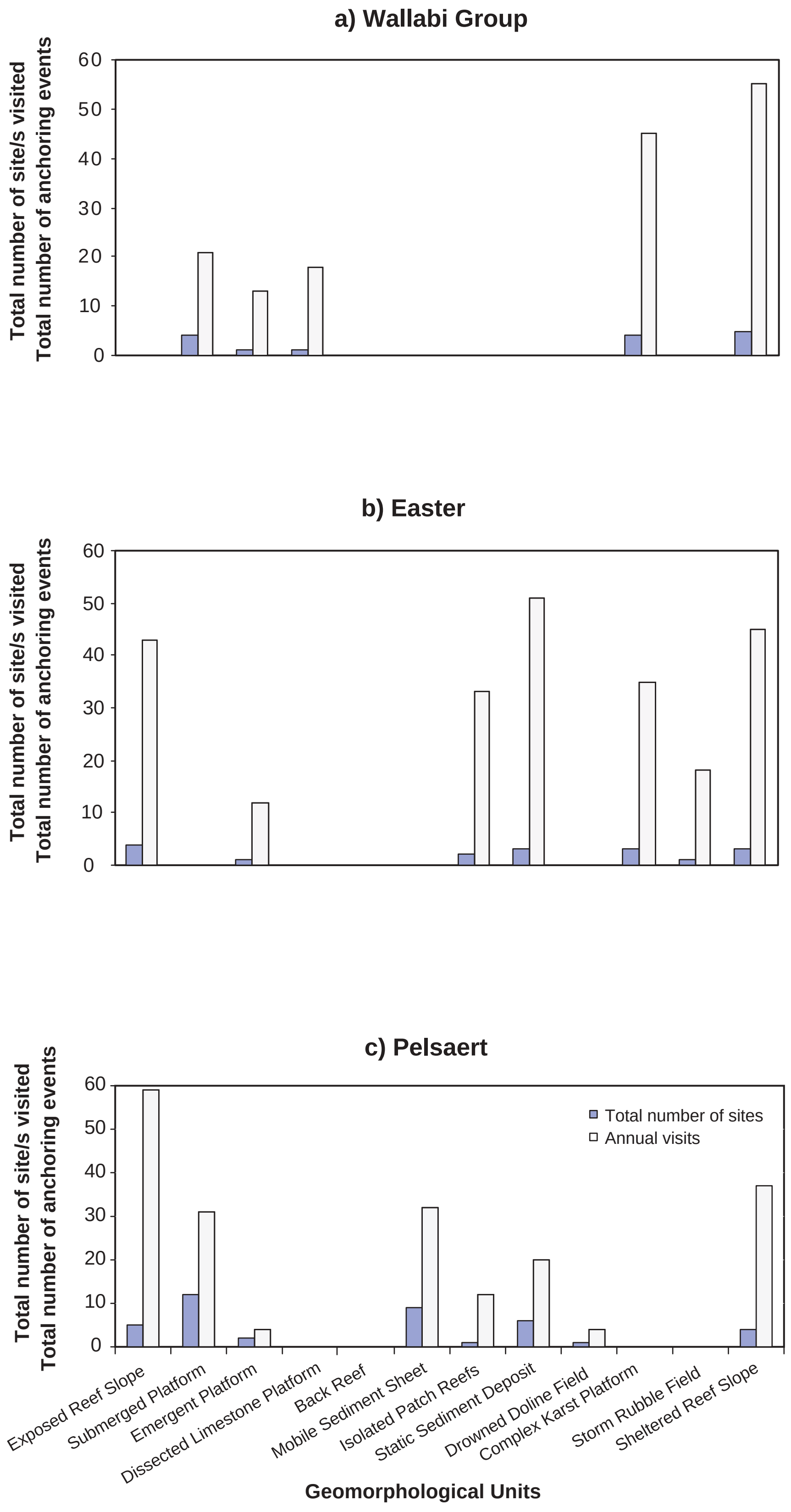


Figure 6.14a, b&c. Total number of dive sites visited and annual number of anchoring events in each geomorphological unit in each island group.

Turtle Bay is a protected and picturesque anchorage where sensitive low energy coral assemblages and seagrasses occur. Frequent anchoring in Turtle Bay and its potential to disturb these sensitive habitats has led to the installation of four permanent moorings to minimise such disturbance.

Beacon Island is visited regularly mainly for SCUBA diving and historical tours. Often boats will moor at the private jetty if prior arrangements are made with the owner. Thus anchoring impacts are minimised. The annual frequency of divers is high (918) and the nearby habitat is sheltered reef slope which is characterised by high energy coral assemblages. The historic Batavia wreck site is popular for diving. The biological community at the site is coral algal pavement and has low sensitivity.

At the Easter Group four popular locations were identified, Wooded, Morely and Leo's Islands and the Anemone Lump. Wooded and Morely Islands are popular protected anchorages for recreational activities ranging from birdwatching to SCUBA diving. At both locations anchoring mainly occurs in unconsolidated sediments which have low sensitivity. However, diving occurs on nearby areas of complex karst and/or isolated patch reef, both of which have coral communities and have high sensitivity.

Leo's Island is popular for surfing and diving. Most boats anchor on the south western side in coral algal pavement which has low sensitivity. Diving occurs on the nearby sheltered reef slope which is a high energy coral assemblage with high sensitivity. A permanent mooring has been installed on the north side of Leo's Island.

The Anemone Lump is a very popular SCUBA diving location. Many interviewees marked anchoring sites around the lump in areas of sand, although some also indicated that anchoring occurs directly on the lump. Anemone lump is an isolated patch reef characterised by high energy coral assemblage. This biological community has high sensitivity. Two moorings are proposed for the Anemone Lump.

In the Pelsaert Group, three locations are popular, the Coral Patches, the Hummock and the old guano jetty on the south-western part of Pelsaert Island. The focus for SCUBA divers at the Coral Patches is the sheltered reef slope which contains a high energy coral assemblage. From the interview data it appears that both anchoring and diving occur in the fragile coral assemblages. One permanent mooring is proposed for this site. The Hummock is also popular for diving, and the biological community is dominated by low sensitivity macroalgae which has a low sensitivity to physical damage.

The area near the old guano jetty on Pelsaert Island is a safe anchorage where many boats congregate for a range of activities. One private mooring has been installed, however, most boats anchor in mobile sediment sheets which are not sensitive to damage. Diving is conducted at this site, although it is most likely to occur in the nearby isolated patch reefs or sheltered reef slopes which both have coral assemblages sensitive to damage.

6.2.4 Potential impacts

The main potential physical impacts to the benthic habitat caused by recreational activities are from anchoring, SCUBA divers and the impacts of boat hulls. Both anchor deployment and retrieval and the associated chains and ropes may disturb or damage benthic habitats such as seagrass or corals. SCUBA divers may break delicate structures such as corals by contact with their body, fins and tank. This is likely to be more of an issue with inexperienced divers with less than optimum buoyancy control or lack awareness of the damage they may cause. In the Great Barrier Reef Marine Park, Rouphael and Inglis (1995) found that 15% of divers caused damage to mostly branching hard corals predominantly from contact by divers' fins. They further noted that 4% of divers were responsible for more than 70% of the damage.

Intuitively, recreational fishing is likely to be a leading pasttime at the Abrolhos. However, as the information about recreational activities was dominated by interviews with charter boat operators, SCUBA diving was identified as the most popular recreational activity at all of the island groups. Most dive sites were in the eastern parts of the island groups and associated with reef slopes, complex karst platforms or isolated patch reefs which contain fragile coral communities sensitive to physical damage.

At each island group certain locations, popular for recreation, were identified. These areas were either safe anchorages (eg. Wooded Island) or attractive dive sites (e.g Anemone Lump). At these popular locations anchoring usually occurs in sediments of low sensitivity, however nearby reef structures may still be affected. The effects of anchoring are being addressed by the installation of permanent moorings. The areas around these moorings are being monitored to identify any associated potential negative impacts.

International studies on the SCUBA diver carrying capacity of reefs in the Red Sea, Caribbean and South Africa indicate that it is between 5000-7000 divers per annum (Hawkins and Roberts 1997, Schleyer and Tomalin 2000). The numbers of divers visiting sites at the Abrolhos is much lower, usually around 100-200 per site per annum, although some popular sites such as the Anemone Lump may have as many as around 1000 divers per year. Therefore, it may be that due to the relatively low numbers there are no significant impacts from divers at the Abrolhos. However, the Abrolhos reefs may have a lower carrying capacity for SCUBA divers in comparison to reefs in the Red Sea, Caribbean and South Africa. The pattern of diving also will be significant in that if diving continues year round, small effects may accumulate over time.

The number of visitors to the islands is likely to be much higher than has been estimated in this study due to the lack of information from private boat owners and from the family and friends of rock lobster fishers. Therefore, due to an underestimate in boats and visitors, potential physical impacts from anchors and SCUBA divers could be more pronounced that has been estimated in this study.

The focus for any future assessment of any impacts from recreational activities should commence at popular locations especially where biological communities of high sensitivity were identified.

6.2.5 Issues for consideration

- Popular areas which receive a high concentration of divers and anchoring need to be monitored if fragile biological communities are present. The carrying capacity of reefs at the Abrolhos Islands needs to be considered.

- Private boat owners and friends and family of rock lobster fishers were under represented in interviews. Consequently, impacts associated with fishing, anchoring and boat hull damage are also not fully understood. Quantitative data are needed for potential impacts to be assessed. This information may be obtained as a part of the proposed visitors permit.
- The requirement for additional moorings and an education program for divers and visitors needs to be assessed.

6.3 Petroleum exploration

6.3.1 History

Four petroleum exploration wells were drilled in waters surrounding the Abrolhos in the late 1960s and 1970s. These wells have been capped and abandoned (Mr S. Doherty, Department of Minerals and Energy (DME), Western Australia, pers. comm.). The DME "released" further areas in Western Australia (including the Abrolhos) for petroleum exploration in 2001. The leases at the Abrolhos are outside of the Fish Habitat Protection Area.

6.3.2 Likely impacts

Current exploration is likely to be seismic with further development unlikely in the near future. Impacts associated with seismic surveys to the benthic habitat are negligible.

6.3.3 Issues for consideration

- Potential issues associated with petroleum drilling are ecotoxicology and turbidity. If exploration drilling were to be conducted, the procedure would need to meet the requirements and approval of the Department of Environmental Protection.

7.0 Discussion

Available data from a number of sources were collated and presented in this report to provide an overview of current knowledge about the marine ecosystems of the Abrolhos Islands and its uses. Existing habitat descriptions provided the foundation for categorising the habitats into general areas (the geomorphological units of Hatcher *et al.,* (1988)) suitable for relating to the widely distributed human uses. Where possible, human activity was related to the dominant biological community within each component of the geomorphological units. The biological communities were rated as having a high, moderate or low susceptibility to physical damage. Hatcher *et al.,* (1988) termed this biological sensitivity, but because sensitivity has a number of interpretations, herein a community's susceptibility to physical impact was referred to as its fragility.

Commercial fishery uses of the Abrolhos resources having the greatest potential to impact on the habitat were the western rock lobster fishery and the scallop trawl fishery. The rock lobster fishers spent much of their time fishing in areas where biological communities were robust and only a small percentage of their effort was targeted in fragile areas. The fragile areas tended to be in the eastern sections of the island groups where lower energy environments allowed the proliferation of branching and tabulate corals. The impact of potting appeared to be relatively minor with the probability of localised disturbance in specific areas as distinct from widespread general damage. The trawl fleet operated over unconsolidated sediments both adjacent to and away from the Abrolhos Islands reef habitats. Scallop recruitment is highly variable, patchy and restricted to sand bottoms, and this determines where the fleet operates. Thus the trawl grounds can be markedly different from season to season. The scallop season is short and so any physical impact is limited to a confined period each year. The trawl grounds can be close to demersal sponge "gardens" containing a variety of organisms and occasionally trawls do impact on this habitat, however, scallops are not found in sponge habitat and so this habitat is not targeted by the trawl fleet.

Recreational activity is likely to have little physical impact on the Abrolhos marine habitats so long as it is managed well. Most recreational vessel anchorages are in unconsolidated sediments and of little concern, but the possibility of anchoring in seagrass beds eg. in Turtle Bay (Wallabi Group), is real but the extent to which anchoring impacts on these biologically sensitive communities is unknown. Pleasure craft and charter boat anchors and anchor chains may be set on or nearby other fragile biological communities (eg. popular dive sites) and cause damage. This has been addressed through the installation of permanent public moorings at popular locations containing sensitive habitats. SCUBA diving is a popular activity and most dives are restricted to the few popular dive sites in each island group. The conduct of divers underwater in relation to the collection of shells, and the potential for divers to damage fragile communities (particularly *Acropora* spp) by physical contact, has not been quantified here. Assessment has been done for South African, Caribbean and Red Sea reefs and there is a limit to the numbers of diver visits (5,000-7,000 per year) specific reefs will tolerate without risk of sustained damage (Hawkins and Roberts 1997, Schleyer and Tomalin 2000). These estimated limits are much higher than present levels of activity on Abrolhos popular dive sites, but the "carrying capacity" of specific Abrolhos habitats is unknown.

Previous exploration drilling for petroleum at the Abrolhos is likely to have little or no impact on the marine environment as only four wells were drilled and these have been capped and abandoned. Areas released for further exploration are outside of the Fish Habitat Protection Area. Future surveys are likely to be seismic which will not impact upon the benthic environment.

Reef Observation Areas (ROAs) were established in the Abrolhos in 1994 for conservation and biodiversity reference area use. These ROAs, covering large areas of biologically diverse and visually interesting habitats, have been very successful and are used frequently by snorkelling and SCUBA diving visitors. The Abrolhos also may function as an excellent scientific laboratory for the study of ecological and micro-evolutionary processes, especially for less mobile species such as molluscs, due to its isolation from the mainland and the replication of habitats in each island group. The genetic divergence of some populations of molluscs and a species of fish (*Craterocephalus capreoli*) have been reported for Abrolhos populations indicating that speciation may be occurring (Johnson and Black 1997a, b, 1998, Parsons 1996) and specialist habitats may be in need of protection.

A number of applied studies have been conducted at the Abrolhos Islands, but no study has examined the health of the Abrolhos marine ecosystem. Nevertheless, the many separate studies have identified the presence of an unusual tropical and temperate mix of species and a high diversity of species and habitats. These features are considered to indicate the marine system is healthy. The Abrolhos is fortunate enough to be placed far out of reach of the general public and so has been left relatively undisturbed. Fishers living at the Abrolhos Islands generally have no desire to ruin the habitat on which their livelihood depends. Indirectly, support for the concept that the marine ecosystem of the Abrolhos is in good health comes from comments relating to its high conservation value. For example, the Report of the Marine Parks and Reserves Selection Working Group stated "of all the marine areas of the Western Australian coast, the Abrolhos is perhaps the most significant for its natural resource, nature conservation, historical and recreational values and the most worthy of reservation" (Anon. 1994). The conservation values of the Abrolhos also have been recognised in the Abrolhos Islands Management Plan (Anon. 1998), by Wells (1997) and by Professor Paul Dayton, Professor of Marine Ecology at the Scripps Institute of Oceanography in San Diego who, after a visit to the Abrolhos, was quoted in a newspaper article as saying "the area was pristine and the unusually fragile coral reefs were in as good a condition as any I have seen" (Zekulich 1998).

The physical disturbance of Abrolhos Islands marine habitats by humans is likely to be inconsequential when compared to natural damage. Strong swells generated during storms and cyclones severely affect the coral reefs. Most of the eastern islands are composed of coral rubble generated during storms and cyclones, which accrete and erode according to weather influences. Nevertheless, natural damage is periodic and anthropogenic disturbance is low level and isolated but persistent, and the effects of damage of this nature might be cumulative. A similar situation on South African reefs led to the conclusion that diver related habitat damage, in some cases, clearly exceeded natural damage (Schleyer and Tomalin 2000). The Abrolhos Islands reef systems are at high latitude and competition for space and light is intense between corals and macroalgae. This has led to the hypothesis that physical damage to fragile corals from human use would alter the delicate balance that exists towards macroalgae (Hatcher *et al.,* 1990). Whether this has occurred over the more than 60 years humans have fished for rock lobsters at the Abrolhos is unknown, but recent comments by experts such as Professor Paul Dayton are relevant.

Extractive and non-extractive human activities at the Abrolhos will incur the likelihood of some physical disturbance to fragile biological communities. This can be minimised with the implementation of appropriate education and management strategies and the introduction of binding standard protocols for user groups. Sound scientific research is the key to the success of such initiatives. Nevertheless, the prospect of some anthropogenic physical disturbance remains, and given the commitment to sustainable multiple use of the Abrolhos marine resources, the level at which this disturbance is considered to be unacceptable, quite rightly is a matter for community debate and consensus.

*** This research report was presented at a three day workshop held in Geraldton between July 11-13, 2001. The first day was a public forum where stakeholders and members of the public were invited along with technical experts and scientists. The second stage involved invited guests only. The workshop examined issues identified in this research report and those raised in the public workshop. A strategic research plan was developed during the workshop, and presented as the companion volume to this report. The powerpoint presentation from the Public Forum are contained on the CD accompanying this volume.**

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10.0 Appendices

Appendix 1: Description of biological communities and sensitivity to damage (after Hatcher *et al.*, 1988).

BIOLOGICAL COMMUNITIES	DESCRIPTION	SENSITIVITY
Plant Communities		
Mixed macrophyte assemblage	Multiple canopies of kelps, corticated algae and seagrass	Moderate
Sargassum spp	>50% cover, perennial stands with crustose understorey	Moderate
Seagrass bed	>50% cover, perennial stands rooted in sediments	Moderate
Meso-Macroalgal assemblage	Monolayers of turf and foliose algae; scattered large fronds	Low
Coralgal pavement	Endo-epilithic, crustose and turf algae; encrusting in vertebrates	Low
Calcareous algal field	Unattached branching coralline algae and rhodoliths	Low
Coral Communities		
High energy assemblage	>50% cover robust forms (thick branching, tabulate and encrusting)	High
Low energy assemblage	>50% cover delicate forms (thin branching, foliose and plating)	High
High diversity assemblage	Species-rich mixtures including massive and solitary forms	High
Coral-macroalgal assemblages	*Acropora* and *Sargassum*, *Eucheuma* or *Lobophora*	Moderate
Filter feeding communities		
Dense invertebrate filter-feeders	Sessile sponges, ascidians, anthozoans and sediment-tolerant corals	High
Depauperate	Low organics; sparse microflora and macrofauna	Low
Infaunal	High organics: rich microflora and macrofauna	Low

Appendix 2: Rock lobster survey.

Skippers Name ______________________________

Address and Phone Number ______________________________

Boat Name and Number ______________________________

What sort of boat is it (jet/other) ______________________________

Number of pots ______________________________

Number of years fished at the islands ______________________________

What proportion of your fishing effort is in 0-10, 10-20, 20+ fathoms

____

____

____

____

Can you please indicate your fishing grounds on the aerial photograph

How many days do you fish at each location? / or What percent of your fishing effort is at each location (fishing effort = potting effort, not catch)?

Does your fishing pattern change during the season? What areas do you fish at the beginning, middle, end of the season?

____

____

____

How often do you pull your pots? ______________________________

When do you finish fishing?______________________________

Has your pattern fishing effort changed over the last 10 years? How?

____

____

____

____

____

____

Appendix 3: Charter boat survey.

Date ______________________________

Name of Boat ______________________________

Name of skipper ______________________________

Name of boat owner ______________________________

Diving Activities

What is the average number of divers per charter?

What is the average length of your dive charters?

Do you have records of their diving qualifications, if so what are they?

____

____

____

Where are the dive sites you visit?

On average how many times per month do you visit each dive site, for each season?

Fishing Activities

What is the average number of people per fishing charter?

What is the average length of your fishing charters?

What type of fishing do people undertake e.g. spear fishing, trolling or line fishing?

For which of these activities do you anchor?

Where are the locations where you anchor whilst fishing?

On average how many times per month do you visit each fishing site, for each season?

Other Activities e.g Birdwatching, Historical, Surfing, ect

What other activities are undertaken? e.g. visit historic sites, snorkelling, walking, bird watching, surfing, windsurfing.

Where do you undertake each activity?

Do you anchor or moor at these locations?

How many times per month would you visit each location, for each season?

Appendix 3 (cont.)

Overnight Stops

Where do you stay overnight?

Do you anchor or moor at these locations?

On average how many times per month do you stay overnight at each location, for each season?

General questions

What do you think of the establishment of permanent moorings at the Abrolhos?

Where would you like to see these moorings?

Do you have any other comments?

Name of Boat and Skipper ______________________________

Activity and Location -diving -fishing -overnight stops -other	**Average length of each trip**	**Average number of people per trip**	**Type of fishing** -spear -troll -line -cray pots -loops	**GPS Location** **Latitude**	**Datum** **Longitude**	**Anchor**	**Moor**	**High season** **March, April, May** **# visits per month**	**Med season** **Sept.-Feb** **# visits per month**	**Low season** **June, July, Aug** **# visits per month**

Appendix 4: Wind roses and analysis of wind frequency.

Wind Frequency Analyses and Wind Roses

The included set of wind frequency analysis tables and/or wind roses show the frequency with which winds of various strengths are observed coming from various directions. These notes should help you to use the information.

Data

Wind speed and direction are measured by a number of means. In some cases, they are only estimated. To find out exactly which method has been used, a search of the appropriate station history file would be required.
The data are collected by the National Climate Centre in the Bureau of Meteorology's Melbourne head office. They are stored in ADAM (the Australian Data Archive for Meteorology), an extensive computer database of meteorological observations.
As the observations are stored, basic checks are performed. Any observations that fail these tests (specifically, any whose quality flag is poorer than "4 - estimated, medium certainty") are excluded from the frequency analyses that follow.

Analysis

The data are collated in a number of ways, depending on the nature of your request.
To group by hour, the observations are assigned to the closest standard three-hour reporting time. For example, all observations between 7:30 am and 10:30 am local standard time are labelled "9 am".
If a seasonal grouping has been requested, then "autumn" is March, April and May, "winter" is June, July and August, "spring" is September, October and November, and "summer" is December, January and February.
The observations are then grouped by speed. The exact number of speed ranges and their size depends on your request. When the speed ranges are labelled, "1 - 10" is used for all speeds greater than 0 but less than or equal to 10. "11 - 20" means greater than 10 but less than or equal to 20.
The data are then grouped by direction; into 8 or 16 bins as requested. When doing this, observations that fall on a bin boundary are split equally between the two bins. For example, when grouping into 8 bins, a direction of "NE" covers all observations with directions strictly between NNE and ENE; "E" covers from ENE to ESE. If the direction is exactly ENE (67.5°), then it will be placed half in the "NE" bin and half in "E" one.

Tables

If you have requested wind frequency tables, then you will get a separate table for each time group. Each table shows the time to which it applies, and the total number of observations used at that time. The percentage frequency with which calm conditions (that is, no wind) are observed are displayed at the top left of the table.
The rest of the table is laid out with directions across and speeds down. To find the frequency with which winds of a given speed and direction occur, follow down the appropriate direction column and across the speed row until they intersect. The value printed there is the frequency you require. For example, a value of "14" indicates that this speed/direction group occur about 14% of the time. "*" indicates the range has occurred but less than 0.5% of the time.
The last column, labelled "All", gives the frequency of each speed range regardless of direction. Similarly, the last row gives the frequency of each direction, regardless of speed.

Roses

Wind Roses seek to make the data in a wind frequency table easier to digest. Although not ideal for quantitative work, they are good for providing a quick visual impression of the wind regime.
Like the tables, there is one wind rose for each time group that you requested. Each rose consist of a central circle, surrounded by branches, each made up of a number of petals.
The circle represents the frequency of calm conditions. The size of the circle is proportional to the number of calms; a scale is given in the legend at the top of the page.
Each branch represents the wind coming from that direction. North is to the top, and the other directions are shown in the legend. In each case, the wind is blowing from that direction toward the calms circle. Each petal corresponds to a speed range from that direction. The length of the petal is proportional to the frequency of that wind; the scale is shown in the legend. The thickness of the petal is used to indicated which speed range it represents.

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More Information

Prepared by Climate and Consultancy Section Regional Office of the Bureau of Meteorology Perth

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Appendix 4 (cont.)

Wind Frequency analysis using available data between 1990 and 2001 for NORTH ISLAND

Site Number 008290 • Locality: ABROLHOS ISLAND • Opened May 1990 • Still Open • Latitude 28°18'11"S • Longitude 113°36'09"E • Elevation 10m

Values are percentage frequencies; * indicates the range occurred but with a frequency of less than 0.5%.

9 am January

Calm 1									881 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	1	1	1	1	*		*	**3**
11-20	1	1	3	6	5	2	1	*	**19**
21-30	*	*	1	8	24	2	1	*	**37**
>30			*	14	24	2			**40**
All	**1**	**2**	**4**	**29**	**54**	**6**	**2**	**1**	**100**

9 am February

Calm *									790 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	1	1	1	1	*	*	*	**4**
11-20	*	1	3	7	3	1	1	*	**17**
21-30	*	1	1	11	24	2	*	*	**40**
>30			*	16	22	*			**38**
All	**1**	**2**	**5**	**36**	**50**	**3**	**1**	**1**	**100**

9 am March

Calm 1									892 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	1	1	1	1	*	1	*	**5**
11-20	1	3	4	5	6	3	2	1	**24**
21-30	1	1	3	19	18	3	1	*	**46**
>30		*	3	14	7	*	*		**25**
All	**2**	**4**	**12**	**39**	**32**	**6**	**3**	**1**	**100**

9 am April

Calm 1									862 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	1	2	1	1	1	1	*	**8**
11-20	2	6	6	7	5	2	1	1	**29**
21-30	2	4	10	17	8	*	1	1	**43**
>30	1	2	3	10	2	1	1	1	**19**
All	**5**	**12**	**22**	**35**	**16**	**4**	**3**	**2**	**100**

9 am May

Calm 1									727 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	1	2	2	1	1	2	*	**9**
11-20	2	5	6	3	4	2	4	1	**26**
21-30	5	6	11	6	6	3	4	*	**40**
>30	1	5	6	3	1	2	3	2	**24**
All	**9**	**16**	**25**	**13**	**11**	**7**	**13**	**3**	**100**

9 am June

Calm 1									657 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	1	2	1	2	*	*	*	**9**
11-20	3	6	3	3	4	2	2	2	**26**
21-30	4	5	9	3	3	4	1	2	**32**
>30	5	5	5	2	2	4	7	4	**33**
All	**14**	**18**	**19**	**10**	**11**	**11**	**10**	**7**	**100**

9 am July

Calm 1									730 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	2	1	1	1	2	2	1	1	**9**
11-20	3	5	6	2	2	2	2	2	**23**
21-30	4	8	9	3	3	4	2	2	**36**
>30	4	5	5	2	1	4	8	2	**31**
All	**13**	**19**	**21**	**7**	**8**	**12**	**12**	**6**	**100**

9 am August

Calm 1									749 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	1	2	1	2	*	1	1	**8**
11-20	1	3	6	4	6	3	4	2	**29**
21-30	2	2	9	5	4	5	5	1	**33**
>30	2	4	4	3	3	6	5	2	**28**
All	**6**	**10**	**21**	**13**	**13**	**14**	**16**	**6**	**100**

9 am September

Calm *									788 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	*	1	1	1	1	1	1	**6**
11-20	1	2	6	6	7	4	2	1	**31**
21-30	2	2	7	8	10	5	5	2	**41**
>30	*	1	3	4	4	4	4	3	**23**
All	**4**	**5**	**17**	**19**	**22**	**15**	**11**	**6**	**100**

9 am October

Calm									833 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	*	1	1	1	*	1	*	**4**
11-20	2	1	3	5	7	3	3	1	**24**
21-30	2	*	4	17	15	6	2	1	**46**
>30	*	*	2	11	6	3	2	*	**25**
All	**4**	**2**	**10**	**34**	**28**	**12**	**7**	**2**	**100**

9 am November

Calm *									865 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	*	1	1	1	*	*	1	**5**
11-20	1	1	2	4	8	5	1	1	**24**
21-30	*	*	2	12	25	6	2	1	**48**
>30			1	9	9	2	1	*	**23**
All	**2**	**2**	**6**	**27**	**42**	**13**	**5**	**3**	**100**

9 am December

Calm 1									882 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	*	1	*	1	*	*	*	**2**
11-20	2	1	2	3	6	2	1	*	**17**
21-30	*	*	1	10	25	4	2	1	**44**
>30			*	13	20	2	*		**35**
All	**2**	**1**	**4**	**26**	**52**	**8**	**4**	**1**	**100**

3 pm January

Calm *									946 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10					1	*	*		**1**
11-20	*			*	2	3	1	*	**6**
21-30			*	*	23	7	2	*	**33**
>30				*	54	4	*		**59**
All	*****		*****	**1**	**80**	**14**	**4**	**1**	**100**

3 pm February

Calm									830 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	*	*	*				*	**1**
11-20			*	1	3	1	1	*	**7**
21-30			*	1	26	5	1		**33**
>30			*	3	55	2			**60**
All	*****	*****	**1**	**5**	**84**	**8**	**2**	*****	**100**

3 pm March

Calm *									915 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	*	*	*	*	1	*	*	*	**2**
11-20		*		1	4	3	1	1	**11**
21-30	*	*		3	32	8	3	1	**47**
>30				5	33	1	*	*	**39**
All	*****	*****	*****	**9**	**70**	**13**	**4**	**2**	**100**

3 pm April

Calm 1									916 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	1	1	1	1	1	2	1	**8**
11-20	1	1	*	4	11	3	4	1	**26**
21-30	*	*	1	10	31	3	1	1	**47**
>30	*		*	5	11	1	1	*	**19**
All	**3**	**2**	**2**	**19**	**55**	**8**	**8**	**3**	**100**

3 pm May

Calm 1									818 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	1	2	2	3	1	2	2	**14**
11-20	3	*	2	6	9	4	3	2	**29**
21-30	2	1	2	14	10	4	4	1	**37**
>30	1		1	4	5	2	3	2	**17**
All	**8**	**2**	**6**	**26**	**27**	**11**	**12**	**8**	**100**

3 pm June

Calm 2									725 observations
km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	2	2	2	1	1	1	1	*	**12**
11-20	3	2	6	4	5	3	3	2	**27**
21-30	4	2	6	8	5	3	4	1	**33**
>30	2	1	2	4	2	5	6	4	**26**
All	**11**	**7**	**17**	**17**	**13**	**12**	**14**	**8**	**100**

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Wind Frequency analysis using available data between 1990 and 2001 for
NORTH ISLAND

Site Number 008290 • Locality: ABROLHOS ISLAND • Opened May 1990 • Still Open • Latitude 28°18'11"S • Longitude 113°36'09"E • Elevation 10m

Values are percentage frequencies; * indicates the range occurred but with a frequency of less than 0.5%.

3 pm July

Calm 1 — 835 observations

km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	3	1	1	2	2	*	1	*	**12**
11-20	5	2	5	5	4	3	2	2	**29**
21-30	5	2	5	7	4	5	2	3	**35**
>30	1	1	3	4	2	3	7	3	**23**
All	**15**	**6**	**14**	**18**	**12**	**12**	**13**	**9**	**100**

3 pm August

Calm 1 — 839 observations

km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	2	1	2	2	1	1	1	**10**
11-20	2	1	3	7	8	4	6	2	**32**
21-30	2		2	8	9	6	6	3	**35**
>30	2		*	5	5	3	4	2	**22**
All	**7**	**2**	**7**	**22**	**23**	**14**	**16**	**8**	**100**

3 pm September

Calm * — 853 observations

km/h	N	NE	E	SE	S	SW	W	NW	All
1-10	1	*	*	1	1	1	1	1	**6**
11-20	1	*	*	4	12	6	4	1	**29**
21-30	1		1	5	20	7	7	2	**42**
>30	*		*	3	9	4	5	2	**24**
All	**3**	*****	**1**	**13**	**42**	**17**	**17**	**6**	**100**

3 pm October

Calm — 933 observations

km/h	N	NE	E	SE	S	SW	W	NW	All
1-10		*		*	*	*	*	*	**1**
11-20	1	*	*	1	6	6	3	*	**17**
21-30	1	*	*	2	27	10	3	2	**44**
>30	*		*	3	30	3	2	1	**38**
All	**2**	*****	*****	**6**	**62**	**18**	**9**	**3**	**100**

3 pm November

Calm — 893 observations

km/h	N	NE	E	SE	S	SW	W	NW	All
1-10				*		*	*	*	**1**
11-20	*			*	3	4	1	1	**9**
21-30	*	*	*	1	25	14	4	1	**45**
>30				1	38	5	1	*	**45**
All	*****	*****	*****	**2**	**66**	**23**	**6**	**3**	**100**

3 pm December

Calm — 898 observations

km/h	N	NE	E	SE	S	SW	W	NW	All
1-10			*	*	*	*	*		**1**
11-20				1	2	2	1		**6**
21-30	*	*		*	21	8	4	1	**35**
>30				*	54	4	*	*	**58**
All	*****	*****	*****	**2**	**78**	**14**	**5**	**1**	**100**

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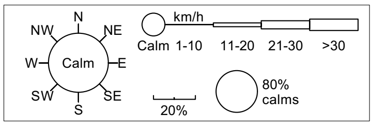
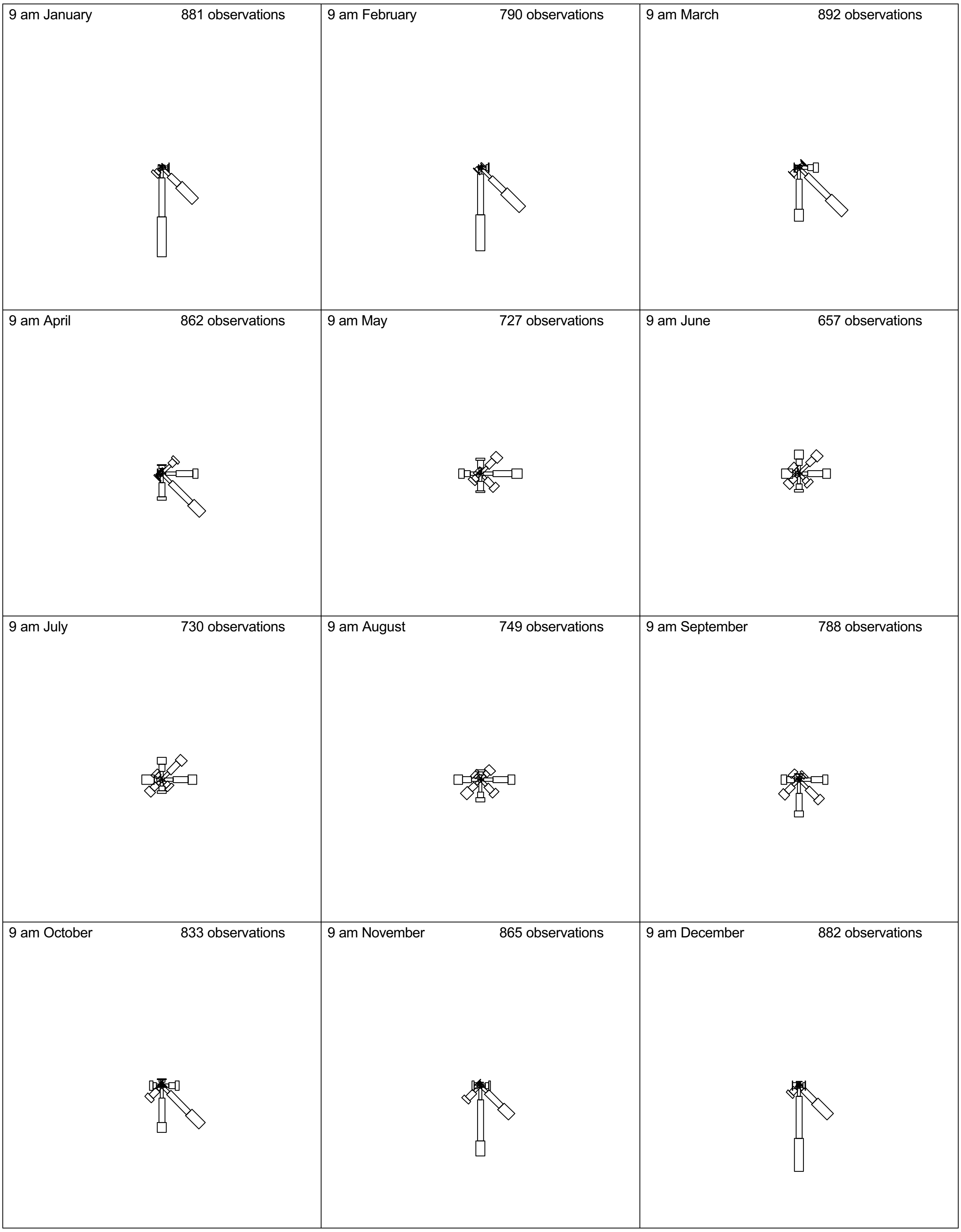
Wind Roses using available data between 1990 and 2001 for
NORTH ISLAND

Site Number 008290 • Locality: ABROLHOS ISLAND • Opened May 1990 • Still Open
Latitude 28°18'11"S • Longitude 113°36'09"E • Elevation 10m





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Wind Roses using available data between 1990 and 2001 for
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Site Number 008290 • Locality: ABROLHOS ISLAND • Opened May 1990 • Still Open
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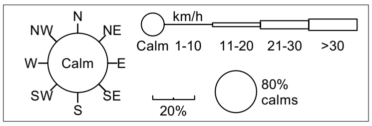

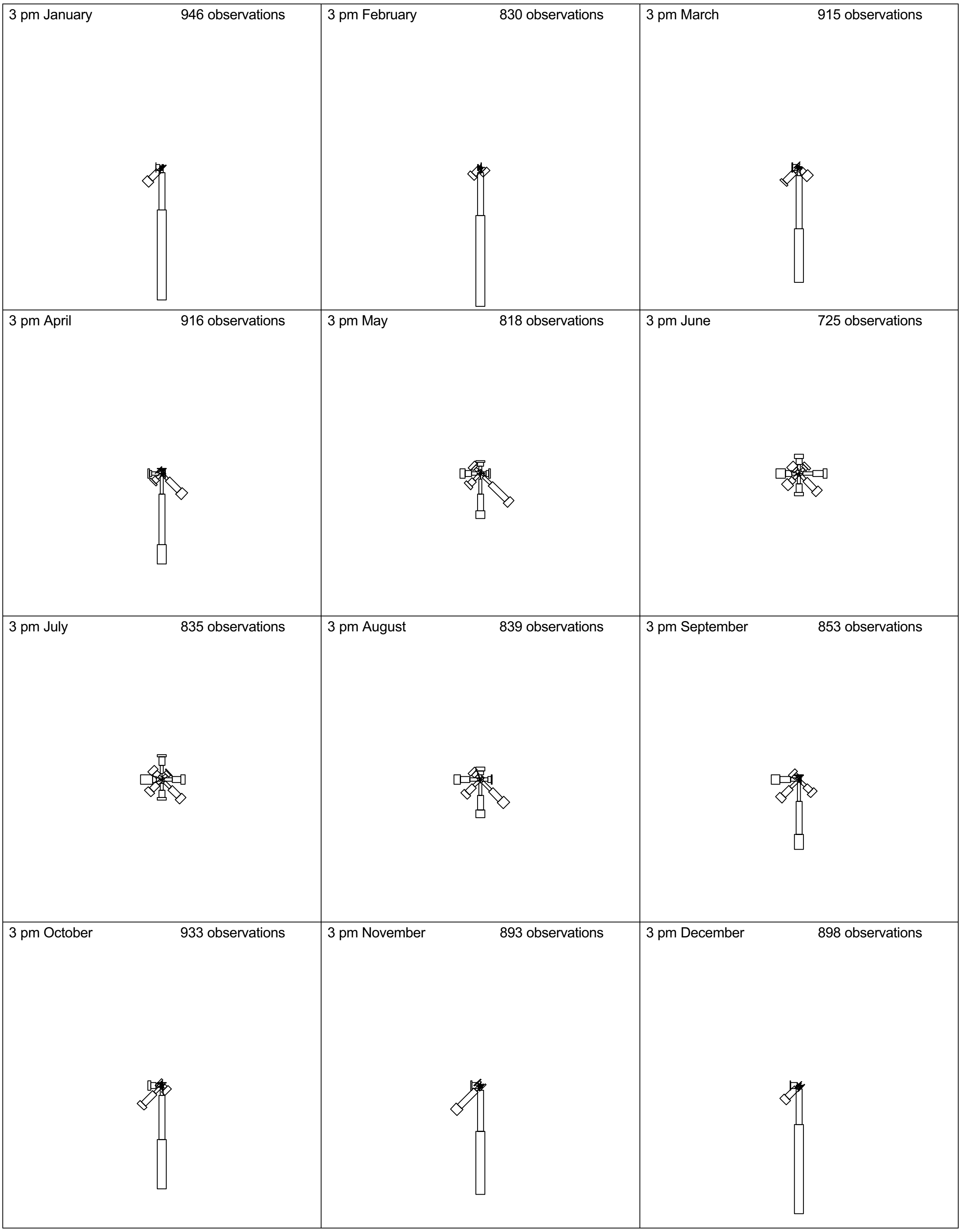

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