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ASSESSING THE EFFECTIVENESS OF NATURAL RESOURCE CONSERVATION AND THE BENEFITS FOR LOCAL COMMUNITIES: The Ranong Biosphere Reserve, Thailand.

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Abstract

The Ranong Biosphere Reserve (RBR) consists of nearly 20 000 ha characterised by mangrove forest and associated waterways; comprising the largest intact area of mangroves residual in Thailand today. Conservation forest status was awarded to this area under the jurisdiction of the Royal Forest Department (RFD). The RFD administers the RBR and has been rehabilitating the mangrove forest after several decades of destructive exploitation for charcoal-making, tin-mining and shrimp farming. The overall aim of the study was to assess the mangrove resources contained within the RBR and evaluate the environmental and socio-economic benefits these resources provide in terms of the sustainable utilisation by traditional coastal communities.

Data was collected using a mixed method approach of satellite remote sensing; quantitative ground-truthing of mangrove resources; and socio-economic surveying of local communities. An attempt was made to calculate the total economic value of the RBR's resources although this proved difficult as accurate financial data was not readily available. Through the analysis of satellite data it was possible to identify encouraging signs that the conservation efforts had been successful to a certain level although evidence sugests that some areas of the mangrove forest had not yet recovered full functionality. Futher management and monitoring will be essential if rehabilitation is to continue.

It seems that local people are aware that much of their economy is reliant on the resources provided by the mangrove ecosystem. The study highlighted many concerns related to user conflicts and violation of regulations. It has been suggested that one way to relieve pressure on natural resources is to explore alternative means of subsistence such as tourism or indeed remarketing strongly identifiable RBR products.

However policy makers choose to move forward it is in no doubt that the local communities of the RBR must be the driving force behind any action, to ensure the long term protection and sustainable use of their beautiful mangrove forest.

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List of Abbreviations

ANN	Artificial Neural Networks
CBD	Convention on Biological Diversity
DBH	Diameter at Breast Height
DMCR	Department of Marine & Coastal Resources
DUV	Direct use values
ETM+	Enhanced Thematic Mapper Plus
FOTO	Fourier based Textural Ordination
GIS	Geographical Information Systems
GPC	Ground Control Points
GPS	Global Positioning System
IEA	International Environmental Agreements
IUV	Indirect use values
LAI	Leaf Area Index
MAB	Man And the Biosphere
NDVI	Normalized Difference Vegetation Index
P_N	Net Photosynthetic Production
RBR	Ranong Biosphere Reserve
RFD	Royal Forest Department
TEV	Total Economic Value
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UTM	Universal Transverse Mercator

CHAPTER ONE

1. Study Focus and Overall Aim

1.1. Introduction

The Ranong Biosphere Reserve (RBR) was designated in 1997 as the fourth UNESCO Man and the Biosphere (MAB) Reserve in Thailand, and the first to incorporate coastal habitats. The RBR consists of nearly 20 000 ha characterised by mangrove forest and associated waterways; comprising the largest intact area of mangroves residual in Thailand today. Conservation forest status was awarded to this area under the jurisdiction of the Royal Forest Department (RFD). The RFD administers the RBR and has been rehabilitating the mangrove forest after several decades of destructive exploitation for charcoal-making, tin-mining and shrimp farming (Macintosh *et al.*, 2002a). The management and conservation of mangrove biodiversity, and habitats for fish and other wildlife, are key objectives of the RBR. Another fundamental concept of the MAB Programme is that management should also include local community participation, with tangible benefits to the local communities, these being greatly dependent on fishing and the utilisation of other natural resources found within the Reserve. Thus, the provincial authorities and the RBR directors acknowledge that local people should still be permitted to use the mangrove resources, provided this is done in a sustainable and non- destructive way.

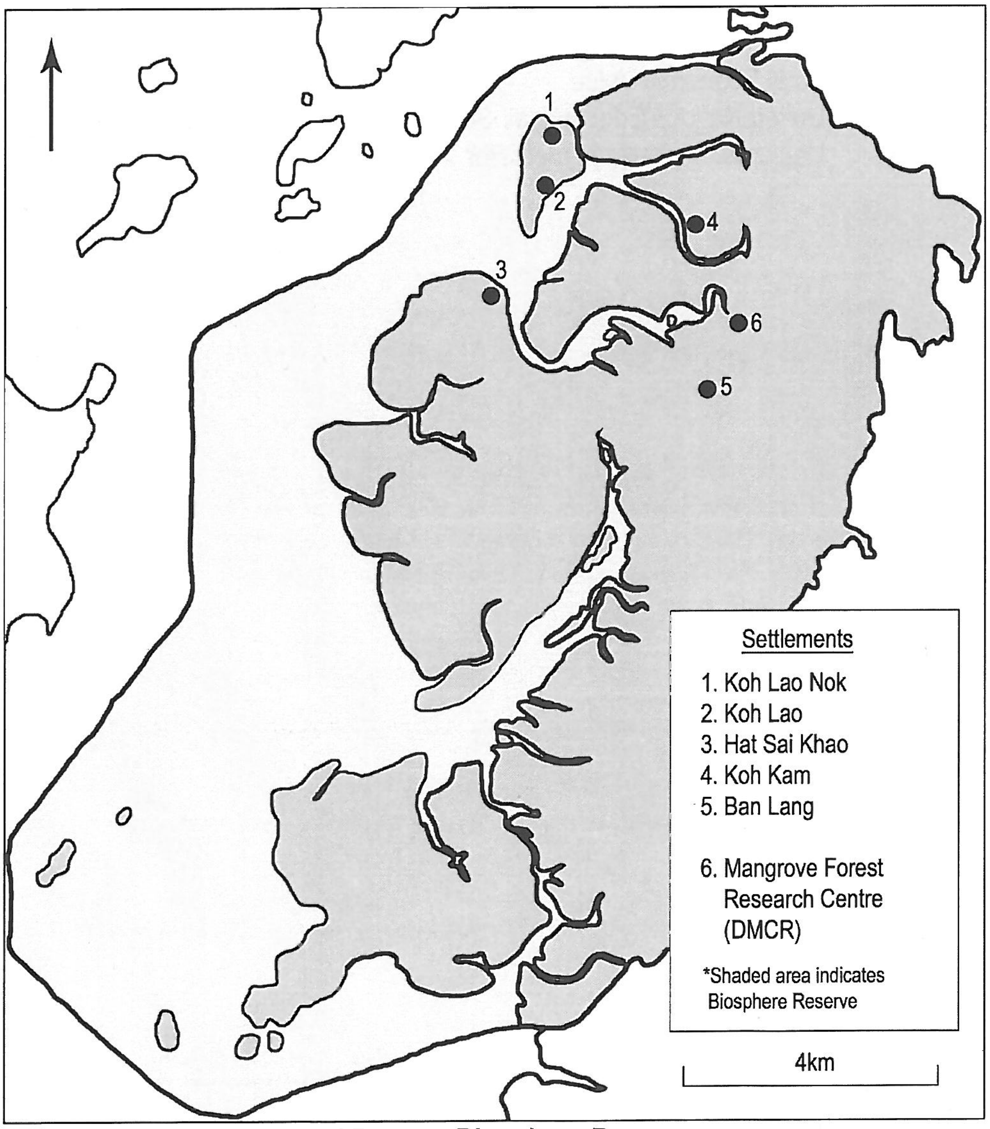


Figure 1.1 – Outline map of Ranong Biosphere Reserve

1.1.1. Location

Ranong Province is situated on the southwest coast of Thailand about 568 km south of Bangkok. Ranong Province borders the Andaman Sea and Myanmar to the west and the Thai provinces of Chumphon to the North, Surat Thani to the East and Phang Nga to the South. Ranong Province is divided administratively into four Amphoes (Districts): Amphoe Muang Ranong, Kraburi, Kapoe and La-un. The Ranong Biosphere Reserve is in Amphoe Muang Ranong centred around UTM coordinates 453800E and 1086600N.

1.1.2. Climate & Tides

Ranong province has a humid tropical climate with the highest levels of precipitation in Thailand. The average annual rainfall in Ranong is estimated as 4,200 mm (based on 45 years data). The quantity of rainfall is in part due to the fact that the area has two monsoon seasons. The Southwest monsoon from May to mid-October is the wet season, followed by a Northeast monsoon dry season from November to February. August is generally the wettest month (average rainfall 820 mm) and January the driest (average 19 mm). The tidal regime along the Andaman Sea is predominantly semidiurnal, with a mean tidal range at the mouth of Klong Ngao of 2.5m and a maximum spring tidal range of 4.4m (Macintosh *et al.*, 1991).

1.1.3. Settlements

Located within and around the RBR there are a number of settlements which demonstrate varying levels of dependency on mangrove resources from low to very high depending on development and traditions of subsistence. Four communities live within the mangrove forest in the buffer and core zones of the RBR. These are a Thai Buddhist village at Ban Hat Sai Khao (fig 1.1) at the mouth of the main estuary (Klong Ngao); a Chinese community at Koh Kam; a Thai Muslim community at Ban Koh Lao; and a group of Sea Gypsies at Ban Koh Lao Nok. The survival of these communities still depends heavily on the collection of fish, shrimp, crabs and molluscs that the mangrove ecosystem provides. The communities in Ban Koh Lao and Ban Hat Sai Khao operate mechanised push net fishing, fish cage culture and shrimp paste processing as their main economic activities. The main activities of the Sea Gypsies at Ban Koh Lao Nok are oyster collecting, spear fishing and push net fishing by hand. The inhabitants of Ban Koh Kam are mainly offshore fishermen; there is also some fish cage culture.

Currently, Ban Koh Lao has 50 rai (about 8 ha) of community forest, to which the villagers have the sole right of utilisation of the mangroves. They have permission to cut trees as long as they replant after cutting. The government also gives them support with training activities and financial provision in the form of funds and loans. In contrast, the sea gypsies at Ban Koh Lao Nok on the other side of the island are not recognised by the government and have no settlement certificates meaning that their use of the resources is not monitored or regulated.

Within the RBR transition zone located in Tambon (Sub-district) Ngao there are five villages: Ban Thung Ngao, Ban Ngao, Ban Tha Chang, Ban Lang and Ban Hat Sai Dam. On average nearly half of the population of these villages are engaged in fisheries, a third in agriculture and the remaining 20% are in other forms of employment. Due to their proximity to the mangroves the residents of Ban Tha Chang, Ban Lang and Ban Hat Sai Dam are more heavily dependent on these resources. In terms of development, all the households in Ban Thung Ngao and Ban Ngao have electricity and tap water, but only some of the households in Ban Tha Chang and Ban Lang have these amenities, while Ban Hat Sai Dam has no electricity or tap water because it is on an island far from other infrastructure. Those families without electricity supplies will be more dependent on the mangroves for fuel.

1.1.4. Biosphere Reserves

The purposes of a Biosphere are to: 1) Conserve the habitat; 2) Provide opportunity for research and education; and to 3) Promote alternative livelihoods. The RBR has succeeded in promoting the importance of conservation and making local people aware of the key issues involved, many rehabilitation projects have been initiated although monitoring in recent years has been limited. Many research projects have been conducted within the Biosphere which has created a good base for this and future projects. Educational activities for local schools have been coordinated in the past and the local people are keen to see this continue. It is when the third purpose is addressed that shortfalls may be apparent; there have been reports of a decline in some economical activities due to various reasons. This needs to be addressed by first studying the resources of the RBR and suggesting actions and/or alternatives; and so being the rationale behind this study.

Biosphere Reserves are organized into 3 inter-related zones in order to enable them to carry out the different activities involved: a core area for the long-term protection of biodiversity; a buffer zone around or next to the core used for recreation, education, research and sustainable resource use, compatible with the ecosystem conservation objectives; and an outer transition area used for agriculture and other rural activities, including human settlements. It is here that the local communities, nature conservation agencies, scientists, non-governmental organizations, cultural groups, and other stakeholders work together to manage and develop the area resources in a sustainable manner.

1.2. Aim of the Study

The overall aim of the study is to assess the mangrove resources contained within the Ranong Biosphere Reserve and evaluate the environmental, social and economic benefits these resources provide in terms of the sustainable utilisation by traditional coastal communities.

1.3. Study Objectives

- To critically evaluate the current literature relating to mangrove survey methods; conservation & management; and economic evaluation of mangrove resources.
- To quantifiably assess the state of mangrove resources contained within the Ranong Biosphere Reserve, both at natural and managed sites.
- To observe local knowledge and use of mangrove resources by communities living within and around the Ranong Biosphere Reserve.
- To evaluate the current economic value of resource use and ascertain whether usage is environmentally and socio-economically sustainable.
- To explore alternative resource utilisation, to optimise economic benefit for local communities.

CHAPTER TWO

2. Literature Review

For the purpose of this proposal the initial secondary research will be a comprehensive but not exhaustive review of current literature categorised into the following four areas of study, which are thought to be central to the aims of this project.

2.1. Ecological Importance and Threats

Mangrove ecosystems are among the world's most threatened biome types (Field *et al.*, 1998), and are disappearing rapidly in many tropical countries where they once were abundant. For example, Malaysia has lost 17% of its mangrove area between 1965 and 1985, India as much as 50% between 1963 and 1977, and the Philippines as much as 70% between 1920 and 1990. Many of the other countries in Asia, Latin America, and Africa have lost between 30% and 70% of their mangrove area in the last 30 to 40 years (Vannucci, 2004). In some countries, and indeed Thailand, the rate of mangrove loss has been extremely rapid and much more recent. From 1975 to 1993 mangrove forest area in Thailand was virtually halved, from 312 700 ha to 168 683 ha. While there are many reasons for the destruction of mangrove forests, including: increasing population pressure; coastal development; mining; conversion to salt ponds and agriculture; and over harvesting of the forests, the largest factor in recent years has been the expansion of aquaculture ponds into mangrove forests. The significant ecological value of mangrove forests has since been realised.

Mangrove trees are found along tropical and subtropical coasts and are the only known woody halophytes (Komiyama *et al.*, 2008). They provide multiple ecosystem services such as: the production of timber for construction and fuel; the protection of uplands and estuaries from battering waves, cyclonic storms (Ellison, 2008) and erosion; and the accretion of sediment to form new land (Hogarth, 1999; Walters *et al.*, 2008). Mangrove areas have high primary productivity associated with the high rate of leaf production, fall and decomposition of the detritus by the inhabiting aquatic fauna. Tree biomass provides various benefits, including: safe habitats; food and spawning grounds for fish and shellfish; provision of habitat for birds and other valuable fauna (Nagelkerken *et al.*, 2008; Walters *et al.*, 2008); and simultaneously supporting incredible diversity of crabs, sponges, tunicates, and other benthic marine invertebrates (Ellison, 2008). The economic benefits resulting from sustained mangrove resources are many and varied, for example: self renewing sites for collecting fish and shellfish; sites for collecting honey; and attractions for tourism operations.

The depletion of mangroves is a cause of serious environmental and economic concern, this stems from the fact that at the interface between the sea and the land, mangroves play a pivotal role in moderating monsoonal tidal floods and in coastal protection. Without the mangrove forests, terrestrial and aquatic habitats are lost, along with the protection for inland agricultural crops and human settlements. Indeed, the shrimp farms that are the main cause for mangrove deforestation are at high risk of being destroyed in the absence of the mangroves natural defences. Mismanagement of mangroves will also affect the entire coastal system, particularly sea-grass beds and coral reefs; this is due to the fact that mangroves are a major component of the tropical belt. Mangroves play a vital role in the intensive physical, chemical and biological dynamics of the coastal area. On a wider scale there may also be climatic impacts resulting from depletion of mangrove forests; as a consequence of the high levels of primary production, mangrove biomes are sites of intense carbon processing with a potentially high impact to the global carbon budget (Dittmar *et al.*, 2006; Alongi, 2007).

2.1.1. Mangroves Supporting Biodiversity

Mangrove ecosystems have potential to effectively compact a diverse range of habitat variation into a small spatial range. The most significant variants are salinity and submergence. The gradient from full strength seawater to freshwater spans nearly the entire range of water potentials experienced by higher plants. The gradient from fully submerged to fully exposed sites further expands the diversity of mangrove habitats (Field *et al*, 1998). In addition to this, the intertidal zone is characterised by highly variable environmental factors, such as temperature, sedimentation and tidal currents. All of these factors enable the mangrove environment to support a distinct range of life. A good example of this are the mudskippers (family *Periophthalmidae*), a special group of fish species found in mangroves, which occupy a specialised niche in the intertidal zone. They are physiologically and morphologically adapted to an amphibious existence in this zone with highly variable environmental conditions, and they are able to dwell on exposed mudflats when other fish species are forced to retreat to deeper waters with outgoing tides (Nagelkerken *et al.*, 2008). The mudskipper is commercially valuable for export to China, harvesting may contribute greatly to the local economy.

The aerial roots of mangroves partly stabilise this environment and provide a substratum on which many species of plants and animals live. Above the water, the mangrove trees and canopy provide important habitat for a wide range of species. These include birds, insects, mammals and reptiles. Below the water, the mangrove roots are overgrown by epibionts such as tunicates, sponges, algae, and economically valuable bivalves. While the space between roots provides shelter and food for motile fauna such as prawns, crabs and fishes which are also valuable to local communities in terms of nutrition and revenue. Due to the high abundance of food and shelter, and low predation pressure, mangroves form an ideal habitat for a variety of animal species, during part or all of their life cycles (Nagelkerken *et al.*, 2008). As such, mangroves may function as nursery habitats for crab, prawn and fish species, and support offshore fish populations and fisheries.

2.1.2. Mangroves supporting Fisheries

In 2000, Naylor *et al.*, stated that about 30% of all commercial fish species are mangrove dependent worldwide. As previously described, the entire collection of mangrove associated biotic and abiotic conditions makes them one of the core fish habitats of tropical estuaries and lagoons (Blaber, 2007). Over the last several decades, a quantity of evidence has demonstrated the strong relationship between mangrove presence and fish catch, with fish catch being positively influenced by the relatively high abundance of mangroves in a region. Correlations have also been found between the extent (area or linear extent) of mangroves and the catches of prawns in fisheries adjacent to mangroves. Such evidence may provide important information on the fisheries–mangrove relationship and form the basis for economic valuation of mangroves.

Almost all fishes living in subtropical and tropical mangroves are euryhaline and able to cope with salinities from almost freshwater (<1 ppt) to at least 35 ppt, but their ability to do so varies from species to species and hence may influence their distribution (Nagelkerken *et al.*, 2008). Anthropogenic land run off may affect salinity therefore causing a reduction in more sensitive species. Salinity is not only relevant to the distribution patterns and survival of fishes in estuaries, but may also affect metabolic processes. It has been theorised that there is potential for fluctuations in salinity to cause significant variability in the short-term growth rates of some species in nursery areas, therefore leading to a decrease in specimen size of offshore catches, and in turn decreased revenue.

2.1.3. Fauna affecting the structure of mangrove forests

It has been shown that biotic factors are important in shaping mangrove forest vegetation structure and ecological processes. Beever et al. (1979) demonstrated that herbivory by the arboreal grapsid crab played a role in the energy flow of mangroves and that export of material via crab biomass could be significant. In support of this, Robertson (1986) demonstrated that crabs had significant impacts on energy flow and export from mangroves, while Smith (1987) showed that, by consuming mangrove propagules, crabs could influence forest structure. Subsequent experimental work revealed that burrowing by crabs had significant effects on sediment chemistry and forest productivity (Smith *et al.*, 1991).

The burrowing activities of certain benthic invertebrates have a pronounced effect on sediment properties and biochemical processes, by enhancing the porosity and water flow through the sediment, assisting in flushing toxic substances (Nagelkerken *et al.*, 2008). In addition, their feeding on the sediment surface (deposit feeding) and plant matter (detritivory) promotes nutrient recycling (Kristensen *et al.*, 2008). In turn, benthic invertebrates are a source of food for vertebrate predators including shallow-water fishes that enter the mangroves at high tide (Sheaves & Molony, 2000).

The foundation for the idea of crabs as ecosystem engineers had just been laid when other invertebrate taxa, such as molluscs and insects, went on the stage. In fact, Bouillon *et al.* (2002), using carbon and nitrogen stable isotope signatures, showed that molluscs' overall consumption of mangrove litter in some Indo-Pacific mangrove forests, and consequent contribution in nutrient dynamics, can be much higher than that of sesarmid crabs. Molluscs can reach an astonishingly high biomass in mangroves and they occupy very different levels of the ecosystem food web. Whilst gastropods contribute to the entrapment of primary production within the system by grazing fallen leaves and consuming mud (mainly composed by mangrove litter) (Cannicci *et al*, 2008).

Many species of molluscs and crustaceans found living within and indeed forming the natural structure of mangrove environments are commercially valuable to local communities and so are harvested in large quantities. It will therefore be important to consider the impact such harvesting may have on the natural formation of the mangroves within the RBR, whilst promoting sustainable efficient use of the resources contained within.

2.1.4. Climate Change

Global climate change combined with anthropogenic impacts will threaten the resilience of mangroves. At a local scale there is little that can be done to prevent the impacts of climate change within the RBR. The most important issue to consider is the alleviation of human induced stresses on the ecosystem to improve mangrove resilience. This must be done whilst still allowing local communities to benefit from their own natural resources.

Gilman *et al* (2008) states that climate change components that affect mangroves include changes in sea-level, high water events, storminess, precipitation, temperature, atmospheric CO^2 concentration, ocean circulation patterns, health of functionally linked neighbouring ecosystems (coral reef and seagrass beds), as well as human responses to climate change. Of all the outcomes from changes in the atmosphere's composition and alterations to land surfaces, relative sea-level rise may be the greatest threat (Field, 1995; Lovelock & Ellison, 2007). In the last century, eustatic sea level has risen 10 - 20 cm primarily due to thermal expansion of the oceans and melting of glacial ice caused by global warming (Church *et al.*, 2001) causing mangroves to retreat inland although this is not always possible due to human development and infrastructure.

With projections now suggesting that mangroves in developing countries are likely to decline another 25% by 2025 (Ong & Khoon, 2003), effective management and conservation strategies are needed to regularly assess vulnerability levels and trends to provide early warning and response measures to reduce the economic costs (Diop, 2003).

2.2. Economics

The intention of economic planning should be to enhance the sustainable welfare of humans. Our well being is generated in part, by the production and distribution of market products and services; but also by the goods and services provided by the ecological environment; by social interaction and culture; by knowledge and physical health. In short, built, natural, social and human capital, respectively. In seeking to augment human well being solely by maximizing the monetary value of market goods (built capital), the current economic system may be acting to undermine our sustainable welfare rather than to enrich it.

When considering the economics of an ecosystem, valuation is a crucial tool for effective economic planning. The total economic value (c) of an area of natural resources comprises of 'use values' and 'non-use values' (see figure 2.1). Use values can be described as direct or indirect, while non-use values are concerned with the value of existence both presently and for future generations.

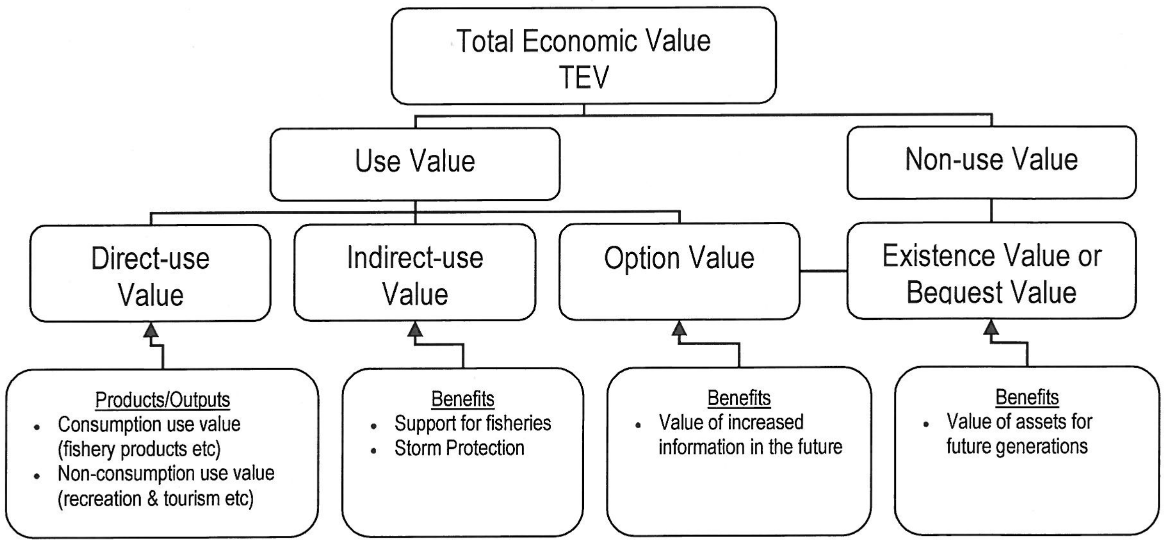


Figure 2.1 – Total Economic Valuation Source: Sathirathai (1998) adapted from Barbier & Cox (1996)

Tools such as TEV can enable all the benefits of a specific ecosystem to be quantified in monetary terms and therefore compared with the costs of management and/or rehabilitation of an area. It is then possible to ascertain whether usage is socio-economically sustainable.

2.2.1. Direct Use Benefits

The annual economic value of mangroves, estimated by the cost of the products and services they provide, has been estimated to be anywhere between US$200,000 - $900,000 per hectare (Wells *et al.*, 2006). A simple calculation shows that the resources contained within the RBR (30 000 ha) could be worth in the region of US$6 – 27 billion. The economic importance of mangrove trees and their associated products has long been realised (e.g. Kokwaro, 1985; Baconguis & Sinohin, 1994), insofar as to point out that the economic value of intact mangrove habitats "vastly outweigh those of cutting the trees" (Bennet & Reynolds, 1993). While many of the services and their supporting ecological functions, discussed in 2.1, are apparent to scientists, it is unclear if and how local beneficiaries perceive such services (Kaplowitz, 2001). Indeed the figures mentioned above mostly refer to the cost of mitigating the negative effects of mangrove degradation and do not ultimately translate into actual revenue from sustainable mangrove utilisation. Education and awareness for local communities is required to illustrate the often non tangible benefits of mangrove conservation and equate these to comprehendible monetary values.

Thailand has been the world's largest producer of cultured shrimp since 1991, the total value of export earnings for shrimp in the late 1990s was around US$1-2 billion annually. The shrimp farming industry was often promoted for the possibility of increasing rural employment and generating foreign exchange (Vandergeest *et al.*, 1999). This indeed was the case but much of the financial investment in coastal shrimp farms comes from wealthy individual investors and business enterprises from outside of the local community (Goss *et al.*, 2001). Although some hiring of local labour occurs, in the past shrimp farm owners have tended to hire Burmese workers, as their wage rates are much lower (Barbier & Cox, 2004). This is indeed the case in Ranong province as its location on the Burmese border allows for a steady supply of migrant workers ensuring that local communities have benefited little from shrimp farming operations that degrade their natural resources.

Indeed, the benefits of the industry may be less than perceived as a result of subsidies and environmental and social impacts (Huitric *et al.*, 2002). A study by Sathirathai & Barbier (2001) claimed that welfare losses associated with the impacts of mangrove deforestation on coastal communities in Surat Thani province were estimated to be around US$27,264 to $35,921 per ha and the rate of mangrove deforestation, although declined in the 1990s, still continues to be an estimated 3,000 ha/year. Indirect displacement can also occur as a result of environmental degradation of mangrove ecosystems beyond shrimp farms due to farm effluents, and the effects of segmentation and drying out of mangroves. This reduces the local flow of ecosystem goods and services available to local appropriators (Huitric *et al.*, 2002) and forces them to find alternate means of subsistence.

Intensive aquaculture is heavily dependent on the environment, particularly when it does not invest in water and pond management treatment facilities. Yet this resource base, which includes wild fry, water treatment and fish for feed, is used freely without compensation (Primavera, 1998). These resources may be easily allocated a monetary value by considering what the cost would be of replacing them with an alternative. In this way an operation may decide if it is financially viable to continue an unsustainable method of farming. There is also the possible risk that the shrimp industry will interfere with other important markets for Thailand such as the tourism, fisheries and rice industries by degrading the natural environment to the extent that these industries are no longer possible in certain areas. In 1990 tourism generated US$4 billion, more than double the maximum income from shrimp farming in 1996 (Huitric *et al.*, 2002).

Recreation and tourism is another direct use benefit of the mangrove resources both in terms of health and welfare of inhabitants and visitors but also of monetary contributions to the local economy from tourists. Tourism of course must be sustainable and the RBR lends itself perfectly to small scale operations offering nature based activities. The term 'eco-tourism' is used frequently; however any non-consumptive activities with relatively low impacts on the ecology and social interactions of the area would be suitable for the RBR. Potential activities include: Nature watching; Boat tours; Fishing; Kayaking; Homestay; Handicraft production; and many more besides.

2.2.2. Indirect Use Benefits

By the 1990s economic damage owing to natural disasters had risen to US$ 659.9 billion. Furthermore, in the last two decades, more than 1.5 million people have been killed by natural disasters (UNDP/BCPR, 2004; EM-DAT, 2005). The most significant natural disaster to hit Ranong and Thailand in recent history was of course the 2004 Tsunami. It was shown that areas where coastal mangroves and coral reefs remained intact sustained much less damage from the Tsunami than areas where the mangroves and reefs had been removed and coastal developments were directly adjacent to open water (Danielsen *et al.*, 2005; Marris, 2005). Hiraishi & Harada (2003) used fluid modelling to determine that 30 trees per $100m^2$ in a 100m wide belt would reduce, by 90%, the flow pressure on the coastline. Danielsen *et al.* (2005) also found that areas covered by mangroves as well as tree shelterbelts were significantly less damaged from the Tsunami wave that hit Cuddalore District, India in 2004. All of which indicates the significance of these coastal ecosystems in protecting against such natural disasters. Mangroves help to protect the homes and businesses of coastal communities but more importantly they also help to protect the physical health of those inhabitants.

The issue of interconnected ecosystem support was touched upon in 2.1.2 in explaining that mangroves support offshore fisheries by providing important nursery habitats, food and shelter for economically important species. They also prevent sediment and land run off into adjacent ecosystems such as seagrass beds and coral reefs, and regulate the flow of nutrients. Without these services artisanal and commercial fisheries would suffer from severely depleted fish stocks at direst cost to the revenue from these activities. In addition, coral reefs are particularly financially valuable ecosystems not just for fisheries but also for tourism. Some sources report that the combined global value of coral reefs is around US$180 billion per year. Coral reef tourism (e.g. diving and snorkling) does not directly affect the RBR but it must be considered for the welfare of the wider economy of Ranong and Thailand. Other indirect use benefits include: groundwater discharge; flood and flow control; shoreline stabilisation; water quality maintenance; and micro-climate stabilisation.

2.2.3. Non-use Values

Intrinsic values such as the natural beauty of biodiversity or cultural heritage are often referred to as existence values. These aspects are not directly utilised but are valuable nonetheless. Existence value is derived from the pleasure in something's existence, unrelated to whether the person concerned will ever be able to benefit directly or indirectly from it (Bann, 1998). It could however be argued that these existence values do directly benefit the human population by contributing to health and welfare, the positive effects of a healthy environment. Bequest values therefore relate to being able to pass on these benefits to future generations.

2.3. Management & Conservation

It has long been recognised by the Government of Thailand that mangrove conservation is important to prevent the negative impacts of human activity on mangrove ecosystems to sustain the benefits which they provide. The Royal Forest Department (RFD) along with other concerned departments have developed a series of policies and programs to manage the conservation of Thailand's mangrove forests. These policies are formulated by considering various situations in order to take appropriate actions. The important criteria are based on:

- The community needs for mangrove resources
- The existing knowledge of the ecology of mangrove resources
- The public opinion on the conservation and management of mangrove resources

- The effective encouragement of community participation
- The utilisation of mangrove resources for the local community as a whole not just for individuals
- The likelihood of success and critical factors

(Adapted from: Vannucci, 2004)

The sustainable management of mangroves now relies upon a zonation strategy where all mangrove forest areas are classified as either belonging to a 'conservation' zone or a 'development' zone. This allows for the natural resources to be both conserved and utilised effectively under strict control of the relevant authorities. Within conservation zones any change or utilisation of the mangroves is absolutely prohibited, the forest must be preserved in its natural state unless it is necessary for the government to implement projects of great economic importance or national security. Issues mostly arise where communities have settled within the conservation zone and impacts from encroachment are significant. This should be managed through the education of local communities as to the importance of conserving their natural resources for future generations. Indeed, this negative aspect may become a positive one, as local communities participate in rehabilitation strategies and collectively work towards stewardship and protection against other groups who may wish to encroach into the area. Conservation in this way will only be possible through an effective awareness and education strategy.

Much like within the terrestrial national parks, some areas of the conservation zone have been set aside for education and nature based tourism activities. These areas not only provide opportunities for the education of local communities but also for schools and other academic institutions wishing to conduct research. This research may contribute to the rehabilitation and conservation effort whilst increasing awareness to a wider audience. As a tourist attraction the area may still be used to support the local economy as an alternative to unsustainable shrimp farming. Local people can provide food and accommodation for visitors in return for financial gain and development of infrastructure. Tourism activities must be limited to selected areas and the impacts of visitation should be mitigated against insofar as the area can still recover seasonally. This can be done through the provision of board walk areas with information provided by interpretation signage.

Within development zones utilisation of mangrove land for fisheries, tin mining, aquaculture and silviculture is allowed but strictly controlled by the relevant agencies to mitigate against the negative impacts of human activity. Mitigation measures will not only ensure the minimisation of negative impacts but will also help to sustain the long term economic benefits. For example, in the case of shrimp farming, sites will be developed behind a narrow stretch of rehabilitated mangrove forest. This stretch of forest will help to retain nutrients, maintain water quality, and provide protection from storms, wind and high tides. The mangrove habitat will be preserved by the farm owners whilst the mangroves will ensure the site may be used for an indefinite period generating opportunity for long term, stable economic gain. The current silviculture system provides that an area within the development zone be divided into several cutting areas or strips, oblong in shape and positioned at a 45 degree angle to the shoreline. Alternate strips are felled every 15 years in a 30 yr cycle, leaving valuable or rare species untouched. This allows the forest to recover within the set period and still provide its valuable ecosystem functions such as shoreline protection and nutrient retention. In this way economic benefits of logging may be enjoyed over the longer term whilst sustaining the mangrove environment.

Development zones may also aid in resolving conflicts with local people and conservation agencies. Where new conservation zones are implemented local communities may feel that their right to utilise the areas natural resources has been taken from them. Indeed they may have no alternative form of subsistence and so the local economy will be adversely affected leading to a general lack of support for the conservation effort. In this case the conservation strategy is likely to fail unless potential conflict is resolved. One way to do this would be to provide alternative land within the development zone along with guidance on how to use this land in a sustainable way. This may initially be a costly process but in the long term will ensure conservation is successful while sustaining the economic growth of the area and good will toward the project.

In both conservation and development zones areas of degraded mangrove forest are often rehabilitated through reforestation programs. Mangrove reforestation aims to conserve natural coastal ecosystems, including the maintenance of most ecological processes, and preserving as much genetic diversity as possible. Species for rehabilitation schemes are chosen dependent on their intended function. Different species will be chosen for new mud flats; and others for abandoned shrimp farms and mining areas. Reforestation of mangroves is typically carried out by the government but also by the private sector, local communities, action groups and students from universities and schools. The RFD has established four Mangrove Seed Centres to supply mangrove seedlings to the public and advise which species should be planted where to ensure the effectiveness of the private sectors efforts.

The future of Thailand's mangroves now seems secure, the recognition that the mangrove ecosystem has a very important role, not only for the life and economy of the communities of the coastal area but also for the country as a whole as part of one of the largest export industries. Significant importance has also been recognised in the mangroves role in shoreline defence. As climate change becomes more apparent, with harsher weather conditions and tidal storms, the protection afforded by the mangroves will become more crucial than before. The roles of community involvement and educational strategies are most important in ensuring the success of conservation programs. Without the support of local people initiatives are less likely to succeed and without education communities may not be aware of the importance of mangrove preservation.

In the past 35 years, Thailand has lost mangrove areas at an alarming rate; the remaining mangrove area is now only little more than half its original size. Current national policy should determine that the existing mangrove areas are preserved and rehabilitated whilst the reforestation of abandoned commercial operations and new mudflats should help to increase the total area of lands covered by mangrove forests thus increasing the opportunities for sustainable economic gain and other benefits that the mangroves afford.

2.4. Remote Sensing

According to Felinks *et al.* (1998), the use of remote sensing systems, in particular satellite imagery for the purpose of assessing and monitoring various types of vegetation change, has increased during the last few decades. Within this context, the use of remote sensing has long been advocated for collecting data over large areas at relatively low cost (Proisy *et al.*, 2007). Remote sensing can be utilised as an important tool for looking at ecosystem diversity and various structural aspects of individual ecosystems. The case being that landscape information derived from remotely sensed data is multidimensional: horizontal, vertical, multispectral and in many cases also multitemporal. Accordingly, remote sensing provides an added dimension to biodiversity studies as it can provide information on species and structural diversity parameters and their changes overtime (Innes & Koch, 1998).

Understanding the patterns of ecosystem properties is crucial to effectively monitor ecosystem change due to anthropogenic activity and climate variation. Remote sensing provides the best methods for looking at large areas of the earth's surface to analyse, map and monitor ecosystem patterns and processes. Patterns and health of vegetation and variation in biodiversity are important ecosystem properties, with strong relationships to critical ecosystem functions. Species richness is the most widely used measure of biodiversity. Mapping patterns of species richness within a landscape can provide a basis for future monitoring and an ecological basis for land management and conservation decisions (Gould, 2000). Satellite remote sensing not only has the potential to provide information for resource management and conservation but also in the assessment of the effectiveness of environmental treaties. Remote sensing data has been used in a wide range of applications such as biodiversity and species richness monitoring, inventory of forest quality and quantity, inventory of farmland showing that remote sensing data has direct relevance to international environmental agreements (IEAs) such as the Convention on Biological Diversity (CBD), the Ramsar Convention on Wetlands, the Kyoto Protocol and the Global Vegetation Monitoring Project (Seto & Fragkias, 2007).

The aim of this section is to review the current practises of mangrove mapping and quantification by the use of remotely sensed data. Monitoring methods will be examined by analysing carefully selected case histories. Data analysis methods will be discussed along with the selection of sensors and platforms dependent on the aims of the monitoring.

Alteration of coastal environments has increased as coastal populations have increased (Ferguson & Korfmacher, 1997), proving the undeniable truth that anthropogenic activity has serious impacts on coastal environments leading to the need for effective conservation and monitoring. Souza Filho *et al.*, (2006) state that coastal environment mapping and coastal change detection is an expensive undertaking and using remote sensing data to carry out field surveys is the most accurate and cost-effective way of reaching results for scientific and management purposes.

Mangroves play an integral role in the ecology of watersheds, including protection against coastal erosion, supporting animal species, and providing nutrients to support a marine food web (Seto & Fragkias, 2007). Despite their ecological and economic importance, historically they have been converted for agricultural and recreational purposes at an alarming rate. Awareness of their importance has now increased and restoration projects expanded rapidly yet they still face the threat of natural disaster recently illustrated by the 2004 tsunami that destroyed widespread mangrove areas throughout southern Asia. Mangroves are also one of the best geo-indicators in global coastal change research and they are an excellent gauge for the detection and quantification coastal modifications (Souza Filho *et al.*, 2006). Souza Filho *et al.*, (2006) also states that critical observations of large and small-scale coastal geomorphology and vegetation provide clues to the natural history, erosion and accretion degree of the shoreline and potential risk of associated natural hazards for any specific coastal site.

A recent paper by Seto & Fragkias (2007) detailed a case study from the Cau Mau province in Viet Nam where 60 000 ha of the Xuan Thuy Natural Wetland Reserve were observed to evaluate the effects of the Ramsar Convention on Wetlands. Using six Landsat images spanning over 25 years, the study derived four measures to evaluate the success of the Convention: (1) total mangrove extent; (2) mangrove fragmentation; (3) mangrove density; and (4) aquaculture extent. Individually, each of these metrics provided a different gauge of the state of the mangroves: area, exploitation, biomass, and development. The methodology used artificial neural networks (ANN) to classify the images among five classes: mangrove, aquaculture, sand, water, and agriculture. To measure mangrove density, a 2x2 pixel moving window was applied to the sites and collected values of the normalized difference vegetation index (NDVI), an indicator of vegetation health and density derived from leaf area index (Seto & Fragkias, 2007). The mean, maximum, minimum, standard deviation and range of NDVI values were calculated for all images. Standard deviation of NDVI is used as a proxy of vegetation heterogeneity, while maximum and mean NDVI are proxies of primary productivity. An increase in NDVI values over time would indicate an increase in vegetation health and heterogeneity, while a decrease in NDVI values would indicate a reduction in vegetation health and heterogeneity.

The case study by Seto & Fragkias (2007) demonstrates that with the appropriate satellite record, in-situ measurements and field observations, remote sensing is a promising technology that can help monitor compliance with international environmental agreements relating to vegetation within specific ecosystems. A later study by Proisy *et al.*, (2007) demonstrated that by applying textural analysis to VHR IKONOS images, previous limitations relating to the estimations of high biomass mangroves can be overcome to provide more reliable results. More precisely Proisy *et al.* applied the Fourier based Textural Ordination principle (FOTO) along with principle component analysis. Although Fourier transform and principal component analysis are common techniques, their combined use in monitoring vegetation is largely new. To compensate for the lack of established software, Proisy *et al.* created an easy to use interface under Matlab®. This new innovation has led the way to explore further the potential of feature fusion techniques in the field of forest survey and vegetation monitoring.

Structural features of mangrove forests can serve as useful indicators of forest condition and have the potential to be assessed with remotely sensed imagery, which can provide quantitative information on forest ecosystems at high temporal and spatial resolutions (Ingram *et al.*, 2005). In addition, Proisy *et al.* (2007) state that besides the condition of the forest, the assessment of forest structure and biomass can determine the surface and energy exchange with the atmosphere and quantify carbon pools. Data may be collected on forest biomes using a variety of methods. One such method is the use of lasers, which supply information on the height and form of the ground surface and different vegetation layers including mean tree height. An alternative tool might be the use of radar. The potential to determine wood volume and other forest attributes using radar data has been discussed on several occasions but there is no evidence that the information content of radar data is significantly more useful than optical remote sensing data (Innes & Koch, 1998). The literature seems to agree that data sourced through remote sensing is most effective and that among satellite data products, QSCAT backscatter, representing canopy moisture and roughness, and MODIS leaf area index (LAI) are the most important variables in almost all cases of forest monitoring (Saatchi *et al.*, 2008).

A study by Ingram *et al.* (2005) investigates the utility of remote sensing for assessing, predicting and mapping two important forest structural features, stem density and basal area, in tropical littoral forests in south-eastern Madagascar. The study analysed the relationships of basal area and stem density measurements to the Normalised Difference Vegetation Index (NDVI) and radiance measurements in bands 3, 4, 5 and 7 from the Landsat Enhanced Thematic Mapper Plus (ETM+). Strong relationships were identified among all of the individual bands and field based measurements of basal area while there were weak and insignificant relationships among spectral response and stem density measurements. NDVI was not significantly correlated with basal area but was strongly and significantly correlated with stem density when using a subset of the data, which represented extreme values. The study then used an artificial neural network (ANN) to predict basal area from radiance values in bands 3, 4, 5 and 7 and to produce a predictive map of basal area for the entire forest landscape. The ANNs produced strong and significant relationships between predicted and actual measures of basal area using a jack-knife method and when using a larger data set. The map of predicted basal area produced by the ANN was assessed in relation to a pre-existing map of forest condition derived from a semi-quantitative field assessment. The predictive map of basal area provided finer detail on stand structural heterogeneity, captured known climatic influences on forest structure and displayed trends of basal area associated with degree of human accessibility. These findings demonstrate the utility of ANNs for integrating satellite data from the Landsat ETM+ spectral bands 3, 4, 5 and 7 with limited field survey data to assess patterns in basal area at the landscape scale.

CHAPTER THREE

3. Methods & Materials

3.1. Ground Surveys

A continued evaluation of current literature provided the grounding and rationale behind the research methods chosen for this study. Empirical data was collected using a mixed method approach of site surveys and satellite remote sensing (see 3.2). The site surveys consisted of two stages which were undertaken concurrently, these are:

3.1.1. Quantitative ground truthing at sample sites throughout the RBR.

The sample sites were chosen after an initial unsupervised classification of the 2009 satellite data set. A local expert was then consulted as to the suitability and accessibility of the proposed sites, and amendments made as required. At each sample site 3 x $100m^2$ quadrats, 15m apart, were sectioned into four 5x5m areas. Firstly, the total number of species and the number of individuals present for each species were recorded through visual identification. Next, the circumference of each tree was measured with a tape measure at breast height (BH=1.3m) and used to calculate average diameter at breast height (DBH) (NB. Rhizophora sp. Was measured above the last root that reached the ground). A circumferential measurement is generally preferable to a measurement of the trees diameter since mangrove trunks are often far from circular in cross-section and therefore do not have a single diameter (Hogarth, 2007). Where a tree forks below 1.3m each stem was counted and measured separately (after English *et al.*, 1997). DBH measurements were later used in conjunction with historical data and tested allometric equations to calculate the biomass of each sample site (see box 3.1). Tree height for each individual was measured and recorded using a telescopic pole. Ground cover with saplings and other forms of undergrowth (shrubs, epiphytes etc) was visually estimated and identified. Lastly, fauna was recorded within a $1m^2$ quadrat over a period of 5 minutes, paying attention to species richness, abundance and indicator species. (see Appendix A: Ground Survey Record Sheet)

Box 3.1 – Worked example of Biomass Calculation

Root Biomass (W_R) $= 0.199\, p^{0.899}$ DBH2.22
Above Ground Biomass (W_{top}) $= 0.251\, p\text{DBH}^{2.46}$ (Komiyama *et al.*, 2005)

Where, DBH = $\dfrac{\text{Circumference at Breast Height}}{\pi}$ and p = Dry weight constant*

e.g. *Rhizophora mucronata* – Dry weight constant p = 0.701, Circumference at BH = 37cm
DBH = $37 / \pi = 11.77$cm
$W_R = 0.199 \times 0.701^{0.899} \times 11.77^{2.22} = 34.46$ (2dp)
$W_{top} = 0.251 \times 0.701 \times 11.77^{2.46} = \underline{75.77 \text{ (2dp)}}$
Mass** = 110.23kg

*species specific value for dry weight constant (p) was taken from table 3 in Komiyama *et al.*, 2005.
** Mass of each individual is calculated and then added to the mass of all trees within the sample site to find the total site biomass

English *et al.* (1997: p147) detailed a method for measuring potential levels of mangrove forest primary productivity (see box 3.2). Measurements of light absorption by the forest canopy are used to estimate leaf area index (LAI). This was then converted to net canopy photosynthetic production using an assimilation coefficient. Light readings were taken at 1m intervals within each sample site (totalling at least 100 readings), and then at an open area before and after the sample site readings were taken. All readings were recorded within 30 mins and at noon +/-2hrs. The solar zenith angle was recorded with a clinometer. (see Appendix B: Ground Survey Light Record)

Box 3.2 – Calculating Net Photosynthetic Production

Apparent leaf area index (L') = $\frac{\log_e(I/I0)}{-k}$

L = leaf area index (m^2 leaf area m^{-2} ground area)
I = mean light flux density beneath the canopy (mean of all values < 3x mean)
I0 = light flux density incident outside the canopy (mean of I0 reading 1 and 2)
k = canopy light extinction coefficient that is determined by the angle and spatial arrangement of the leaves. English *et al.* (1997) use a value of 0.5 which will be kept the same for this study.

Corrected leaf area index (L) = $L' . \cos(\theta r) . \eta$

L' = apparent leaf area index
θ = solar zenith angle
$\cos \theta r = \cos(\theta . \frac{\pi}{180})$ = solar zenith angle in radians

$\eta = \frac{\text{total number of readings – number of readings 3 x > mean}}{\text{total number of readings}}$
= canopy cover expressed as a ratio

Net photosynthetic production (P_N) = A . d . L

A = average rate of photosynthesis (gC m^{-2} leaf area hr^{-1}) for all leaves in the canopy. English *et al.* (1997) recommend a value of 0.432 for the wet season.
d = number of daylight hours approx 12
L = leaf area index correct for solar zenith angle

3.1.2. Qualitative observation and semi structured interviews with local communities.

Local people were interviewed about their use of mangrove products at various locations in the RBR (see table 3.2). Examples of these products were collected and photographed. Following the initial field visit a semi structured interview template was prepared to be used during subsequent interviews with local stakeholders to gain an understanding of their activities, the species utilised in Ranong, the price and marketing details of the products, and the villagers' perceptions of the mangrove resources and perceptions of the management activities implemented in the RBR. Additional information may be obtained from key informants, village leaders and local officials. (see Appendix C: Questionnaire – English version)

Table 3.2: Socio – economic data for communities to be surveyed (Macintosh *et al.*, 2002b).

Village	Population (in 2000)	Religion	RBR Status	Dependency on mangrove resources
Hat Sai Khao	252	Buddhist	Buffer Zone	Very High

Koh Lao	406	Muslim 90% Buddhist 10%	Buffer Zone	Very High
Koh Lao Nok (Sea Gypsy)	230	None	Buffer Zone	Very High
Koh Kam	204	Muslim & Buddhist (Myamar & Chinese)	Core Zone	High
Ban Lang	588	Muslim	Transition Zone	Very High

3.2. Satellite Data

The remote sensing data consists of two near anniversary Landsat TM scenes taken 9 years apart (2000 & 2009). Both scenes were geometrically processed using ground control points (GCPs) recorded during the ground truthing stage (see 3.1.1) using a handheld GPS unit. The ground truthing data was also used to perform a supervised classification map of the study site from the 2009 data set. Both sets of satellite data were also analysed and compared in terms of:

- Primary production
- Species composition
- Temporal changes in density & fragmentation

3.2.1. Primary production (derived from LAI & NDVI)

The first stage of processing is to 'mask' all non-mangrove pixels. This was done by applying a formula document which states that if a pixel's digital number (DN) falls below a certain threshold (in this case the threshold has been set at 40), then that pixels shall be set to 0. The program is then set to ignore all null values and so we are left with only mangrove pixels for further processing. The formula document used was as follows:

```
CONST Threshold = 40 ;
CONST Band4 = @1 ;
CONST Band3 = @2 ;
CONST Landmask = @3 ;

IF (Band4 > Threshold OR Band4 == 255) Landmask = 1
ELSE Landmask = 0 ;
@4 = Band4 * Landmask ;
@5 = Band3 * Landmask ;
```

For both data sets a data file in the red and near-IR parts of the electromagnetic spectrum were connected as a tiled pair with the near-IR image selected as image 1 (@1) and the red as image 2 (@2). Next a formula document was created to represent the formula in box 3.3. The formula document equation was as follows:

```
(@1 - @2) / (@1 + @2) ;
```

Box 3.3: The use of vegetation indices in the remote sensing of mangroves (Adapted from: Green *et al.*, 2000)

Vegetation Indices are complex ratios involving mathematical transformations of spectral bands. As such, vegetation indices transform the information from two or more bands into a single index.
E.G., the normalised difference vegetation index (NDVI) is a common vegetation index calculated from red and infra-red bands. For each pixel in the two wavebands the following is calculated:

$$NDVI = \frac{\text{infrared} - \text{red}}{\text{infrared} = \text{red}}$$

Since dense vegetation reflects strongly in the near-IR and reflects poorly in the red part of the electromagnetic spectrum, the NDVI can approach a value of 1 in areas of dense vegetation. By contrast areas with little or no vegetation will have similar reflectance in the near-IR and red part of the spectrum or in some cases lower reflectance in the near-IR than red, giving NDVI values approaching 0 or even negative values (with theoretical lower limit of -1).

Using the formula document options the output image type was selected as a '32-bit floating point' before being applied to the connected images to produce the NDVI image. Next we performed the regression of LAI on NDVI to allow the mapping of LAI from the two data sets. A simple linear relationship exists between LAI and NDVI defined by the regression equation:

$$LAI = \text{intercept} + \text{slope} \times NDVI$$

LAI data from the ground truthing (see 3.1.1 and box 3.2) along with the corresponding NDVI values for each sample site were entered into an Excel spreadsheet. Using Tools, Data Analysis to regress the column of LAI values against the column of NDVI values, two piece of information were determined: the slope of the regression line and the intercept. A new formula document was created to represent the equation above and make an 8-bit image of LAI, it was as follows:

(intercept + slope * @x) * maximum LAI value ;

Multiplying by the maximum LAI value will spread the LAI measure over more of the display scale (0-255) @x is the NDVI image previously made. (N.B. Mangrove LAI values over 8 are rare so a figure of 10 is recommended as a round max LAI value). Next a palette is applied to display the LAI image into 5 ranges of LAI to make visual interpretation easier.

Using a histogram of the LAI image we can then decipher the percentage of mangroves that belong to each of the 5 LAI classes and in turn the area (ha) covered by each class. The LAI data was then used in the equation given for Net Photosynthetic Production (P_N) (see box 3.2) and the total amount of carbon fixed per year was calculated for the whole of RBR. This was done for both data sets and the results compared as a whole and through the ranges of LAI.

3.2.2. Species composition

A supervised classification of a number of band combinations was used to create around 20 mangrove classes. A histogram document of each of the band classes was then analysed to ascertain which band combination most closely correlates with the actual ground truthed data. This band combination was used to create an image representative of the species found at each location throughout the biosphere reserve. After Woodfine (1991), a 3x3 edge enhancement filter was applied to accentuate the boundaries of between different mangrove areas. The classification was performed using the maximum likelihood decision rule.

3.2.3. Classification of Diversity Classes

Data pertaining to the volume and variety of mangrove species found within each 10 x 10m quadrat was used in conjunction with the Shannon-Wiener biodiversity index to put a numeric value on the combined levels of species richness and evenness found at the study sites. The Shannon-Wiener index is represented by the following equation from Krebs (1989).

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

The sites were then assigned to one of 10 mangrove diversity classes depending on the biodiversity index values. Class 1 will represent the least diverse areas whilst class 10 will represent the most diverse areas. As in 3.2.2, a supervised classification of a number of band combinations was created to display the 10 diversity classes. A histogram document of each of the band classes was analysed to ascertain which band combination most closely correlates with the actual ground truthed data.

CHAPTER FOUR

4. Results

4.1. Processing of Remotely Sensed Imagery

After an initial unsupervised classification of the 2009 satellite data set, a local expert was consulted as to the suitability and accessibility of 24 proposed sites. Further advice was sought from international and local scientists who had previously carried out research within the RBR. It was recommended a further 8 sites should be included in the study. A total of 5 796 trees were identified and measured within 97 separate 10 x 10m quadrats. Figure 4.1 shows the locations of the 32 study sites.

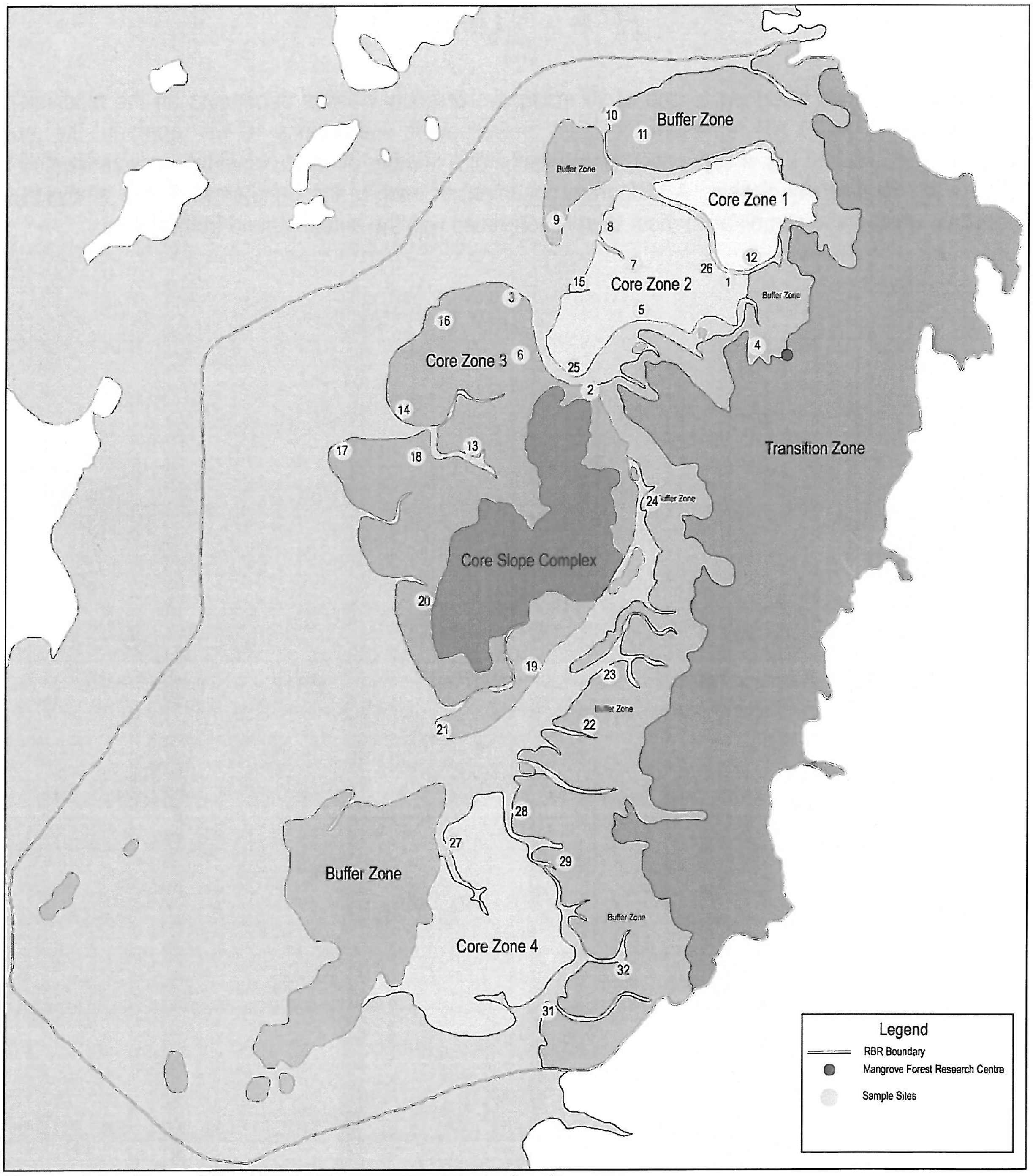


Figure 4.1 – Map of the RBR showing the 32 study sites.

4.1.1. Leaf Area Index (LAI)

Of the various biophysical variables to be evaluated from satellite imagery, LAI has received the greatest interest given its direct relationship with numerous ecological processes including net primary productivity, rates of photosynthesis, transpiration and evapotranspiration (Kovacs, et al. 2005). Numerous studies have identified a strong relationship between LAI, generated from mean canopy closure estimates, and estimated NDVI for a variety of satellite platforms.

LAI may be estimated by the use of direct or indirect methods although the choice of method will affect the results and must be considered during analysis. Direct measures, although sometimes more accurate, have been found to be not only destructive, tedious and labour intensive but nearly impossible for large areas of forest. Consequently, numerous indirect techniques such as those used for this study, have been developed that allow for more rapid data collection without the need to harm the vegetation. However, in some cases indirect methods have been found to underestimate the value of LAI in very dense canopies, as it does not account for leaves that lay on each other, and essentially act as one leaf according to the theoretical LAI models.

The following figures and tables show the results of NDVI and LAI analysis for both data sets from November 2000 and March 2009 (See Appendix D for the original satellite images):

Figure 4.2 – Image representing the LAI of the RBR in November 2000

Table 4.1 – Summary of pixel values for Fig 4.2

LAI Range		Pixel Value	No of Pixels	% RBR	Area (hectares)
<2		1-19	26104	13.95	2349.36
2-4		20-39	107642	57.52	9687.78
4-6		40-59	53378	28.53	4804.02
6-8		60-79	0	0.00	0
>8		80+	0	0.00	0
Totals			187124	100	16841.16

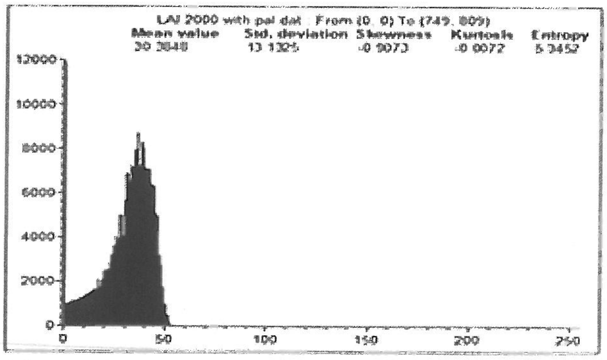


Figure 4.3 – Histogram representing the pixel values of Fig 4.2

Figure 4.2 clearly shows large areas totally 71% of the RBR have an LAI value that is less than 4. This would indicate that the numerous ecological processes outlined above would have been happening at a decreased rate of efficiency. The health of the ecosystem at this stage was likely to have been poor, possibly resulting in a reduction of direct use benefits for local communities.

Table 4.2 – Summary of pixel values for Fig 4.4					
LAI Range		Pixel Value	No of Pixels	% RBR	Area (hectares)
<2		1-19	16797	7.84	1511.73
2-4		20-39	38885	18.15	3499.65
4-6		40-59	147371	68.78	13263.39
6-8		60-79	11198	5.23	1007.82
>8		80+	0	0.00	0
Totals			214251	100%	19282.59

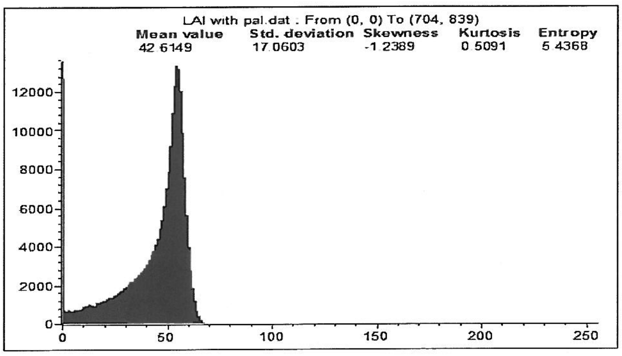
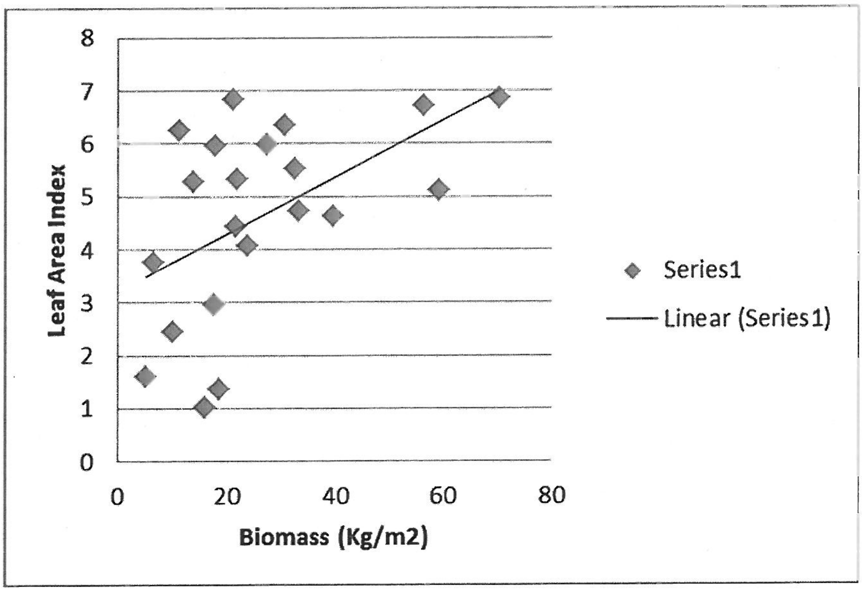


Figure 4.4 – Image representing the LAI of the RBR in March 2009

Figure 4.5 – Histogram representing the pixel values of Fig 4.4

Looking at figure 4.4 it is possible to see a drastic change in the distrubution of LAI values across the RBR. The 2009 image shows that during the 9 year interlude, LAI has increased so that now 74% of values fall into the class of 4 or above. Furthermore, when comparing the total area representing mangrove cover, it is apparent that since 2000 mangrove habitat has expanded by nearly 2 500 ha. This is an increase of 15% over a 9 year period.

4.1.2. Correlation with Biomass:



The results suggest that LAI does not correlate strongly enough with biomass to be used as an indirect method of calculating the total mass of the RBR. It would be difficult to draw precise conclusions although it may be possibly to use the information when locating areas to be set aside for community forest schemes or monitoring conservation projects with specific goals.

Figure 4.6 – Chart showing the relationship between LAI and Biomass values estimated during ground truthing

4.1.3. Estimation of net photosynthetic production (P_N):

The approximate net photosynthetic production (P_N) of the whole mangrove canopy per m^2 of ground area over a day can be described by the following equation (see box 3.2):

$$PN = A \times d \times LAI$$

Where A = average rate of photosynthesis (g-C m^{-2} leaf area hr^{-1}), d = day length (hr), and LAI is the leaf area index estimated for each pixel in the image (see tables 4.1 and 4.2). For mangroves in high soil salinities in the wet season a reasonable estimate for A = 0.432 g-C m^{-2} hr^{-1} and day length in Ranong is on average about 12 hours.

Table 4.3 – Summary of P_N throughout the class ranges of LAI

LAI Range	Daily P_N per m^2 (g-C m^{-2} d^{-1})	Annual P_N per ha (t-C ha^{-1} yr^{-1})	Total P_N in 2000 (t-C yr^{-1})	Total P_N in 2009 (t-C yr^{-1})
<2	5.18	18.92	44454	28604
2-4	15.55	56.76	549925	198657
4-6	25.92	94.61	454499	1254823
6-8	36.29	132.45	0	133487
>8	46.66	170.29	0	0
		Totals	1 048 877 tonnes	1 615 571 tonnes

In 2009 the RBR fixed nearly 600 000 tonnes of carbon more than it did in 2000; this is an increase of 54%. This may be an over estimation but when comparing these results to the increase in LAI values detailed in 4.1.1 the overall picture seems to be showing a dramatic improvement in the health of this mangrove forest.

4.1.4. Species classification

Over the last decade attempts to discriminate mangrove species using satellite imagery have been increasingly successful, although prior to that the coarse spatial resolution of the earlier platforms made the task virtually impossible. More recent analyses of the newer generation of high spatial resolution satellite sensors (i.e. IKONOS and QuickBird) have indicated that the separation of mangrove species is now possible using these data (Wang et al., 2004).

The platform used for this study is of course Landsat and has a lesser spatial resolution than either IKONOS or Quickbird. However, after the analysis of data from various band combinations it has been possible to create an image (Fig. 4.10) representing the predominant species in various areas throughout the RBR. The following charts show the level of correlation of the ground truthed data and the supervised classification of the satellite data when percentage of species cover was compared. Figure 4.7 clearly shows the band combination with the highest degree of correlation to the ground truthed data is a colour composite comprised of bands 4, 2, and 1. However, figure 4.9 suggests that while species identification may be possible using Landsat data, more accurate results will be achieved by applying the method to genus identification only.

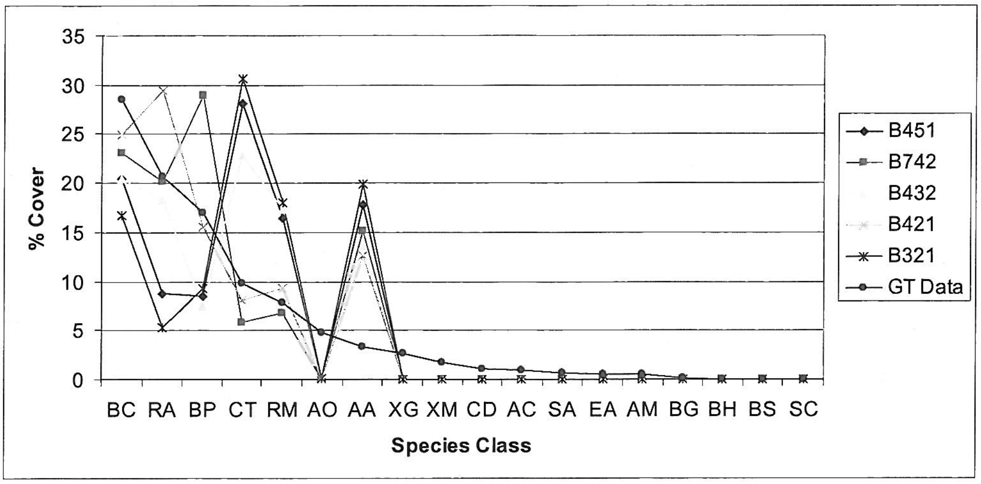


Figure 4.7 – Chart showing the level of correlation of various band combinations with actual ground truthed species data.

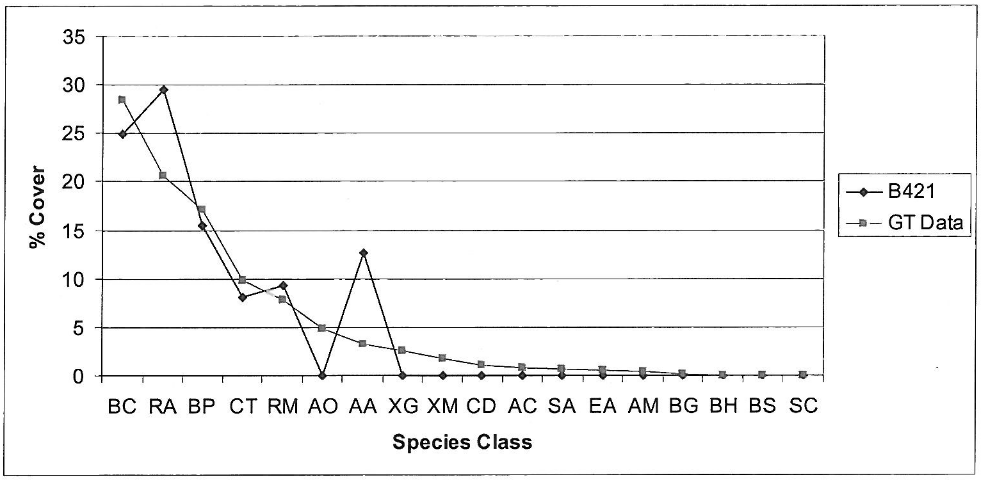


Figure 4.8 – Chart showing the level of correlation of band combination 421 with actual ground truthed species data.

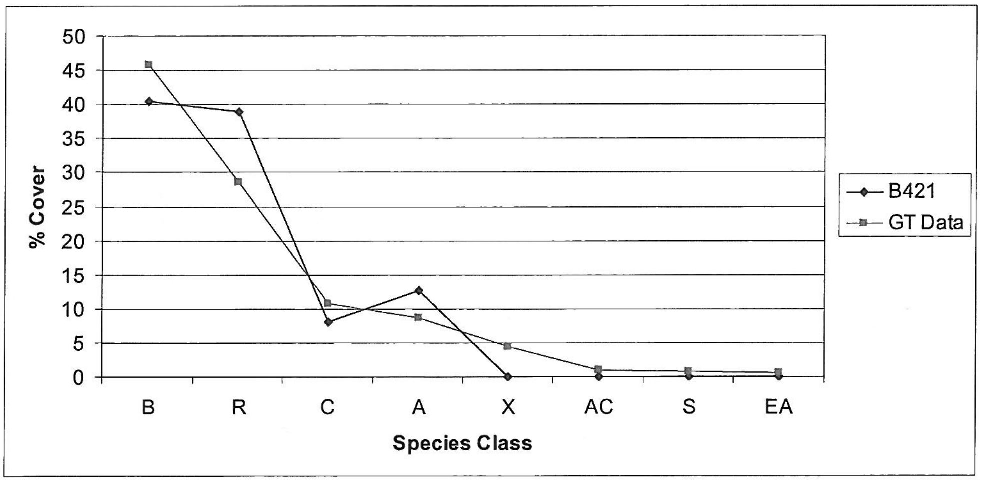


Figure 4.9 – shows a greater level of correlation when species are grouped by genus.

*(Fig 4.7 and 4.8 x-values: BC *Bruguiera cylindrica*; RA *Rhizophora apiculata*; BP *Bruguiera parviflora*; CT *Ceriops tagal*; RM *Rhizophora mucronata*; AO *Avicennia officinalis*; AA *Avicennia alba*; XG *Xylocarpus granatum*; XM *Xylocarpus moluccensis*; CD *Ceriops decandra*; AC *Aegiceras corniculatum*; SA *Sonneratia alba*; EA *Excoecaria agallocha*; AM *Avicennia marina*; BG *Bruguiera gymnorrhiza*; BH *Bruguiera hainesii*; BS *Bruguiera sexangula*; SC *Sonneratia caseolaris*)
**(Fig 4.9 x-values: B *Bruguiera*; R *Rhizophora*; C *Ceriops*; A *Avicennia*; X *Xylocarpus*; AC *Aegiceras corniculatum*; S *Sonneratia*; EA *Excoecaria agallocha*)

For full list of Mangrove species surveyed during this study see Appendix E.

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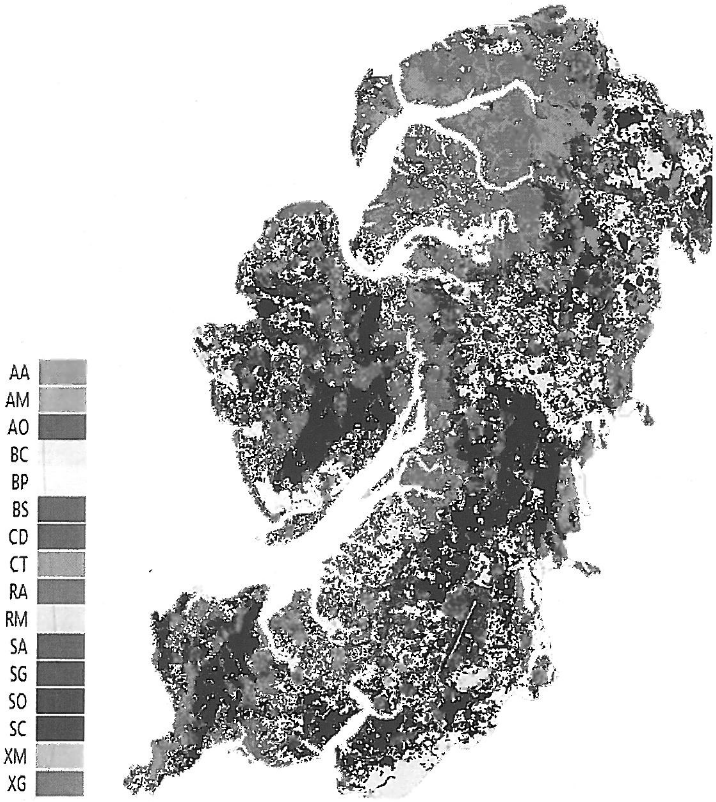


Figure 4.10 – Image of the RBR representing the distribution of species surveyed.

The image shows large areas of *Rhizophora spp* and *Bruguiera spp* which are the species that were most commonly identified during data collection. It must be noted that these are the species most used for rehabilitation programs so this may be seen as a sign that conservation efforts are indeed having an effect. The areas coloured black have not been identified using this method, although with more extensive ground truthing it may be possible to gain a more accurate representation of the species distribution as a whole.

4.1.5. Biodiversity Classification

Figure 4.11 – Chart showing the level of correlation of various band combinations with actual ground truthed biodiversity data.

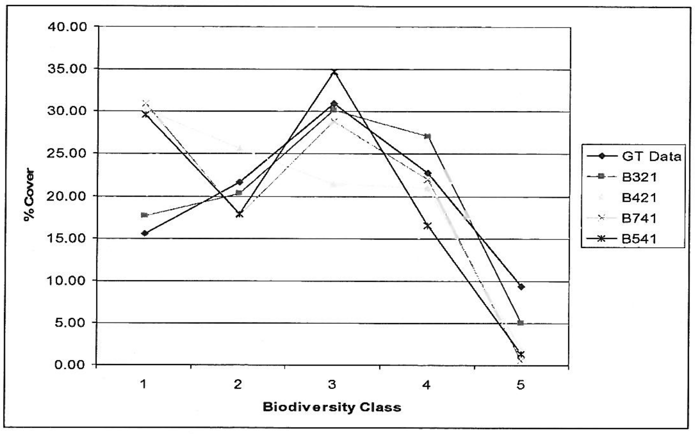
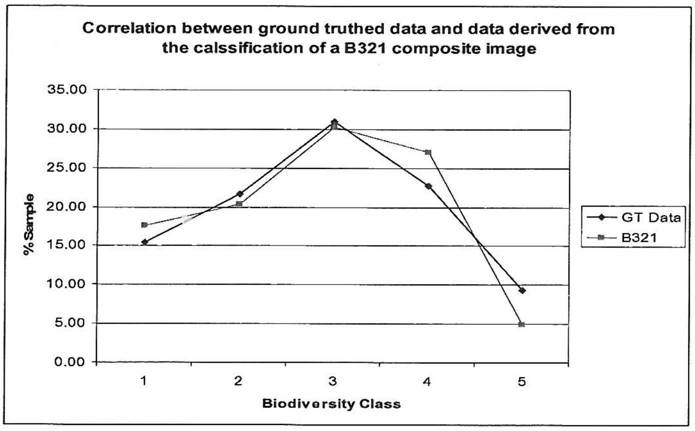
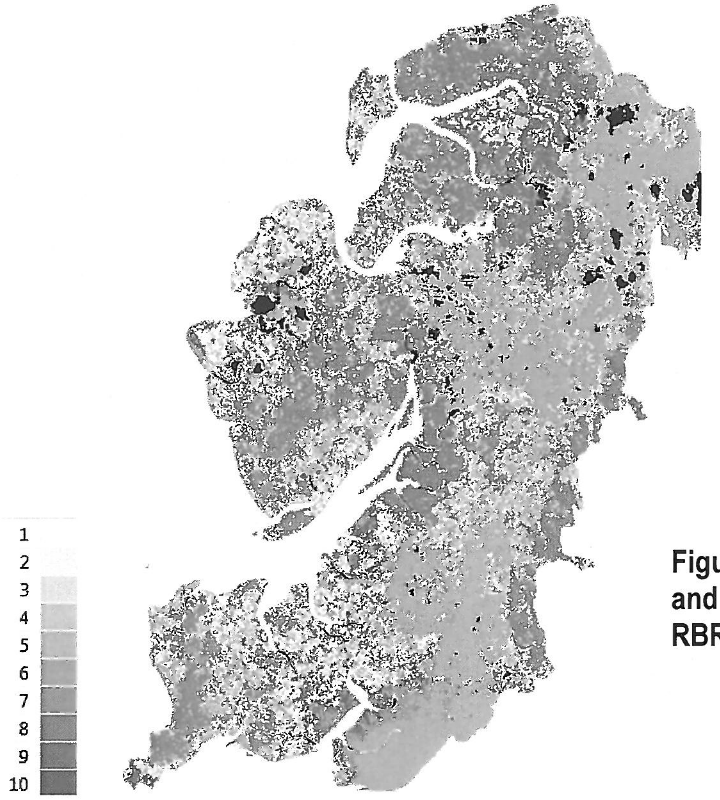


Figure 4.12 – Chart showing the level of correlation of band combination 321 with actual ground truthed biodiversity data





Biodiversity Class	Diversity Index Range
1	0.00 – 0.19
2	0.20 – 0.39
3	0.40 – 0.59
4	0.60 – 0.79
5	0.80 – 0.99
6	1.00 – 1.19
7	1.20 – 1.39
8	1.40 – 1.59
9	1.60 – 1.79
10	1.80 – 1.99

Figure 4.13 – Image representing the range and distribution of biodiversity within the RBR

A variety of studies have set out to determine which areas within the RBR are of greatest biodiversity value. However, extrapolation of such biodiversity observations requires maps or spatial data recording the extents and distributions such ecosystems. The method used for this study has aimed to use data that is already spatially referenced to achieve a more complete picture of the state of mangrove biodiversity throughout the study site. At this point, it is important to emphasise that the applications presented here rely on numerous assumptions about map accuracy and the representativeness of the sample species data. A more thorough and extensive ground truthing phase and satellite data with higher spatial resolution would greatly improve the accuracy of mapping.

However, figure 4.13 clearly shows the areas of greatest biodiversity are to be found in the remotest areas. The area surrounding the DMCR's research station looks to fall within the high class ranges, a great deal of research and rehabilitation has been conducted in this area and conservation efforts seem to be paying off. It is also interesting to note that inhabited areas such as Koh Lao and Hat Sai Khao show very low levels of mangrove diversity. When considering the core zones of the RBR they too show low levels of diversity though this is undoubtedly because the reforestation projects that have taken place in these areas usually only utilise one or two species of mangrove.

The conservation value of certain areas and the potential for conservation management are both likely to be inversely related to the intensity of land use by people. The results of this study may be useful in rezoning the RBR by contemplating which areas are most biologically diverse but also which areas are most utilised by local communities. This will be discussed further in the next chapter when consideration will be given to not only to the biological value of certain areas but also to the economic value of areas used by those reliant on the goods and services provided by the mangrove ecosystem.

4.2. Socio-Economic Data

Information on the resources exploited and their socio-economic importance was gained through interviews with the local people following the questionnaire structure outlined in Appendix C. Forty two households took part in the study, this equates to approximately 12.5% of the total population of the 5 villages sampled. The information gathered is discussed and presented below by first detailing the economic activities and the species utilised (see Appendix F for a full list of species). Consideration will then be given to the community perceptions of the RBR and issues relating to conflicts and management.

4.2.1. Economic Activities

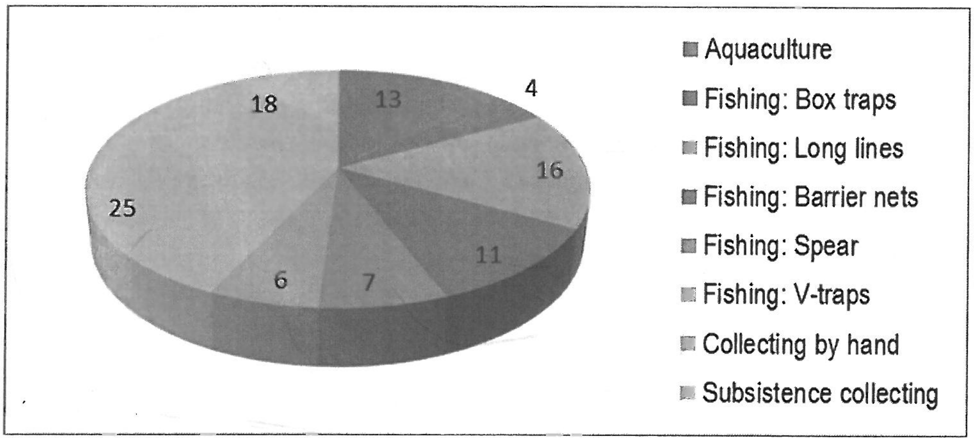


Figure 4.14 – Chart showing the percentage population engaged in various economic activities

The survey respondents identified three main groups of economic activity: aquaculture, fishing, and collection by hand. Fishing was then separated into the five main methods, whilst collection by hand for resale was distinguished from subsistence collecting. Much of the fish catch and associated products are sold locally or go to larger markets in Thailand, usually Phuket or Bangkok. A small portion of these products find their way to the international market and are exported as far away as China, Taiwan and Hong Kong. The economic benefits from the utilisation of mangroves and related species are considerable, but have been very difficult to quantify as yet. Figure 4.14 shows that collection by hand is widely undertaken throughout the RBR. Where subsistence collection would have been undertaken by every household as a secondary occupation, there is now a huge market for the species collected in this way, and so this activity has become the main source of income for many families. Fishing remains as the main occupation of most households, but with increasing social and environmental pressures, aquaculture is becoming ever more popular.

4.2.2. Aquaculture

Cage culture of finfish was introduced to Ranong about 20 years ago by the Bay of Bengal project (BOBP). Initially, sea bass (*Lates calcarifer*) were reared as this species could be produced in hatcheries. Sea bass fingerlings were given free by the Department of Fisheries to the fishermen being trained in cage culture. After phase 2 of the BOBP project ended in 1992, the fishermen switched to rearing grouper which they could catch easily in the mangroves. A number of species were recorded, but the most common species cultured seems to be *Epinephelus coioides*.

Fingerlings are obtained from a wholesaler at a cost of THB 30 per fish or from traps and catching by hand. The cages are stocked with about 350-400 fish with an expected yield after 4 months of 300kg. The fish are then sold back to the wholesaler in Phuket for around THB 140-170/kg. A medium sized cage culture farm (12 cages, $3m^2$) can earn around THB 100 000 per annum, although the initial investment to build a raft of that size is around THB 200 000.

There are several green mussel *(Perna viridis)* farms operating a rope culture system from floating bamboo rafts in the Ban Hat Sai Khao area situated on the seaward edge of the Klong Ngao estuary. After an initial investment of THB 30 000 for materials to build the raft and around THB 4 000 for the seed mussels, there will be an expected harvest of around 4 000kg. The wholesale price for mussels is THB 6/kg meaning that in 7 – 10 months one mussel raft can produce about THB 24 000 in revenue.

Opposite Koh Lao, mud crab *(Scylla olivacea)* culture was identified as a significant and growing activity in response to the strong demand for soft shell crab. Many families are attempting to culture mud crab for soft shell production because it is so lucrative although this has proved difficult in certain areas due to poor water quality. The crabs are kept in special plastic boxes (1 per box) for soft shell rearing, while net cages are used to rear meat crabs. Some of the crab seed is caught locally but the vast majority comes from Myanmar as there is not a sufficient wild population in Ranong. The farm visited during the study stocked around 20 000 crabs at one time for soft shell production. The crabs stay in the boxes for no longer than 30 days and so turnover rate is very high. Soft shell mud crabs are sold at THB 220/kg, the farm can produce in excess of 3000kg per month.

4.2.3. Fishing

Groupers (*Epinephelus spp.*) are the most valuable fish group associated with the RBR. Although long line fishermen occasionally catch very large individual groupers, it is the trapping of grouper fingerlings and table sized fish using box traps which contributes most to the local fishing economy. The trapping of fingerlings is in high demand due to the increase in aquaculture, this often leads to a shortage and will undoubtedly affect wild populations. It was a reported that an income of THB 10 000/month would be typical for this activity.

In Ban Hat Sai Khao there were several boats with large engines, specifically used for long line hook fishing. The boats are equipped with 10 sets of long lines hook, each line having 120 hooks. Cuttlefish (*Sepia spp.*) and short bodied mackerel (*Rastrelliger brachysoma*) are used as bait and the species caught will include: seabass *(Lates calcarifer*); red snapper (*Lutjanus bohar*); milk shark (*Rhizoprionodon acutus*); jackfish (*Carangoides spp.*); Indo-Pacific king mackerel *(Scomberomorus guttatus*); catfish *(Plotosus canius)* and string ray (*Dasyatis spp.*). In total a team of 5 men can earn THB 5 000 for a two day trip, with various costs (e.g. bait, fuel, and ice) adding up to around THB 1 350.

V-net traps consist of loose seine netting attached between a v-shaped frame made from mangrove stakes (mainly *Rhizophora* wood). They are used by a number of the villages but particularly at Koh Kam. They catch mostly shrimp and only during the spring tide, so they allow the sea gypsies to spear fish in or around the V-nets when the tide is low. From a single net 8m wide, the harvest weight may be between 200-300kg. Around three quarters of the catch will consist of small low value fish that are used to make feed for caged fish. This can be sold for THB 2/kg, the rest of the catch will usually consist of: shrimp (small THB 15/kg, large THB 140/kg); squid (THB 30/kg); various large fish for eating (THB 15/kg); and dog-tongued sole *(Cynoglossus sp.)*(THB 25/kg).

Villagers from Ban Ngao fish with fixed barrier nets set at low tide around the mangrove forest. These are anchored to the substratum with wooden pegs made from *Xylocarpus* mangrove. They also lay lines with baited hooks in the canals which are left until the following low tide. Various species such as catfish

(Plotosus canius); grouper (*Epinephelus spp.*); and mullet *(Liza spp.)* are caught this way. Over fishing in this area has caused a dramatic reduction in the harvest yield. Previously they could catch about 100 kg per harvest, but now 10-20 kg is more typical. Barrier netting in this area is now only a secondary occupation for the people of Ban Ngao.

Motorised push net fishing was difficult to collect information on has it is an illegal activity. It is likely that most of the shrimp *(Acetes sibogace)* used in the production of 'kapi' or shrimp paste is collected in this manner. Kapi is a very profitable product for the many of the villages, but the method of collection is very destructive to the habitat, destroying juveniles of many species and has a large bycatch.

4.2.4. Collection by hand

There are two species of cockle that are collected by hand in Klong Ngao: *Anadara granosa* and *Anadara cf. troscheli*. Women and children collect seed cockles, as a supplemental income, at low tide by raking the sand/mud and locating the cockles by hand. They usually collect about 5-10kg of cockles a day; and sell the cockle seed at THB 15-18/kg. In the past, when there were no cockle farms to sell to, the small cockle seed were simply thrown away because they were of no value. However, now that there are several cockle farms in Kapoe District, cockle seed are in high demand. Cockles of an edible size will sell at market between THB 30-80/kg depending on availability.

Oyster species collected in the RBR include *Crassostrea commercialis; C. lugubris*; and *C.belcheri*. Again, only women and children collect oysters as a secondary occupation. This is usually done every 3-5 days and income generated will be around THB 1000/month per woman. In addition to cockles and oysters local women also spend time collecting many species of clams (e.g. *Meretrix lusoria)* and sea snails (e.g. *Cerithidea obtusa)*. These are less abundant and fetch a lower price at market so often this is either subsistence collecting or as an outdoor hobby. When sold at market a collector may receive THB 100/day income.

There are two main species of sesarmid crabs that are collected from the mangrove forests at night. The species are *Episesarma mederi*, which prefers the intertidal zone; and *E.versicolor*, which is more aquatic. These sesarmid crabs are collected, and then preserved with salt, to be sold as a delicacy. The men collect sesarmid crabs during the night; in one trip a group of 15 men will collect around 150kg in a 9 hour period. The crabs are then sold at a local market for THB 20/kg, but when they have been processed and salted they will sell for THB 50/kg.

Eel (*Anguilla spp.*) collecting is carried out by hand using a small net and a stick to probe burrows in the mud where the eels live. They are sold according to size and fetch anything between THB 100-350/kg. All the eels are exported to China, Hong Kong and Taiwan by a Bangkok middleman. Thai people in general do not eat eel, but there is a large and valuable international market, meaning that eel collection is increasingly profitable.

4.2.5. Community Perceptions

Very few of the people living and working within the RBR boundaries really understood its purpose. The only regulation they knew about was that they were not supposed to cut down trees, although many admitted to doing so. The most common species to be used for construction of homes and fishing gear are *Rhizophora spp.* and *Bruguiera spp.*, however most people would like to use *Xylocarpus spp.* because the wood is denser although this is not often found at an appropriate size due to overuse in the recent past.

Its seems that most people thought the actual area set aside for the reserve was much smaller, and were surprised to learn where its actual boundaries lie. Very few knew anything about the zonation strategy, but some did know about the research centre. When asked why they thought conservation of the mangroves was important, the most common answers were 'to maintain aquatic species populations for fishermen to catch' and 'because the mangroves are very beautiful'. Some respondents understood that the mangroves played a role in maintaining water quality although they could not explain why.

Several people mentioned the decline of certain species of marine animals, both in quantity and quality from five years ago. The main reason stated for this decline was the increase in people who live, collect and fish in the mangrove areas of Ranong.

4.2.6. Conflicts & Management

While some people admitted to being in violation of the current RBR regulations, (felling trees and motorised push net fishing) particularly on the island of Koh Lao; many others stressed the need for enforcement and the implementation of additional restrictions. Fishermen from Hat Sai Khao, were anxious about the long term effects of local people using smaller net sizes to increase their catch, they also thought that there should be size restrictions on the boats that fish in the mangrove canals. Community leaders voiced concerns about people from outside Ranong province fishing in the waters of the reserve. They felt very strongly that the Government should impose restrictions on who should be allowed to use the RBR resources.

Members of local government from the Tambon Ngao (district) and Changwat Ranong (provincial), administrative offices agreed that stakeholder involvement would be the main strategy for implementing any further restrictions on resource usage in Ranong. They felt that it would be necessary to develop a plan of environmental stewardship for those living in the area in addition to the allocation of funding and resources for enforcement. In response, several key members of the community indicated that they would be interested in pursuing a shared responsibility scheme with the local government, where they could have greater input when decisions were made about their own resources.

CHAPTER FIVE

5. Conclusion & Recommendations

Although the results presented in 4.1 seem encouraging consideration must be given to how and if local communities are directly or indirectly benefiting from the restoration of mangrove resources. Conclusions will be drawn as to whether current usage is environmentally and socio-economically sustainable; and suggestions for alternative resource use and allocation will be made. The first section of this chapter shall explore the various limitations of early restoration projects and explain: how, although they may appear to have been successful in repopulating the area with mangrove trees, the ecosystem as a whole may not have been fully rehabilitated.

5.1. Limitations of restoration

The rationale for mangrove restoration has changed very slowly over the years from just silviculture to recognition of mangroves as a diverse resource (Bosire et al,2008). Although throughout much of the RBR, projects have unfortunately, emphasised planting mangroves as the primary tool in restoration, rather than first assessing the causes for the loss of mangroves in an area, then assessing the natural recovery opportunities, and how to facilitate such efforts.

Some of the restoration projects that moved immediately into the planting of mangroves without determining why natural recovery had not occurred were unfortunately doomed to failure, either when the saplings failed to become established or where higher levels of ecosystem function were not restored. This was an unfortunate waste of conservation resources as often there would be a significant capital investment in growing mangrove seedlings in a nursery before existing stress factors at a proposed restoration site are assessed, often resulting in a major failure of planting efforts.

In addition, it seems that of the many restoration efforts to have taken place in the RBR, few were embedded in the larger framework directed by the DMCR. This framework should have considered not only the fate of the planted mangroves in terms of stand structure and regeneration, but also the return of biodiversity and recovery of all other ecosystem processes.

5.2. Mangrove Resources

The analysis of the remotely sensed data in combination with data collected during ground truthing shows a vast improvement in the condition of mangroves over the 9 years interceding the two data sets. The analysis of the LAI images shows an increase from just 29% of image pixels representing an LAI value of more than 4 in 2000 to 74% of values fall into the class of 4 or above in 2009. Increased LAI indicates an increased level of productivity along with other biophysical factors. The mangrove resources contained within the RBR at both restored and natural sites are undoubtedly showing a great improvement in state since the first data set was collected in 2000.

When examining the map of restoration sites in Appendix G, and figure 4.4 it is not visually apparent that there is a difference between natural and restored sites. It is however important to consider to what extent restored mangrove sites support faunal recolonisation. From observations of the benthic communities (see Appendix H for a full list of species identified) found at the 32 study sites, it was found that crab diversity at some of the replanted sites was higher than at several of the pristine natural mangrove sites, and both biomass and crab numbers were consistently higher in the more established replanted areas. However, the natural sites were consistently characterised by large numbers of sesarmid crabs, which may act as an indicator for when restored sites reach a certain level of functionality to be considered successfully recovered. As highlighted in the previous section, the restoration projects that focused primarily on planting the trees rather than assessing all of the stress factors involved, may never regain full functionality and increased populations of sesarmid crabs.

5.3. Socio-economics

Relating to the theoretical model of total economic valuation (p.7) consideration will be given to socio-economic data gathered in terms of direct, indirect use, and existence values.

5.3.1. Direct use values (DUV)

Although the survey indicated a heavy reliance on DUV (78.8%), it is nearly impossible to give an exact figure for TEV. The respondents were often vague about the value and yield of their crop, whilst some communities, most notably the Sea Gypsies on Koh Lao had very little concept of how much or how often. Nearly all respondents however, recognised the link between degradation of the ecosystem and the reduction in DUV. The local communities clearly understand that without attempts to preserve the mangroves of the RBR, their economy will be negatively affected and financial benefits will decline.

5.3.2. Indirect use values (IUV)

Respondents recognised that in terms of IUV, the mangroves provided support for offshore fisheries in terms of nursery habitats for key economic species of fish. They did not however, highlight the importance of mangroves in terms of storm protection or tsunami defence. This may have been due to a flaw in survey design or because of a cultural response to the recent and devastating tsunami of 2004. Thai people like to leave the past behind them, and few that lived through the disaster would offer information willingly. IUV represented 17.6% of TEV.

5.3.3. Existence value

Existence value (3.6%) not related to the DUV or IUV were mentioned rarely and were mainly based on aesthetic merit. This reflects the fact that the local communities are so reliant on these resources as a means of subsistence they do not necessarily have time to consider intrinsic value for future generations when providing for their families in the present is of paramount concern. This may be altered by providing alternative means of financial gain and by relieving the already exploited DUVs, through exploring further opportunities of benefiting from IUVs.

5.4. Alternative uses

There are several products that are strongly identified with the RBR. Shrimp paste or 'Kapi' is probably the most important of these, as revenue from this product significantly contributes to the local economy. Currently the collection methods used to harvest the small shrimp (*Acetes japonicus*) required for kapi production are destructive and illegal during certain seasons. These restrictions are often violated due to the economic importance of the product. Alternative means of subsistence need to be explored in order to reduce negative environmental impacts. Once sustainable production issues are addressed, kapi could be marketed under and premium 'eco' label. This is a strong product and would appeal to high end restaurants and consumers in Bangkok, Phuket and the international markets. If a premium selling price could be achieved, it would negate the need for off season harvesting and therefore reducing adverse impacts and promoting a higher yielding harvest period.

If alternative marketing strategies cannot be found for exploited resources and products, substitute subsistence method must be explored. One area that is under developed in Ranong is sustainable tourism. In developing a concept of community tourism, the local stakeholders will require much assistance from government and the TAT (Tourism authority of Thailand). Strategies should be developed carefully to prevent an influx from the 'backpacker' market which in the past has led to rapid and unsustainable development with disastrous consequences for both the environment and cultural heritage of an area (e.g. the islands of the gulf of Thailand in the 1990's). Instead, Ranong is perfectly positioned to market itself to two groups of visitors: those willing to pay a premium for an authentic unspoilt experience; and those seeking the opportunity to study this unique environment and participate in practical conservation activities.

The first group of visitors will be looking for a mixture of rustic authenticity mixed with aspects of luxury and pampering. There are several well established hotels in Ranong that could provide the latter and coordinate short trips to the villages of the RBR. Villagers would be paid to provide home cooked food, chalet style accommodation, fishing trips & tours, and craft demonstrations. There would be opportunities for the villagers to sell their sustainably produced mangrove products such as kapi, honey, cashews, natural hair & beauty products, and woodcrafts.

The second group of visitors will expect an opportunity to explore local knowledge of Ranong's mangroves. In collaboration with the DMCR's Mangrove Forest Research Centre, local people will be able to provide guided tours of the mangroves by fishing boat. The TAT could help by producing a multi-lingual audio tour, and student tourists could gain practical conservation skills by taking part in replanting projects or help to collect survey data for monitoring schemes. In this way the need for continual monitoring of impacts may be met whilst generating income for the local economy.

5.5. Recommendations

5.5.1. Conservation

A key focus of this project was to provide objective data and advice from which policy makers could assess the conservation options and determine optimal policies that would balance the needs of conservation with the various socioeconomic needs of the people in the area. A question that needs to be addressed for future RBR management and restoration is whether mono-specific planting is at all appropriate. Considering that natural mixed species stands even if dominated by few species are common, conservation managers should consider the possibility that in some reforestation projects, mono-specific planting may not be ideal, and even counter-productive.

Further research is required to effectively model vegetation development and ecosystem interactions, which may be a helpful tool in developing a comprehensive mangrove restoration framework. This framework will allow conservation managers to plan not only for reforestation, but also faunal recolonisation and the return of ecosystem function. In addition to specifying planting requirements for various areas, the framework will also set out a monitoring strategy to determine future actions. Several of the replanted sites visited during data collection required further action (e.g. thinning of young plants as the sites became more established) to maintain the rate of recovery. Close monitoring would also help to identify any further modifications of the framework.

5.5.2. Management of Resources

It was clear that very few respondents to the socio-economic survey really understood the purpose of the RBR, and certainly all were unaware of the current zoning plan (Appendix I). This lack of awareness and the various conflicts outlined in the results of this study suggest the need for a new zoning plan developed with the assistance of local people who possess abundant knowledge of Ranong's mangrove resources and how they are used. This local knowledge combined with remotely sensed data and information collected by scientists over the past 13 years of the reserve's existence, should be used to create a more effective and collaborative approach to zoning. Developments in technology have made the mammoth task of collating and interpreting vast quantities of varying data more viable, and in this instance it is recommended that conservation managers employ a geographic information system (GIS) complemented by a decision support software package such as MARXAN.

Once a more effective zoning plan has been established and effectively communicated to all users of the reserve, communities should be supported in the development of localised management plans. These plans should not only incorporate protection and preservation issues but will also detail the way in which alternative uses are to be explored. A representative stakeholder group will be formed to meet with members of local government and conservation managers in a very much 'bottom up' approach to developing future strategies. Where new regulations are formulated it is important that communities feel they are making an 'agreement' for the good of all, rather than rules are being 'imposed' that are understood by only the minority.

Finally, it is suggested that further research is required to ascertain a more exact value of the financial benefit of conservation to the local economy. An accurate estimate of the return on capital employed would be useful in securing future funding for mangrove research and conservation. During periods of large scale economic recession it is these hard facts that are important to governments when allocating financial resources. More often than not intrinsic values are overlooked and so to maintain present levels of investment, the scientific community should be looking to emphasise the economic significance of environmental conservation and sustainable development.

Word Count: 14 957

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Appendix A: Ground Survey Record Sheet

Site Name/# ______________________ Date: ______________________

UTM Coords ______________________

Tree number	Photo ref#	Species	Height	CBH	ave DBH	% Ground cover
						Q1
						Q2
						Q3
						Q4
						CBH = circumference at breast height
						DBH = Diameter at breast height
						BH = 1.3m
						ave DBH = CBH/π
						Notes

Appendix B: Ground Survey Light Record

Site Name/# ______________________ Date: ______________________

Start Time: ______________________ End Time: ______________________

solar zenith angle (start):				solar zenith angle (end):				Directions
I0 start reading:				*I0 end* reading:				
#	light reading	#	light reading	#	light reading	#	light reading	Start time and end time must be no longer than 30 mins apart. *I0* reading to be taken in open area, in open water if necessary.
1		26		51		76		
2		27		52		77		
3		28		53		78		
4		29		54		79		
5		30		55		80		
6		31		56		81		
7		32		57		82		
8		33		58		83		
9		34		59		84		
10		35		60		85		Notes
11		36		61		86		
12		37		62		87		
13		38		63		88		
14		39		64		89		
15		40		65		90		
16		41		66		91		
17		42		67		92		
18		43		68		93		
19		44		69		94		
20		45		70		95		
21		46		71		96		
22		47		72		97		
23		48		73		98		
24		49		74		99		
25		50		75		100		

Appendix C: Questionnaire – English Version

Questionnaire:

Resource Use and Economics of the Ranong Biosphere Reserve, Thailand

Name of village………………………………………Sub-District………………………………Amphoe…………………………
Province………………………………………………Date…………………………………………Time………………………………
Name of interviewer…………………………………………Name of interviewee…………………………………………………
Age……………………………………………………Gender…………………… ………………Religion……………………………

Infrastructure / amenities………

Location description………

1. Main occupation………

   Secondary activities……………………………………………………………………………………………………

2. Activity description

   a. ☐ Collection by hand ☐ Fishing gear (Net…………… other…………………) ☐ Cultivation (……………………)
      ☐ Plantation ……………………………………………………………………………………………………

   b. Size of tools & equipment……………………………………………………………………………………………

   c. Cost of tools & equipment……………………………………………………………………………………………

   d. Duration of crop harvest……………………………………………………………………………………………

   e. Number of people involved (including age and gender)……………………………………………………………

3. Natural resources required for successful operations

   ………
   ………

4. What is collected / produced / natural resources consumed

   ………
   ………

5. Describe the area / location type

   ………
   ………

6. Produce details

   a. Cost price………

   b. Selling price (from primary producer)………………………………………………………………………………

   c. Revenue per month…………………………………………………………………………………………………

   d. Amount of produce sold……………………………………………………………………………………………

   e. Final destination of produce…………………………………………………………………………………………

7. Perception of the RBR

   a. Do you know about the RBR? How do you know about it?

      ☐ Don't know about RBR ☐ Know, because...

   b. If you know about the RBR., why do you think the RBR is important / how does it benefit you?

   ....

   ....

   c. What do you think about the RBR, and what concerns do you have in relation to yourself and your community?

   ....

   ....

8. Perception of Mangrove Forest

   a. Do you think the mangrove forest is important, if so why?

   ....

   ....

   b. What do you think was local perception of mangrove resources 15 years ago?

   ....

   c. In the future, what do you think the local perception of resources will be?

   ....

   d. What do you think about the current management of the mangrove forest and how could it be best utilised for the benefit of the local community?

   ....

   ....

   e. Have you participated in a mangrove restoration project? Give details.

   ....

   ....

9. What do you think are the main conflicts with local people and RBR management strategies? What do you want to happen to solve any problems?

   ....

   ....

10. Do you want to be involved in the protection, restoration and sustainable management of the RBR?

   ....

   ....

11. Have you ever used timber from mangrove and which species have you used?

   ....

   ....

12. Any other comment

   ....

   ....

   ....

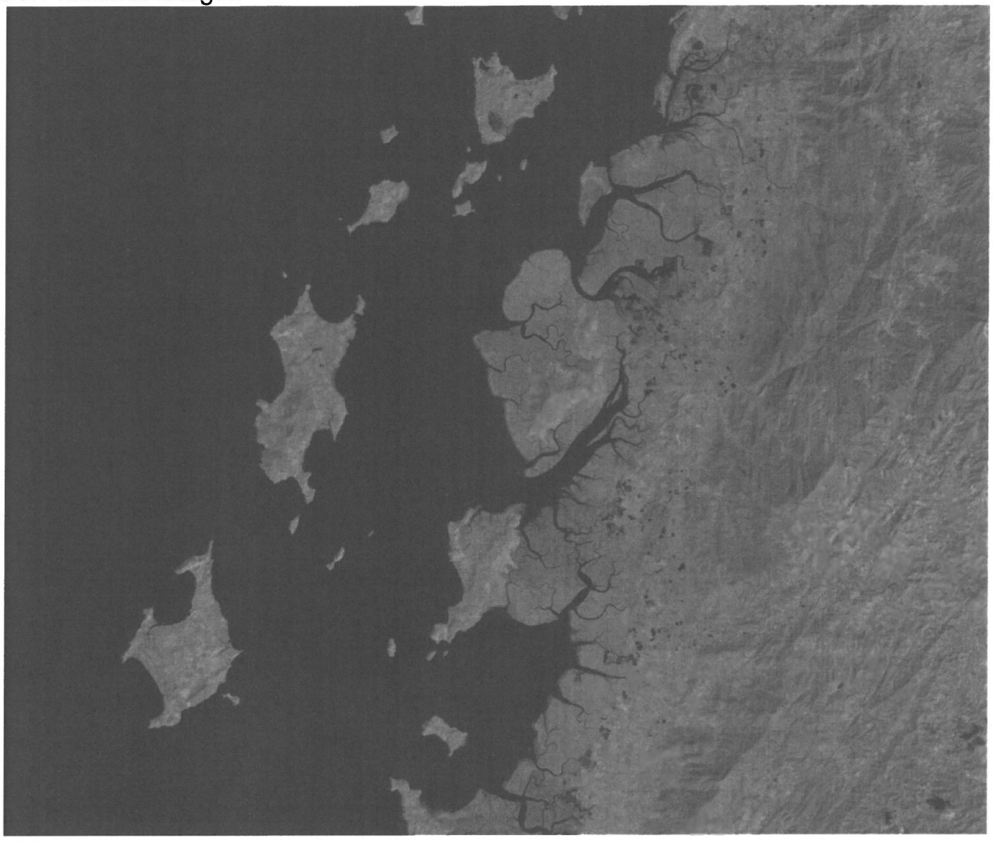
Guidance Notes:

1. Main occupation of the head of the head of the household. What earns the most income or what they spend the majority of their time doing.

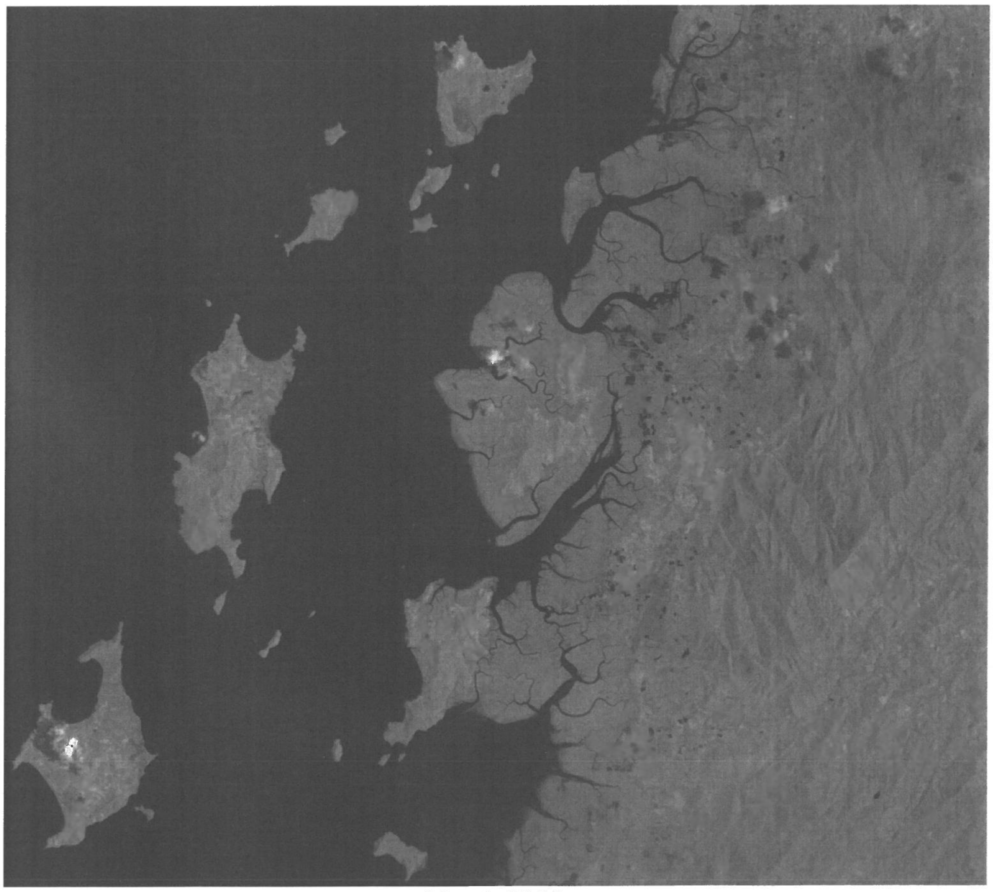
   Secondary activities may be undertaken by other members of the family (wife, parents, children etc) or when off season for main occupation

2. b. Indication the scale of operations I.e. hands tools for small operations or push net fishing for larger operations etc
3. i.e. Trees for timber, nutrient recycling/ retention for water quality, correct salinity, etc
4. Timber, fish, shell fish, crabs etc
5. Ask to point out location on map
6. May need to calculate monthly revenue and costs from other information given, try to gather as mush data as possible.
7. Do they know the purpose of the RBR, do they know about restrictions and/or zoning?
8. Do not lead this question, try to find out exactly what their perceptions are.
9. Explain strategies and possible conflicts ask what they think
10. Explain how they can be involved.
11. Why do they use specific species is it because of suitability or abundance issues

Appendix D: Satellite Images



November 2000



March 2009

Appendix E: List of mangrove species identified

Latin Name	Thai Name
Acanthus ebracteatus	Nuac bpra mor khao
Acanthus ilicifolius	Nuac bpra mor muang
Acanthus volubilis	
Acrostichum aureum	
Acrostichum speciosum	
Aegialitis rotundifolia	
Aegiceras corniculatum	Lep mu nang
Avicennia alba	Somere khao
Avicennia marina	Somere talay
Avicennia officinalis	Somere Dam
Avicennia rumphiana	
Bruguiera cylindrical	Tuah khao
Bruguiera gymnorrhiza	Pang ga hua som dawk deang
Bruguiera hainesii	
Bruguiera parviflora	Tuah dam
Bruguiera sexangula	Pang ga hua som dawk khao
Ceriops decandra	Blawng khao
Ceriops tagal	Blawng daeng
Cynometra ramiflora	
Excoecaria agallocha	Dtah tum
Finlaysania maritima	Gla po bla
Heritiera fomes	
Heritiera littoralis	
Kandelia candel	
Lumnitzera littorea	
Lumnitzera racemosa	
Nypa fruticans	
Pemphis acidula	
Rhizophora apiculata	Gonkang Bai Lek
Rhizophora mucronata	Gongkang Bai Yai
Scyphiphora hyrophyllacea	
Sonneratia alba	Lampoo talay
Sonneratia caseolaris	Lampoo
Sonneratia griffithii	Lampen talay
Sonneratia ovata	Lampen
Xylocarpus granatum	Dtamboon khao
Xylocarpus moluccensis	Dtamboon dam

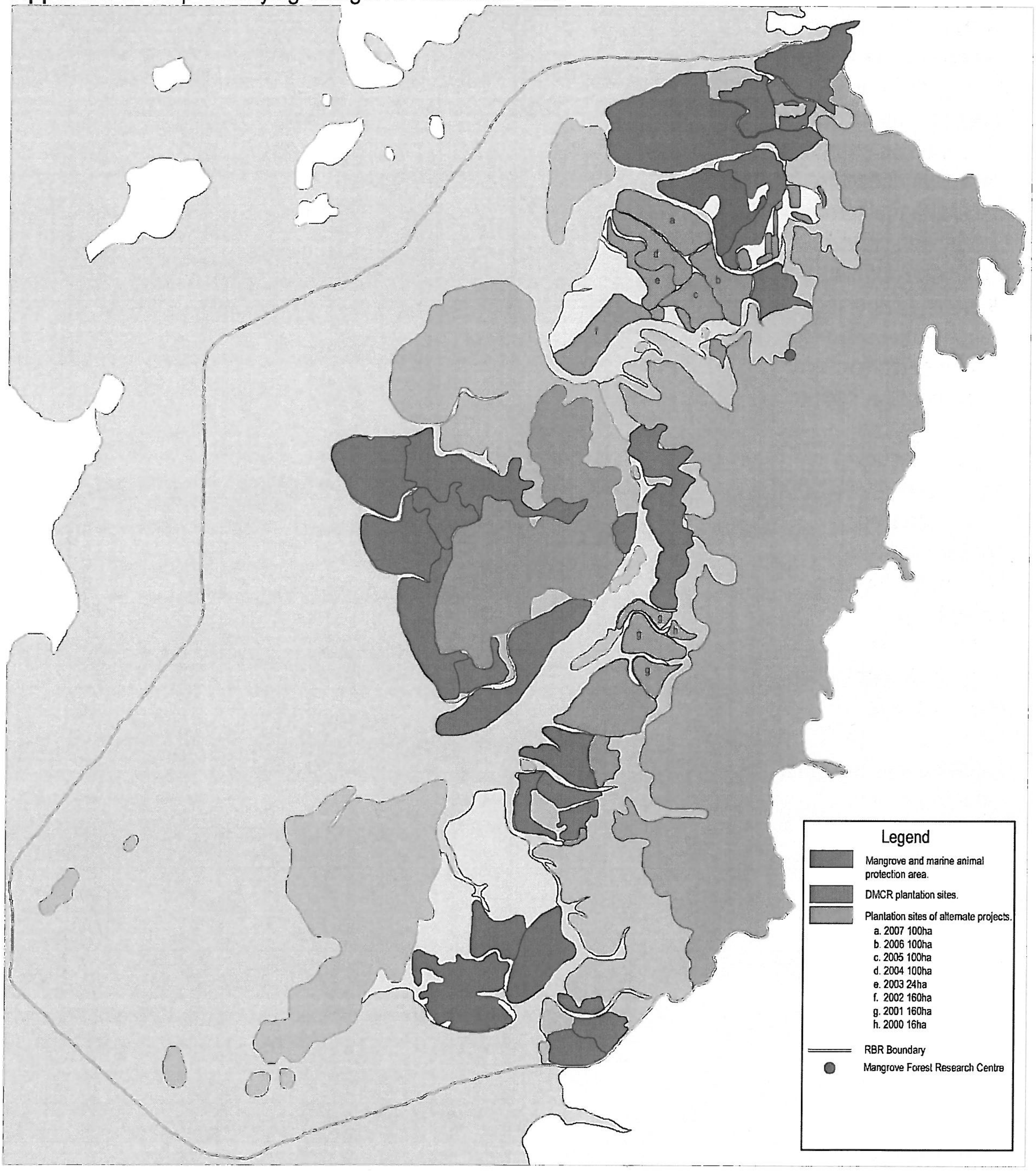
Appendix F: List of species utilised by communities in the RBR

MOLLUSCS
Anadara granosa
Anadara cf. troscheli
Crassostrea commercialis
Crassostrea belcheri
Crassostrea lugubris
Perna viridis
Modiolus metcalfei
Arcuatula arcuatula
Meretrix lusoria
Solen strictus
Lingula lingula
Natica sp.
Strombus sp.
Cerithidea obtusa
Cerithidea rhizophorarum
Nerita planospira
Nerita articulata
Bactronophorus thoracites
Onchidium sp.
Sepioteuthis lessoniana
Loligo duvauceli
Octopus membranaceous

CRUSTACEANS
Scylla olivacea
Scylla paramamosain
Scylla tranquebarica
Portunus pelagicus
Portunus sanquinolentus
Portunus sp.
Episesarma mederi
Episesarma versicolor
Thalassina anomola
Squilla mantis
Miyakea nepa
Penaeus merguiensis
Penaeus monodon
Metapenaeus sp.
Metapenaeus sp.
Parapenaeopsis maxillipedo
Acetes sibogace

FINFISH
Epinephelus coioides
Epinephelus bleekeri
Epinephelus malabaricus
Lates calcarifer
Lutjanus bohar
Lutjanus argentimaculatus
Liza subviridis
Valamugil cunnesius
Liza vaigiensis
Plotosus canius
Lutjanus johni
Cynoglossus sp.
Anguilla sp.
Dasyatis spp.
Anodontostoma chacunda
Seriolina nigrofasciata
Thryssa mystax
Scatophagus argus
Boleophthalmus boddarti
Boleophthalmus dussumieri
Periophthalmodon schlosseri
Eleutheronema tetradactylum
Carangoides spp.
Rastrelliger brachysoma
Secutor ruconius
Leiognathus bindus
Scomberomorus guttatus
Sillago sp.

Appendix G: Map identifying mangrove restoration sites



Appendix H: Species identified during survey of benthic communities

Assiminea brevicula
Assiminea beddomeana
Boleophthalmus sp.
Boleophthalmus boddarti
Brachidontes pharonsis
Cassidula aurisfelis
Cassidula multiplicatus
Cerithidea cingulata
Cerithidea obtusa
Chicoreus capucinus
Chiromanthes eumolpe
Clithon oualaniensis
Clyeomorus pellucide
Chthamalus sp
Crassostrea sp
Diopata sp
Dostia violacea
Ellobium aurisiudae
Epixanthus frontalis
Epiactis sp
Goby sp
Isognomon ephippium
Paguroidea fa
Littoria sp
Littoraria melanostama
Littoraria scabra
Metaplax elegan
Metopograpsus latifrons
Nerita articulata
Nerita planospira
Nassarius jacksonianus
Nodilittorina trochoides
Parasesarma plicatum
Saccostrea cucullata
Scopimera globosa
Sesarma sp.
Teredo sp
Telescopium telescopium
Uca sp.
Xenostrobus balani

Appendix I: Current zonation map