BIOMASS AND REGENERATION OF MANGROVE vegetation in Kien Giang Province, Vietnam

Nick Wilson

Conservation and development

of the Kien Giang Biosphere

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Abbreviations used

AGB – Above ground biomass

BA – Basal Area (area of a trunk cross section at 1.3 m height or above the prop roots on *Rhizophora*)

BGB – Below ground biomass – when reported as a number it refers to tree root weight, but more generally to other living and dead biomass material in the soil as well as living roots.

DBH – Diameter at breast height (by convention, the diameter of the trunk at 1.3 m height or above the prop roots on *Rhizophora*)

DW – Dry weight

KG – Kien Giang Province, Vietnam

Cover: Tall *Sonneratia caseolaris* mangrove forest, Vinh Quang.

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1. Introduction

This report forms part of a broad project on the shoreline and mangroves of Kien Giang Province (KG) on the west coast of Vietnam, which is part of the 'Conservation and Development of the Kien Giang Biosphere Reserve Project'. The broad project includes:

- A biomass, carbon and diversity project, including the feasibility of a REDD[1] project in KG and an assessment of regeneration needs and potential (this report) (principally Dr Nick Wilson).
- A general survey of the tree biodiversity KG mangrove (to which observations from this sub-project contributed) (principally Dr Norm Duke).
- Mangrove and coastline mapping via remote sensing (using in part location and vegetation date supplied from this sub-project) (principally Mr Nguyen Hai Hoa and Dr Norm Duke).
- The assessment of shoreline condition via a video filming technique (principally Mr Jock Mackenzie).
- Contributions to the rehabilitation of shoreline erosion and environmental services of mangrove and livelihood projects in KG.

This report can be read separately, but also as part of the wider project. It presents findings and conclusions in a brief manner, but often with fuller details in appendices if appropriate. Some brief additional documents have been supplied to GTZ in KG in addition to the report (Table 1).

The terms of reference called for plot work to generate contribute to the development of vegetation units for mapping in KG mangroves and to examine mangrove biomass and carbon stocks, given current discussions about financially valuing carbon stores in vegetation. This has been done, while also developing a picture of the nature of the mangrove vegetation (species complement, height, density etc). Contributions to the remote sensing aspect of the wider project through supplying quantitative parameters such as species presence and height within plots and many incidental observations have been done. Observations and experience in identifying coastal erosion derived in field work has been communicated to the shoreline condition

As the project progressed it became evident that the small area of mangrove vegetation in KG, with often moderate biomass as a result of the nature of the vegetation and cutting. The mangrove area is also much smaller than it once was and continues to decline. This suggests the desirability of the restoration of the mangrove vegetation and this report moves towards this end from the initial attention to carbon and biomass. The value of the mangrove vegetation as a carbon store, along with other ecological services such as shoreline protection, near-shore productivity and food and material provision can be enhanced.

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[1] REDD (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) (UN-REDD 2010). This proposed approach aims to value and pay for the avoidance of forest deforestation and degradation on a probably national scale, under the auspices of the UN.

Table 1: Preliminary internal reports supplied to GTZ in Rach Gia

- Progress notes (preliminary report)
- Response to progress notes
- Dot points on KfW visit
- Rapid biomass/biodiversity survey methods
- Plus numerous annotated photographs left in Rach Gia

2. Background: Brief context on forests and carbon

Forest ecosystems are made up of carbon-based life forms in plants and animals (biomass), along with sometimes large amounts of leaf litter and living or dead organic material in the soil. Trees and shrubs make the bulk of above ground biomass in a forest, with the total biomass of a stand varying markedly depending on the climate and soil and, in the case of mangrove vegetation, the frequency and duration of tidal inundation. The age of the forest and its constituent trees is also a factor. In relatively young forests the carbon stored builds over time as the trees and forest grow. Soil carbon stocks also rise.

The relationship between the size of trees and their biomass is not linear – meaning that as the diameter and height of the tree increases its biomass increases in a disproportionally greater way. A typical mangrove tree may increase in dry biomass by greater than 5 times with every doubling of its trunk diameter of which about half is carbon. This means that a forest of thin trees, even if tightly packed, may have only a fraction of the biomass of a forest of wider spaced large trees. It is the size of the trees and their density that is the principal determinant of stand biomass. The wood density of the tree further affects the carbon content of the plants and hence that of the stand of vegetation.

All carbon in biomass derives ultimately from atmospheric carbon dioxide (CO_2) via plant growth. Removal of forest cover and the burning or rotting of cut biomass returns carbon to the atmosphere in the form of CO_2, or sometimes methane (CH_4) in the case of rotting. Hence forests are a standing store of sequestered atmospheric carbon, despite some turnover over on a daily basis. Some of the turnover (productivity) breaks down to return to the atmosphere, but other fractions enter food chains or are stored in the soil. Soil carbon can be stable for long periods. Sedimentary environments like mangrove ecosystems can facilitate the burial of biomass and sometimes form peat due to restricted breakdown of biomass in the wet soils. Soil carbon may oxidise to the atmosphere when cleared and dried.

The biomass of mangrove vegetation, like that of all forest ecosystems, provides environmental services including inherent biodiversity values, human food and materials, primary productivity as a basis for aquatic food webs and protection of the shoreline if wide enough. Recent focus on the storage of carbon by forest ecosystems that would otherwise be in the atmosphere has led to proposals to give sequestered carbon a financial value beyond the in-kind value they already have, either through large REDD mechanisms, voluntary carbon trading funds or via project funding. Even without a direct financial mechanism, the value of mangrove biomass is increased by the need to regulate atmospheric CO_2.

3. Methods and activities undertaken

Visits were made to KG in July-August 2009 and January 2010. Central to this project were extensive field investigations over much of the coastline. Many observations on the nature and condition of the mangrove vegetation were made, along with the collection of plot-based data using a rapid field assessment methodology. The methodology was largely devised for this task (details in Appendix 1). Rapid survey techniques vary in approach and are best adapted to the specific task at hand, considering the time and resources (including equipment) available. By their nature, they are short cuts to a complete analysis of ecosystems, but aim at essential features to answer particular questions.

Time was spent in field and office discussions with GTZ staff and with provincial officials. Further time in KG was spent during the first trip in discussions on coordination with other project members and in treating of field samples and data analysis. The rapid methodology was refined with discussions and field testing during the early part of the first visit to KG in 2009. Time was also spent in organising equipment and in discussions with other project members on methodology and coordination of the threads of the wider project, such as integration with remote sensing.

A total of 41 plots were sampled (approximate localities in Figure 1; precise details in Appendix 2), with the assistance of GTZ and Department of Agriculture and Rural Development (DARD) staff. Plots are spread across the Province, albeit concentrated in the Rach Gia to Vam Ray region. This was partly for ease of access and partly because GTZ has had a focus on the Vam Ray area (Hon Dat District) and continuing investigations in that area is useful. More plots may have revealed more in An Bien and An Minh, although much of the mangrove there is subject to rapid erosion or is planted *Rhizophora* subject to cutting which is hard to sample adequately. Twelve plots in total were contributed by Jock Mackenzie, Nguyen Hai Hoa and/or Norm Duke in concert with Vietnamese staff. Numerous descriptive features of the vegetation were gained, including:

- Species and vegetation types present.
- Heights, diameters and density of trees to estimate biomass and carbon content.
- Seedling and small tree numbers in the first phase plots.
- Degree of cutting.
- Precise localities along with the summaries of the collected data for calibrating remote sensing.

Estimates of above ground biomass (AGB) were made using published allometric equations and one for Vietnam of Dr V. N. Nam, who made it available for this exercise. Details are provided in Appendix 3. Some minor assessment of dry biomass and height of *Nypa* palm and small trees was done, although this is very preliminary due to the lack of good equipment and its partial failure.

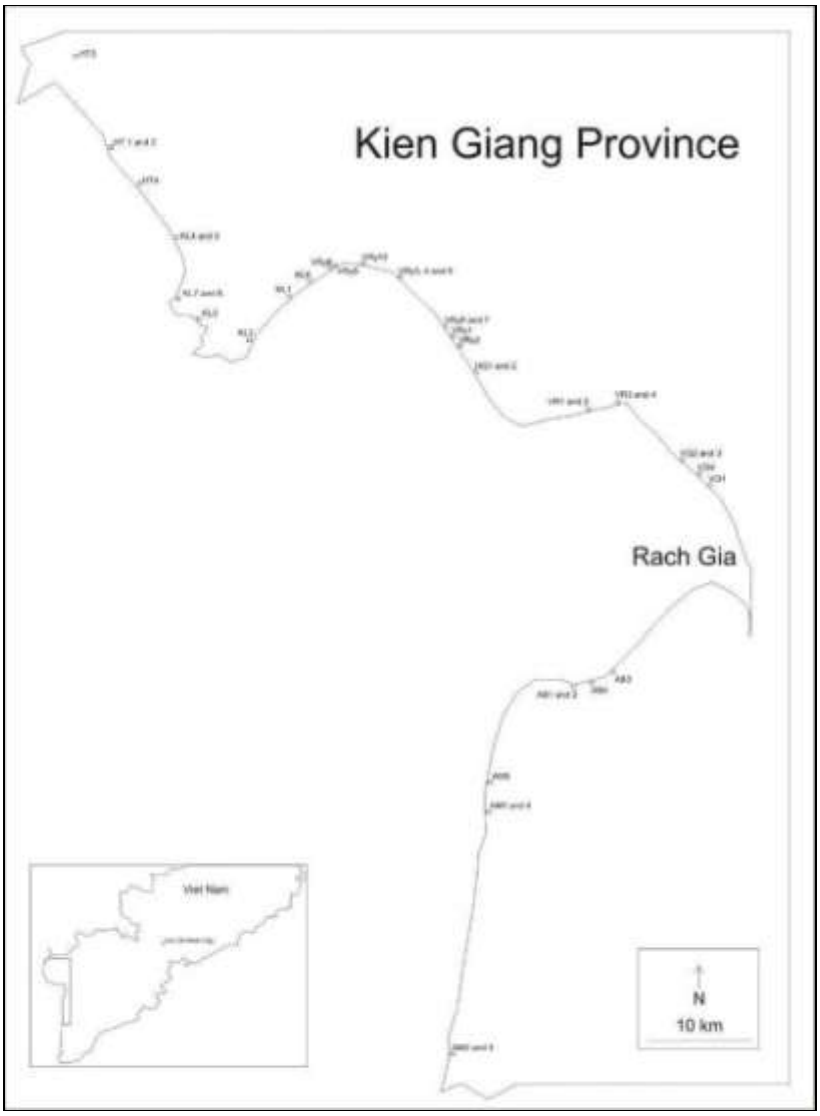

Figure 1: Approximate plot localities in Kien Giang Province

4. The mangrove vegetation of Kien Giang Province

4.1 General vegetation description

The character of the mangrove vegetation of KG is described generally in this section, with some quantitative findings outlined in the next. Most of Kien Giang's mangrove vegetation remains along the open coastline, with additional areas within rivers and streams, such as the Cai Lon and Giang Thanh Rivers. There are relatively large areas associated with the Giang Thanh River system in Ha Tien, but this has been considerably reduced.

Kien Giang Province has relatively little mangrove compared to some other places in Vietnam, notably the neighbouring Ca Mau Province (Hong & San 1993). Mangrove vegetation is, however, present over nearly all the coastline, barring rocky headlands and its inherent benefits are spread across the whole province. Hong & San (1993; Section 4.5) discuss mangrove patterns for Ca Mau, but there is little published information on KG prior to this exercise.

Kien Giang's mangrove vegetation has some interesting features, but is otherwise similar in general pattern to other areas of Vietnam and South East Asia. It is nearly all subject to cutting and no doubt has been for a considerable time, which may affect species composition (e.g. see point 5 below) as well as biomass. This is discussed further in Section 5.4 and the biodiversity of the province is also treated in the wider project. Very simply, the basic pattern includes:

1. The sea fringe is dominated in most places by *Avicennia alba* (Vietnamese name: Mắm trắng) (Figure 2). This is also typical of much of Ca Mau (Hong & San 1993). Stands of *A. alba* are also typical in the natural re-colonisation of abandoned aquaculture ponds (Figure 21). *Sonneratia alba* (Bần trắng), which is typical of the sea front in other places (Giesen *et al.* 2006) was only seen sporadically with *A. alba* at the front of the mangrove in northern parts (Ha Tien).

2. *Sonneratia caseolaris* (Bần chua) with *A. alba* is dominant in the sea fringe that makes up most of the mangrove in the central area from about Rach Gia north to around Vam Rang (cover). In places, blocks of both *A. alba* and *S. caseolaris* have been planted at the front of the mangrove, extending it seaward. These are mostly clear but sometimes difficult to distinguish from natural stands[2]. It is possible that nearly all of the valuable *S. caseolaris* stands were planted and have grown very.

3. With distance from the sea, a more 'mixed' mangrove develops at mid to high tide levels where a number of other species colonise after the first development of mangrove vegetation, joining the initial species (Figure 3). This is the richest type in terms of biodiversity and can develop dense, stable vegetation, with some of the biggest trees. *Avicennia* is still a major component. Hong & San (1993) refer to this vegetation as an *Avicennia alba-Rhizophora apiculata* community, which is appropriate, but other species such as *Bruguiera* spp. (Vet), *Xylocarpus* spp. (Xu) and *Sonneratia alba* (Bần trắng) also appear.

4. In the north of the Province, the greater extent of the mangrove allows a drier mixed forest to develop in places, with species such as *Phoenix paludosa*), *Heritiera littoralis* (Cui biển) and *Ceriops tagal* (Dà vôi) more prominent.

5. Mixed forests with an elevated proportion of *Excoecaria agallocha* (Giá) are present in places subject to past or present cutting of the forest. *E. agallocha* is favoured by heavy cutting, with some stands heavily dominated by *E. agallocha* (left of Figure 14), but others can still have a reasonable species complement.

6. In the northern areas of Kien Luong and Ha Tien Districts, stands of an upper intertidal 'scrub' of about 2-3 metres height and good diversity are present (Figure 4). Plants such as *Scyphiphora hydrophylacea* (Côi), *Lumnitzera littorea* (Cóc đỏ) and *L. racemosa* (Cóc vang) that are rare or absent elsewhere in KG are present, along with commoner species such as *E. agallocha*. South of Kien Luong, the mangrove forests are typically too narrow to support this vegetation.

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[2] Information on planting has been difficult to procure.

7. Stands of the palm *Nypa fruticans* (Dừa nước) can be present at the rear of the mangrove on the coast, or at the front along canals or rivers (Figure 5). There are natural occurrences, although many are planted, even on a small scale, due to the utility of their leaves and, to a lesser extent, their fruit. There are some relatively large planted areas along rivers and widespread planting at the rear of the mangrove, seemingly including the replacement of other mangrove trees in at least a few places.

8. Fringing strips of mangrove 'associate' species are present at the rear of the tidal influence, with characteristic species such as *Hibiscus tiliaceous* (Tra nh) and *Thespesia populnea* (Tra b) and numerous others. This is a typical situation.

9. Significant areas of *Rhizophora apiculata* (Đước) have been planted in blocks. This species is native to this coast, but natural stands like the planted blocks are not found, although there are some fringing stands on small streams on Phu Quoc Island. The older planted stands are about 18 years old and approach 13 metres in height in a good site.

10. Low thickets of plants such as the daisy *Pluchea indica* (L), the shrubs of *Acanthus* spp. (Ô rô), the mangrove ferns *Acrostichum* spp. (Ráng) and the scrambling *Clerodendrum inerme* (Dây chùm gong) grows on degraded former mangrove land (Figure 18). Trees may be absent as tidal exchange is compromised or alternatively because the thicket is suppressing tree regrowth.

Some of the notable features of the vegetation uncovered during this project include:

1. The *S. caseolaris* to the north of Rach Gia, particularly in the Vinh Quang area are perhaps the tallest in Vietnam and are very tall for the species generally (Giesen *et al.* 2006). These trees may be planted, but at a maximum of about 21 metres are very notable. This is amongst the highest biomass forest in KG (Section 4.2). Weaver bird nests are present in some of the trees.
2. *Sonneratia caseolaris* prefers brackish conditions, but is well developed on the ocean front in KG. This is because the tidal water is so low in salinity (effectively fresh water) during the wet season. Other brackish species, including vines, herbs and trees (see Point 8, below) are found within the mangrove although they are not usually considered mangrove plants.
3. There are three *Avicennia* species present, with *A. alba* easily the most common. However, the numbers of another species *A. marina* (Mắm biển) are quite high and the species occurs on mud, which is somewhat unusual in Vietnam (V.N. Nam, pers. comm.).
4. There more mangrove diversity in the north of the Province, including species such as *S. hydrophyllacea*, *Lumnitzera littorea*, *Aegiceras corniculatum* (Sú) and the palm *Phoenix paludosa* not seen elsewhere.
5. *Lumnitzera littorea* with its red flowers was previously poorly known in Vietnam, but is widely present in the high intertidal scrub mangrove in the north of the Province. Its co-occurrence with the white flowered *L. racemosa* is apparently unusual; Giesen *et al.* (2006) state that the two species have not been collected from the same site previously.

6. There are odd mixed stands of mangrove present in places subject to coastal retraction, where upper fringe species, such as *T. populnea* and *H. tiliaceous* currently coexist with low intertidal mangrove species. In essence, the retracting coast has brought greater tidal exchange that in turn has brought regeneration of mangrove species, while the previous fringing species remain healthy. This situation is found particularly in An Minh and An Bien, but also in Kien Luong.
7. Natural mangrove regeneration is generally very good within the forest area (e.g. Figure 21) and is not a problem overall in KG, although some species may be restricted more than others (see also Section 5.5).
8. A significant number of species are associated with the mangrove in KG, but are not generally considered core mangrove species, including many climbers. Most are typical and are detailed in Hung & Tan (1993). A few interesting tree species found within or at the tidal edge of the mangrove, including *Barringtonia acutangula* (Chi) and *Cerbera odollam* (local name: M) in or on the edge of the brackish *S. caseolaris* mangrove fringe and *Phoenix paludosa* and *Instia bijuga* (c) in the north. Some details are given in Appendix 4. Vascular epiphytes are not uncommon on tropical mangrove trees and Hung & Tan (1993) record some from Ca Mau, but none were seen on the trees of KG.

There is direct impact on the trees and vegetation even where the forest remains. Minor cutting of mangrove trees within the forest is very widespread, as are the collection of food and the scavenging of debris. Some observations on this point include:

1. Every stand visited has cutting, principally of small size specimens for poles or perhaps firewood. In places, it is not obvious why trees were cut. Some large *S. caseolaris* are being cut for timber using boats for transport (Figure 17).
2. Numerous species (c. 11; Appendix 2) are cut, but most commonly *R. apiculat*a, *A. alba* and *E. agallocha*. Species such as *E. agallocha* (especially), *Avicennia* spp. and *S. caseolaris* can resprout, but cutting of the trunk below the branches of *Rhizophora*, *Ceriops* and *Bruguiera* above a small size results in their death. The scarcity of these species in places may reflect cutting.
3. In a stretch of coast from Vinh Quang towards Vam Rang, large *S. caseolaris* are being coppiced, reportedly for the regrowth to provide material for shaded fish attractions. Fresh cutting over about 700 m^2 is shown in Figure 6 and the long term result in Figure 7. This is particularly large scale for the cutting of trees within a forest area, as opposed to clearing.
4. Cutting is found at the front of narrow eroded mangrove fringes, suggesting a disconnection between the needs or knowledge of locals in cutting trees and that of the protective role of mangroves.

Figure 2: Young ocean front forest dominated by small *Avicennia alba*, Vam Ray.

Figure 3: ‘Mixed’ mangrove forest, with *Avicennia alba* in centre larger than in Figure 2. This older forest is a progression from that in Figure 2, with higher biomass and greater diversity.

Figure 4: Scrubby open mangrove vegetation at high intertidal levels in the Giang Thanh River system, Ha Tien. Although always short, the openness and height of this site partially reflects cutting.

Figure 5: Stand of *Nypa* palms showing cutting of fronds and clumping habit, Vam Ray.

Figure 6: Recent large scale cutting of mature *Sonneratia caseolaris* for coppicing. Note large stump in foreground. Cutting such trees has large biomass implications.

Figure 7: Large stumps left after repeated cutting of large *Sonneratia caseolaris* for coppice shoots for fishing purposes.

4.2 Quantitative vegetation description

Some trees and shrubs were multi-stemmed, giving a total number of 1219 trunks (ramets). Brief features of the vegetation are outlined to show the range of variation in the mangrove vegetation of KG in this section. Appendix 2 has summaries of all plots. Biomass/carbon work is shown in Section 5. The 41 plots were spread nearly the entire length of the KG coast (Figure 1), with a concentration in more central areas. The plots made up an area of 2773 m^2, containing 911 trees and shrubs taller than 1.3m (genets) and a total of 1219 stems (ramets). There were 22 tree and shrub species taller than 1.3 m within the plots, plus four common species of understorey plant (two *Acrostichum* and two *Acanthus* species). This represents the majority of KG's recorded mangrove diversity.

Overall, the mean height of the trees above 1.3 m height in each plot ranged from 2.1 m to 11.2 m, with an overall mean of 6.2 m. This does not represent the canopy height as it also includes smaller trees of sub-canopy height. A calculation of the tallest 'stratum' of trees in the plots gives a range of 2.4 m to 12.5 m, with an overall mean of 9.1 m. This represents an approximate canopy height as seen from an aerial photograph, albeit possibly with gaps present. The canopy cover of the plots ranged from 58% in a heavily cut site to a number of plots with 82 or 83%. The shortest vegetation is upper intertidal scrub in Ha Tien and the tallest is the *S. caseolaris* vegetation north of Rach Gia.

The height of the tallest trees in each plot ranges from 5m to 16.9 m, with a mean of 10.1 m. Details of the dimensions for the tallest individuals of some species observed within and outside plots are given in Table 3. Many of the tallest trees are within plots, suggesting the plots represent the tree height in the vegetation well, despite the tallest observed trees of some species being outside plots.

Tree diameter (DBH)[3] ranged from 2.3 cm to 14.2 cm, with an overall mean of 6.4 cm. The basal area (BA) of the plots[4] was summed, then expanded to a per hectare figure for comparison between plots (Appendix 2), with a range from a very low 3.8 m^2 ha^{-1} to 54.7 m^2 ha^{-1} and an overall mean of the plot mean values of 22.5 m^2 ha^{-1} (Table 2). Stand BA is a useful measure as it incorporates all of the factors that determine the size and spacing of trees. The quadratic mean diameter of a stand represents a tree with the mean basal area of the plot (Van Laar & Akça 2007) and is a good complement to stand BA, as indicates the tree size present.

The average diameter at the top of cut stumps in the plots was 7.0 cm. The percentage of cut stumps to living stems varied from 0% (one plot only) to 450% in a heavily cut multi-stemmed *R. apiculata* plantation. Biomass and cutting are discussed in more detail in Section 5.2 and 5.4.

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[3] By convention, 'diameter at breast height' (DBH) is used for

the measurement of tree diameter at a height of 1.3 m, except for unusually growth forms, such as *Rhizophora*, which are measured above the protuberances.

[4] 'Basal area' refers to the cross-sectional area of trees at the height of measurement, rather than at ground level.

Table 2: Summary details of mean height, diameter and basal area and quadratic mean diameter for all plots.

Plot Number	Mean height of all stems (m)	Approximate canopy height (m)[1]	Mean diameter of all stems (cm)	Quadratic mean diameter of plot (cm)	Basal area (m^2 ha^{-1})
AB1	4.9	7.9	3.1	4.1	6.6
AB2	4.8	9.0	4.7	6.4	18.9
AB3	5.8	9.1	5.3	6.4	17.6
AB4	10.3	10.3	10.1	10.4	46.2
AM1	8.0	10.5	6.3	6.7	16.8
AM2	10.5	10.6	6.6	8.4	35.0
AM3	9.5	10.2	6.7	6.2	19.5
AM4	9.7	11.1	7.2	7.5	8.9
AM5	3.6	6.7	3.0	3.9	13.2
HQ1	3.8	7.0	3.4	4.1	5.0
HQ2	3.8	9.9	3.7	6.2	12.9
HT1	5.0	7.4	4.5	6.0	27.1
HT2	3.6	7.2	3.0	3.9	3.8
HT3	2.1	2.9	2.4	2.6	3.8
HT4	4.8	11.1	8.1	12.0	51.0
KL1	7.7	9.5	8.3	9.2	18.7
KL2	5.3	7.1	5.1	5.8	9.0
KL3	2.5	3.6	2.3	2.9	9.0
KL4	8.2	10.8	7.8	9.0	22.0
KL5	4.9	8.9	4.1	5.5	18.0
KL6	4.1	7.3	3.1	4.2	6.2
KL7	4.0	6.2	3.6	4.0	16.4
KL8	3.9	5.6	3.3	3.5	19.0
VQ1	6.8	16.4	10.4	15.0	38.4
VQ2	4.6	13	6.8	13.2	54.7
VQ3[1]	N/A	N/A	N/A	N/A	N/A
VQ4	7.2	14.0	10.3	13.2	36.8
VR1	9.9	11.0	13.4	14.1	23.5
VR2	6.6	11.8	5.6	7.4	28.8
VR3	10.8	11.5	14.2	15.5	34.5
VR4	8.8	10.1	13.6	14.0	34.5
VRy1	4.9	8.1	5.1	6.6	11.2
VRy2	11.2	8.3	12.3	7.1	22.6
VRy3	6.4	11.5	6.8	12.5	28.7
VRy4	7.4	10.2	6.7	7.8	52.6
VRy5	4.7	8.8	5.3	7.4	29.1
VRy6	5.6	7.4	6.3	7.0	18.2
VRy7	10.4	9.6	7.5	9.0	24.6
VRy8	4.6	12.0	8.0	8.0	23.3
VRy9	4.3	6.4	7.0	8.4	21.3
VRy10	3.8	5.5	4.6	4.7	13.9

[1] A manual calculation based on an assessment of the tallest trees across the plot (see text).

[2] Plot VQ3 is a *Nypa* only plot and so is not strictly comparable to the others.

Table 3: Maximum tree heights and their diameter for selected tree species

Species	Tallest height in plot (m)	Diameter of tallest tree in plots (cm at 1.3 m height)*	Plot name	Approx. max. height seen outside plots (m)
Avicennia alba	12.0	29.0	HT4	12-13
A. marina	11.5	15.6	KL1	None taller
Bruguiera cylindrica	10.0	15.7	KL1	None taller
B. gymnorhiza	3.8	3.5/2.9 (2 stems)	VQ2	11
B. sexangula	4.5	3.4	VRy1	6-7
Ceriops tagal	5.0	19.0	HT1	None taller
C. zippeliana	10.3	14.4	AM2	None taller
Excoecaria agallocha	8.75	7.3	VRy5	None taller
Lumnitzera racemosa	9	11.1	HT2	None taller
Rhizophora apiculata (apparently natural)	10.6	20.0 (above prop roots)	HQ2	15-16
R. apiculata (planted)	13.7	33.0 (above prop roots)	VRy3	None taller
R. mucronata	5.5	4.5 (above prop roots)	VRy2	12
Sonneratia caseolaris	16.9	37.6	VQ1	20-21
Sonneratia ovata	10.5	10.5	VRy6	None taller
Thespesia populnea	6.5	6.8	KL2	None taller
Xylocarpus granatum	9.5	31/29.5 (2 stems)	VRy7	None taller

* *Rhizophora* measured above prop roots.

4.3 Area of mangrove vegetation

The present and former area of mangrove vegetation in KG will be outlined in detail in the remote sensing part of the overall project and quantification of coastal erosion will be done in the shoreline survey, but some observations gained during field work and examination of aerial imagery are given here, as they relate to biomass and carbon storage.

It is evident that mangrove vegetation was formerly more extensive and is continuing to contract in KG. There is continued conversion of mangrove vegetation to aquaculture, wide scale erosion of the front of the mangrove and diffuse cutting for timber products. Some details are included below:

1. A dramatic feature of the sea-edge mangrove vegetation in KG is the degree of erosion that is occurring, both in terms of depth of mangrove being lost and the length of coast affected. The rate can be very rapid. Figure 8 shows approximate retraction at one site near Hon Queo between 2003 and 2007. The coast was eroding before that and there is further 50 m of mangrove loss at the southern point between 2007 and late 2009 (not shown), with the sea immediately threatening large aquaculture pond dykes. Figure 9 shows a localised break-through on to a small dyke enclosing a pond built into the mangrove area in An Bien.
2. The worst affected areas in KG are those of relatively straight open coast, where the mangrove fringe is often thinnest. It is well known that open coasts where fringing mangroves have been lost are subject to erosion by sea waves (Mazda *et al.* 2002). Sea-front erosion, including sites with

mangroves, is widespread in Vietnam, with very high rates of erosion in places (> 30 m per annum) (Cat *et al*. 2006). This includes in the Mekong Delta, although the authors appear to underestimate erosion in KG greatly.

3. Anecdotal statements to the effect that in places mud containing mangroves can come and go (hence eroding areas become depositional and vice versa) were made to the author. This may be so, as sediment can certainly be redistributed by changes in wave action, storms etc, but the scale of erosion does suggest a larger problem. There is a continued large loss of mangrove biomass and its productivity and shoreline protection benefits, which is magnified as a problem by the narrow mangrove fringe in much of KG.
4. Mature vegetation is being eroded, with many large trees falling into the ocean (Figure 11). In essence, an escarpment forms at the front of the mangrove and sea wave action undercuts the trees particularly during the SW monsoon. The eroding edge where mature mangrove is being undercut is relatively easy to pick on aerial imagery as a broken line of large trees, often with isolated large trees in the sea and no mud in front of the mangrove (e.g. Figure 8).
5. Mature trees survive best and can be left isolated in the sea at the front of the mangrove, particularly large *R. apiculata*, with their dense aerial roots and large *S. caseolaris*, with their long pneumatophores giving greater aeration and thus survival in deeper water. This is only a temporary measure however (Figure 12).
6. Of concern is the possibility that mud supply is inadequate or is not being spread as widely, as continued mud supply must be a factor in mitigating continued sea level rise (mud building on top of previously deposited mud can continue at a rate that matches the rate of sea level rise). Other factors, such as the distribution of mud now being channelled by dykes and canals or changes to the sea bed profile through localised dredging might contribute to the deficit of mud in places.
7. The conversion of mangrove habitat for aquaculture ponds continues despite the small area of mangrove present. Much clearing and cutting of mangrove is evident, including illegal cutting/clearing. For example, a long fish pond has been cut into the middle of the mangrove at Vam Rang illegally (Figure 13). Clearing of regrowth *Excoecaria* near Vam Ray is another example (Figure 14).
8. Large scale conversion continues, such as in the vicinity of Hon Queo where very large ponds have been recently dug (Figure 15) and very extensive continued conversion of upper intertidal mangrove vegetation of interesting floristic composition in the Giang Thanh system in Ha Tien.

Figure 8: Mangrove retraction between 2003 and 2007 at Hon Queo. Yellow line represents 2003 mangrove front. Note canals cut through forest between dates, plus further loss since 2007 (not shown) (Image: Google Earth).

Figure 9: Sea broken through the thin remaining mangrove fringe, threatening the small dyke enclosing aquaculture pond, An Bien.

Figure 10: Waves washing into the eroding front of *Avicennia alba* forest, Vam Ray.

Figure 11: Eroding front of mature mangrove with fallen *Sonneratia caseolaris*, Vinh Quang.

Figure 12: Mature *Rhizophora apiculata* surviving longer than *Avicennia alba* in erosion zone, Vam Ray. Picture taken within several metres of Figure 10.

Figure 13: Unauthorised fish pond dug within a relatively wide and well developed mangrove, Vam Rang.

Figure 14: Recent clearing of largely *Excoecaria agallocha* regrowth after previous clearing, presumably for pond development, Vam Rang. All the viewed area is mangrove habitat.

Figure 15: Recent development of large ponds in mangrove forest, with no retention of vegetated areas between ponds, Hon Queo. Remaining mangroves in distance.

5. Biomass and carbon content

5.1 Introduction

Some tree details and stand BA were given in Section 4.2, with fuller summary details in Appendix 2. Details of the biomass and carbon estimates of the vegetation are given in this section. Forty plots were calculated using tree allometric equations, while one plot (VQ3) is a *Nypa* only plot which has to be estimated differently. An outline of the basis of the analysis is given in Appendix 3.

The numbers reported are a snapshot view of the biomass of KG's mangroves at the time of the surveys and it is obviously subject to change with time. Increases in biomass through growth and/or colonisation are possible as are decreases through erosion, cutting or clearing. Originally, it was envisaged that an ongoing study would be set up to estimate the annual production of biomass (productivity). However, the placing of equipment such as litter traps proved problematic, particularly whether items of potential value (if only shade cloth) would be secure. Further survey work also was not possible despite training.

Key biomass and carbon information suitable to this early stage were gained with the work completed, although tracking the ongoing productivity (plus critical changes to mangrove area) would be useful. Some selected prior work on mangrove productivity is alluded to. Ultimately, this was a rapid survey.

Ecosystems have a below ground biomass (BGB) in living (roots) and dead material and estimates are provided from published equations. No sampling has been done in KG, as the sampling is not simple and laboratory facilities are required. It is root weight (RW) that is quantitatively estimated, rather than the total underground biomass of the system, including dead and buried material, which is higher.

5.2 Results of biomass and carbon analyses

Biomass estimates incorporate uncertainties in sampling and analysis, such as to how well a plot represents a wider vegetation type. This is especially important when exceptional results are found, such as the high biomass in the small HT4 plot. It is, however, judged that the vegetation is well represented (e.g. KL7 and KL8 are matched pair of plots and have virtually identical results). Caution is required in applying the equations (e.g. different authors may sample differently) and it is valuable to be conservative at each step to minimise over estimates and circumspect in quoting the figures.

Biomass and carbon content do not strictly follow BA (it depends on tree size versus their spacing). Table 4 gives biomass and carbon estimates for the plots, expanded to a tonnes dry weight (DW) ha^{-1} basis. The structural variability in KG's mangrove is shown in the range from a low AGB of 10 t DW ha^{-1} in riverine upper intertidal scrub vegetation in Ha Tien (Plot HT3) to a high AGB of 424 t DW ha^{-1} in a multi-stemmed *R. apiculata* plantation (Plot AB4). The author did not collect the data for the latter plot, so it is difficult to be certain but the high value may be a function of an unusual multi-stemmed form in big trees. Two plots have an AGB equivalent to c. 300 t DW ha^{-1}. HT4 (309.2 t DW ha^{-1}) is a plot with relatively large (20 – 29 cm dbh) and dense *A. alba* trees and VQ2 (318 t DW ha^{-1}) is in tall *S. caseolaris* forest. Biomass of the high value plots would be higher without cutting.

Table 4: Biomass and carbon estimates for mangrove plots in Kien Giang. See text for more details.

Plot	AGB (t DW ha^{-1})	RW (t DW ha^{--1})[1]	Total biomass (t DW ha^{-1})	Total carbon content (t ha^{-1})	Total CO_2 equivalent (t ha^{-1})[1]
AB1	24.4	11.9	36.3	17.8	65.3
AB2	96.1	38.4	134.5	65.9	241.9
AB3	69.1	32.5	101.6	49.8	182.7
AB4	424.9	10.2	435.1	213.2	782.4
AM1	135.6	4.4	140.0	68.6	251.8
AM2	187.1	73.4	260.5	127.6	468.5
AM3	154.7	5.5	160.2	78.5	288.1
AM4	74.5	4.0	78.5	38.5	141.2
AM5	56.2	18.5	74.7	36.6	134.3
HQ1	25.0	6.6	31.6	15.5	56.8
HQ2	89.1	17.5	106.6	52.2	191.7
HT1	136.6	50.9	187.5	91.9	337.2
HT2	15.8	4.6	20.4	10.0	36.7
HT3	10.4	1.9	12.3	6.0	22.1
HT4	309.2	131.4	440.6	215.9	792.3
KL1	127.8	36.1	163.9	80.3	294.7
KL2	37.3	8.7	46.0	22.5	82.7
KL3	45.6	4.1	49.7	24.4	89.4
KL4	195.1	16.9	212.0	103.9	381.2
KL5	51.2	17.3	68.5	33.6	123.2
KL6	20.4	10.1	30.5	14.9	54.8
KL7	99.8	11.1	110.9	54.3	199.4
KL8	99.2	12.4	111.6	54.7	200.7
VQ1	203.5	72.2	275.7	135.1	495.8
VQ2	318.0	108.9	426.9	209.2	767.7
VQ3[2]	1.4	ND	NA	1.1 (above ground only)	2.3 (above ground only)
VQ4	174.8	66.4	241.2	118.2	433.7
VR1	235.2	14.3	249.5	122.3	448.7
VR2	101.6	37.5	139.1	68.2	250.1
VR3	145.5	48.2	193.7	94.9	348.3
VR4	83.1	34.4	117.5	57.6	211.3
VRy1	48.2	11.0	56.3	27.6	101.2
VRy2	71.0	37.5	108.5	53.2	195.1
VRy3	205.2	13.9	219.1	107.4	394.0
VRy4	124.6	61.2	185.8	91.0	334.1
VRy5	191.7	51.5	243.2	119.2	437.3
VRy6	133.3	45.5	178.8	87.6	321.5
VRy7	84.6	36.9	121.5	59.5	218.5
VRy8	212.2	11.6	223.8	109.7	402.5
VRy9	88.5	45.9	134.4	65.9	241.7
VRy10	132.4	14.7	147.1	72.1	264.5
Sums	**4903.2**	**1240.0**	**6275.6**	**3075.0**	**11285.4**
Means	**125.9**	**31.0**	**156.9**	**76.9**	**282.4**

[1] *Nypa* not included in RW data, sums or mean carbon figures.

[2] *Nypa* only plot estimated differently to other plots.

The higher mangrove biomass values in KG compare reasonably well with published values (Saenger 2002; Komiyama *et al.* 2008; Alongi 2009). Some biomass values, however, are low, although this may be in keeping with the vegetation type. Some *A. alba* stands have low biomass because of their young frontal position. Overall, biomass is moderate.

AGB figures of more than 600 t DW ha^{-1} have been measured in mangrove forests, but they are generally between 150 t DW ha^{-1} and 350 t DW ha^{-1} in well developed tropical mangroves (Alongi 2009). The mean AGB for the plots in this study is 126 t DW ha^{-1} and the median is 100.7 t DW ha^{-1}, in comparison to a mean of 247 t DW ha^{-1} and a median of 193 t DW ha^{-1} in the literature compiled by Alongi (2009). Many published studies concentrate on tall forest and sampling of the range of vegetation in KG including young forest, some significantly cut forest and scrubby vegetation may have reduced the mean somewhat relative to the published figure. A number of points can be made:

1. There is significant standing mangrove biomass, and hence carbon storage where the vegetation remains, although cutting does affect it in many places. However, the areas concerned can be small, for example the fringe of high biomass *S. caseolaris* forest in Vinh Quang and this is not assessed in this part of the wider project. Historically, the area and carbon store would have been much greater.

2. The highest biomass plots illustrate the fact that for a given species the size of trees contributes most to high biomass, although spacing of trees (density) is also a factor. It follows that allowing trees to grow to maximal size is the way to maximise biomass, certainly for a given density of trees.

3. Wood density is a factor in biomass and carbon storage, with heavier timbered species being better stores for a similar size. This accounts in part for good biomass figures in *R. apiculata* plots, even though tree density may be relatively low. The tall *Sonneratia* plots have high biomass because of tree size and spacing, as wood density is less than half that of *R. apiculata*.

4. Some trees have re-sprouted with multiple stems after cutting, giving them a BA that exceeds the original stem. *Excoecaria agallocha* is easily the most significant case. For simplicity, stems are treated as separate (Appendix 3) and a few plots may have somewhat elevated biomass as a result (e.g. VRy5). This only applies to the cutting of small trees.

5. Trees below the size limit sampled for the allometric equations were included, as any error in biomass will be minor (something that would not apply if trees much larger than sampled were analysed) (Appendix 3). Virtually all trees in the scrubby vegetation in Ha Tien (Plot HT3) were strictly too small to use the allometric equations, but it is useful to illustrate the situation there.

6. Root weight as an estimate of BGB for species other than *R. apiculata* is based on a common allometric equation and is not as statistically strict a relationship as AGB. Komiyama *et al.* (2005) suggest it is for ‘academic’ purposes rather than strict management, but it remains useful to illustrate carbon storage potential below ground. For *Rhizophora apiculata* an equation of Dr V. N. Nam developed in Vietnam is used.

5.3 Discussion and implications of the biomass and carbon survey

5.3.1 Above ground biomass

There are a number of features and implications arising from the mangrove biomass (and hence carbon) investigation in the vegetation and some of these are given below:

1. The range of biomass values is to be expected, given the variety of settings present. Patterning can be fine in KG and short distances from one vegetation type to another can produce significant changes in biomass. Plots KL4 and KL5 are continuations of each other, but KL4 samples planted *R. apiculata* (AGB = 195.1 t DW ha^{-1}), whereas KL5 is relatively young and low biomass *A. alba* forest (AGB = 73.2 t DW ha^{-1}). The plots VR1 and VR2 are a similar situation.

   Plot HT2 is in open, low biomass forest on an apparent raised area (AGB = 15.8 t DW ha^{-1}) and is parallel to and about 20 m from HT1, which samples relatively tall mixed forest of moderate biomass (AGB = 136.7 t DW ha^{-1}). By contrast, KL7 and KL8 are very close and have effectively identical biomass (AGB = 99.8 versus 99.2 t DW ha^{-1}), as the vegetation is clearly consistent. It is clear that such variability is a feature in KG's mangrove forests, both naturally and due to significant human intervention and it follows that mapping must be appropriately fine grained to match.

2. The biomass varies in vegetation dominated by one species, which may appear similar in remote sensing. For example, frontal forests heavily dominated by *A. alba* range in AGB from 20.4 t DW ha^{-1} (Plot KL4) and 24.4 t DW ha^{-1} (Plot AB1) to 124.6 t DW ha^{-1} (Plot VRy4). AB1 is close in distance to AB2, but the latter *A. alba* forest has four times the biomass, as it is older. Maturity is a key factor in forest biomass, which accounts for the low biomass of young frontal *A. alba* forests.

3. In a normal progression on an open coast, biomass increases from the colonising frontal vegetation to a higher biomass and more species diverse 'mixed' forest inland. Parallel plots indicate this happening in places in KG where sufficient depth of mangrove remains. The colonising *A. alba* may still be present, but the trees are bigger and other species establish, increasing both diversity and biomass. A pattern of increasing biomass with distance from the shore (and hence maturity) is in keeping with the findings of Komiyama *et al.* (1988). Typically, soil carbon levels increase with maturity as well (Alongi 2009).

   For example, plot HQ1 is low biomass *A. alba* frontal forest (AGB = 25.0 t DW ha^{-1}), while plot HQ2 running parallel inland has greater biomass (AGB = 89.1 t DW ha^{-1}) from bigger trees, despite similar density. Likewise, the plot VRy5 (AGB = 191.7 t DW ha^{-1}) is inland of plot VRy4 (AGB = 124.6 t DW ha^{-1}). The latter has high biomass for an *A. alba* plot, which may be due to erosion bringing more mature vegetation to the front, but the gain with maturity can still be seen.

4. Some plots on eroding coasts contain an odd mix of species as a result of recent colonisation by lower intertidal mangrove species into upper mangrove fringe areas. Examples are plots AM2 (AGB = 187.1

t DW ha^{-1}) and AM5 (AGB = 56.2 t DW ha^{-1}). It is likely that the odd geomorphic setting and the emerging species mixes might produce ‘odd’ biomass results as well.

5. All this variability in the small mangrove areas of KG does militate somewhat against accurate expansion of biomass estimates across greater areas using remote sensing, despite this being necessary to estimate a standing budget for the Province.

6. Tall *S. caseolaris* forests to the north of Rach Gia have high biomass (cover picture), although the opportunities for great expansion may be limited. However, there are some younger planted stands that should continue significantly increase biomass, such as sampled in plots VR2, VR 3 and VR4. It is uncertain whether they can reach the biomass of the Vinh Quang stands as the water is not as brackish further away from Rach Gia.

   Sonneratia caseolaris has been planted in Vietnam and elsewhere for dyke protection and general reforestation and recorded growth rates are fast. Anecdotal statements that some tall *S. caseolaris* forests in KG were only about 20 years old could not be confirmed as planting records were not available, but clearly there is very rapid growth in good conditions in central KG. In Hai Phong City, Vietnam planted *S. caseolaris* of 8-9 years age had a mean diameter of 18.25 cm (maximum 28.6 cm) and a mean height of 8.62 metres (maximum 13.6 m) (Cat *et al.* 2006). In introduced plantings in China, *S. caseolaris* trees reached means of 13.4 m tall and 18.3 cm in diameter at 10 years (Chen *et al.* 2009). Litter fall in the Chinese plantings was 15.1 t DW ha^{-1} y^{-1}, showing that even young forests deliver significant amounts of biomass to the ecosystem.

7. Although large blocks of *R. apiculata* are not now found naturally on the KG coast, there has been good biomass gain in the planting programs dating to the early 1990s. The very high biomass of the plot AB4 (AGB = 424.9 t DW ha-^{1}) may be anomalous, but other stands unlikely to be older than 18 years are over 200 t DW ha^{-1}.The study of Tan (2002) in Ca Mau is particularly relevant and the results are comparable with this study. In fact, one plot (VRy8) was suggested to be 16 years old and its AGB of 212.2 t DW ha^{-1} is identical to Tan’s calculation at 16 years. Another plot (VRy1) was suggested to be 18 years old and has a slightly lower AGB of 205. 2 t DW ha^{-1}, but from a lower density of trees.

   The growth rates found by Tan (2002) are applicable to KG, as are biomass figures if the density is similar. Based on this and other work in the Mekong Delta (Clough *et al*. 1999 in Alongi 2002; Figure 4), good quality *R. apiculata* stands at 35 years of age will be expected have an AGB of about 325 t DW ha^{-1}.

8. The growth of *R. apiculata* is well studied in Asia, including in planted stands (e.g. Ong *et al.* 1995; Clough *et al.* 2000; Tan 2002; Komiyama *et al.* 2008; Alongi 2009). Some AGB figures are given in Table 5. The figures found for KG are within the range of relative low to moderate figures in Thailand to high figures in Malaysia.

Table 5: Some above ground biomass figures from *Rhizophora apiculata* stands of known age.

Place	**Age**	**AGB (t DW ha^{-1} y^{-1})**	**Source**
Ca Mau, Vietnam	5	41.9	Tan (2002)
Ca Mau, Vietnam	10	143.4	Tan (2002)
Ca Mau, Vietnam	15	202.8	Tan (2002)
Ca Mau, Vietnam	25	277.6	Tan (2002)
Ca Mau, Vietnam	35	326.9	Tan (2002)
Thailand	3	65.4	Alongi (2009)
Thailand	25	344	Alongi (2009)
Thailand	15	159.0	Christensen (1978)
Malaysia	5	106.4	Alongi (2009)
Malaysia	18	352	Alongi (2009)
Malaysia	85	576	Alongi (2009)
Malaysia	20	114	Ong *et al.* (1995)

9. Clough *et al.* (2000) estimated an annual net primary production of *R apiculata* in the Mekong Delta by litter fall of 9.41 t DW ha^{-1} y^{-1} in a 6 year old stand and 18.79 t DW ha^{-1} y^{-1} in a 36 year old stand, showing good mangrove productivity and significant carbon input to the ecosystem.

10. Biomass estimates for *Nypa* are preliminary, but they show that AGB is low in *Nypa* compared to woody species (a 6 m frond is approximately 1 kg DW). Even though many fronds are possible per area, the AGB of the *Nypa* only plot (VQ3) is low (Table 4). This reflects (Section 5.2), but if all fronds were intact the AGB of this stand would still be < 5 t DW ha^{-1}. Although left after harvesting, the swollen frond bases have little biomass, being c. 85% water by weight. Most mass is in the rachis (stem) of the frond. *Nypa* contributes little to AGB when scattered in the forest; in the forest plot with most *Nypa* (VR3) only 2% of the AGB is from the eight large *Nypa* clumps (all cut).

    The AGB figure underestimates *Nypa*'s contribution as it excludes the large below ground biomass from a branching rhizome (Appendix 4) and to a lesser extent the fruit. Figures are unavailable, but it is still likely that *Nypa* is not the best contributor to carbon storage (see Section 5.4).

11. Blocks of *R. apiculata* planted for a purpose other than carbon storage are now significant carbon stores that will continue to increase for some decades. The same applies to now tall *S. caseolaris* and to a lesser degree to planted *A. alba* of lower biomass. The plantings of *A. alba* would be expected to commence a more natural progression in the mangrove vegetation and thus generate greater biodiversity than the plantings of *R. apiculata.*

12. Much, if not nearly all, of the mangrove in KG is at a relatively young stage of development, even where current cutting is not intense. Factors such as past or ongoing cutting, regrowth after storm damage or the relatively recent colonisation of fresh mud may be influences. Changes in hydrology brought about by the construction of dykes and canals may have altered the distribution of mud.

Regardless of the reasons, with time and protection the mangrove forests will gain biomass and carbon storage. The largest trees seen of some species are shown in Table 3, showing the potential other trees may reach with significant increases in carbon sequestration in some cases.

13. Mangrove forests have a disproportionately high share of global carbon cycling (Alongi 2009) and Komiyama *et al.* (2008) conclude that mangrove forests are 'highly efficient' carbon sinks in the tropics, on the basis of high primary productivity and low soil respiration. The higher biomass forests at least in KG must accord with that, given reasonable information on soil carbon.

5.3.2 Below ground biomass

The underground carbon store in KG's mangrove vegetation must be significant, as living and recently dead root biomass and buried material. Mangrove carbon dynamics in the sediment and in tidal waters is complex (Kristensen *et al.* 2008; Alongi 2009) and published values of BGB vary between species and sites (Komiyama *et al.* 2008; Alongi 2009), but some statements can be made:

1. The estimates in Table 4 are indicative, but they serve to illustrate the sort of range and quantities expected. The range arises because of the size and density of the trees, but also the different species present in the plots sampled. Generally, high BGB usually accompanies high AGB and maturity in forests enhances BGB along with AGB. However, a high below ground carbon store can persist with any progression to lower biomass upper intertidal forests.

2. In general, young forests on fresh mud will have relatively low BGB, due to the small trees and the lack of build up of soil carbon. The short upper intertidal forests, such as at Ha Tien, have low amounts of living BGB, but often have built a considerable carbon store in their history of growth and sedimentation (Figure 16). Tall dense forests develop a high BGB, through the rapid growth and turnover of root material and burial.

3. With time, carbon is buried in the sedimentary environment of a mangrove forest; Alongi (2009) suggests that 10% of global mangrove net primary productivity is buried. The rate of breakdown can be low in waterlogged mangrove sediments, accounting for the building of often high carbon content separate from the present root systems. Much of the carbon store is persistent in the soil.

4. Observation shows there are some organic rich soils in the mangroves of KG. Examples include fibrous dark soils in tall *S. caseolaris* forest and peat lenses derived from partially degraded large roots seen in dug sediments at Vam Ray. Recently dug soils for aquaculture in Ha Tien show considerable amounts of coarse woody material, along with a humic character (Figure 16).

5. The overall mean root weight is about 25% of mean AGB. Although comparisons can be difficult because of differing definitions and methodologies, this is greater than the mean of 19% in the studies analysed by Alongi (2009), but less than suggested by Komiyama *et al.* (2008). The 25% figure of BGB to AGB is probably a good conservative starting point in general discussions about the carbon status of the mangrove forest in KG, notwithstanding the variability that will be present.

Figure 16: Sediment dug and exposed during construction of aquaculture ponds, showing coarse organic content and now-bleached humic character, Ha Tien.

5.4 Protection and cutting

Self evidently, the valuation of vegetation for its carbon content needs that it be retained. This also applies to other inherent values such as shoreline protection. However, as noted in Section 4.3, the remaining mangroves of KG are not secure from coastal erosion, conversion to aquaculture and timber cutting. Large scale conversion to aquaculture and coastal erosion are the largest influences as they result in the removal of the vegetation. Erosion is not deliberate, but it does come down to a choice between aquaculture and mangrove biomass (even though a few mangrove trees sometimes fringe fish ponds).

There is tree cutting throughout the mangrove forests, with varying influence on biomass and possibly species composition. Some observations include:

1. Only one plot had no cut stumps (Appendix 2) indicating the scale of cutting. Most is of small trees for local use. Small scale cutting gives mangrove forests an additional direct value, but too much cutting can reduce standing biomass. The impact depends on the scale of cutting (the number and/or size of trees) and the species cut. The average diameter at the top of the stump was 6.85 cm, although this includes a number of large trees and most stems cut are smaller than this.
2. The biomass reduction in a number of plots is minor as only a few small trees are taken, but major reduction in standing biomass when big trees have been removed is present. Although the removal of small trees may enhance the growth of those remaining in young forests, the removal of big trees

diminishes biomass for a long time due to their contribution to biomass. The small compensation of a localised increase in light and reduced root competition does not compensate for the loss.

To illustrate, the removal of large *S. caseolaris* trees can be seen in standing biomass figures. Plot VQ4 has several large stumps present and a biomass of 174.5 t DW ha^{-1}, but the nearby VQ2 with only smaller stumps has an AGB of 318.2 t DW ha^{-1}. Adding an estimate from the stump diameter in VQ4 gives 319.0 t DW ha^{-1}, virtually identical to VQ2 and an apparent reduction of 46%. A similar calculation in the plot VR4 suggests a reduction of c. 42% over what would have been standing. The coppicing of large *S. caseolaris* (Figures 6) has biomass implications, although less than felling at ground level. A single *R. apiculata* 18 cm in diameter cut in the plot VR1 diminished the biomass by more than 15% such is the power of the removal of large trees to affect stand biomass.

3. Comprehensive and repeated cutting even of small to moderate size trees affects stand biomass, if enough. Open patches and low thickets of species such as *Acanthus* and *Acrostichum* are present in places as artefacts of cutting (Figure 18 and can be seen as tree-less areas in Figure 20). There is considerable lost biomass potential within these areas. A plot (VRy1) with low thicket patches returned an AGB of 48.2 t DW ha^{-1}, with one large tree pushing the figure up. The plots VRy6 (AGB = 133.3 t DW ha^{-1}) and VRy7 (AGB = 94.6 t DW ha^{-1}) are only about 850 metres from VRy1, but have not experienced the same tree removal. In fact, VRy1's setting suggests it should have greater AGB than the other plots. Forests with such a cutting history probably have at least 50% lower AGB over a reasonable spatial scale than they would have if intact.

   Overall estimation of the biomass foregone within the forests in total by cutting is difficult, but the remote sensing may detect features such as low thickets and reduced canopy cover to gain a good indication in concert with the biomass figures.

4. Some species can resprout. *Nypa* is a special case (below), but *E. agallocha* is a small tree that coppices strongly with multiple stems and ultimately cutting may not diminish biomass. *Avicennia* and *Sonneratia* spp. may coppice, but sometimes do not do so when small. A larger problem occurs with *Rhizophora*, *Ceriops* and *Bruguiera*, as cutting them above a small size is fatal (Figure 19). At least one branch must be left for plants to survive which typically does not happen. The higher wood density in the Rhizophoraceae than in other mangrove species accentuates the biomass consequences. Stumps of the Rhizophoraceae were widely seen and there may be some selection against them in places. Limited thinning of planted *Rhizophora* when small should not affect ultimate stand biomass, due to the reduction of competition in a monoculture.

5. *Nypa* is cut because of the value of its fronds for thatching and most of the large *Nypa* seen in KG have been cut and usually repeatedly so (Figure 5). This includes relatively large managed stands in Ha Tien. *Nypa*'s clumping manner from the large rhizome means the harvest of fronds does not kill the overall plant. As discussed in Section 5.3.1, foregone AGB with *Nypa* cutting is there, but relatively low when balanced against the utility of the product.

Figure 17: Large *Sonneratia caseolaris* stump, Vinh Quang. This site is eroding.

Figure 18: *Acrostichum* and *Clerodendrum* thicket and scattered trees, Plot VRy1, Vam Ray. This should all be forest. The very dense thicket can suppress tree regeneration.

Figure 19: Stump of mature *Rhizophora apiculata* within mixed forest, An Bien. Cutting trees of this relative size noticeably affects standing biomass.

5.5 Regeneration and restoration

Although the biomass study has shown there is considerable carbon storage in remaining KG mangrove forests, the total is not great in comparison to some other forest blocks. There is also clear reduction in biomass through human agency within the remaining mangrove area, by conversion to aquaculture ponds and cutting. The current area of mangrove is also shrinking. Although any total figures on current and potential storage rely on the remote sensing task, the general conclusions should stand.

Given the value of mangroves and the possibility of financial support for carbon storage, it follows that enhancing the area and biomass of the mangrove area is desirable. Expanding the mangrove area seaward has been recognised in KG and elsewhere in Vietnam, including investigations in erosion zones in KG. Although often for shoreline protection, there is inevitably biomass benefit. There has been less recognition of the potential to enhance mangrove biomass within the existing mangrove area. It is beyond the scope of this report to discuss in much detail policy initiatives or dyke protection mangrove planting programs (both of which are in flux), but some observations are useful:

1. The mangrove area is much reduced in KG to the point of mostly being a narrow fringe. This is well recognised, with most of the discussion on reinstating a wider mangrove barrier pertaining to seaward extension of the mangrove front. This is desirable in KG, despite problems in establishing mangroves on open coasts. A context is the recent Prime Ministerial decision (667) on coastal dyke strengthening that includes a desirable target of 500 m mangrove width, recognising the role played in attenuating wave action. Sea walls now effectively set the landward mangrove limit over most of KG, something

that is likely to become more pertinent with continued erosion and sea level rise. If their position is fixed, seaward extension is the only option in increasing the gross mangrove area.

2. Sea front mangrove plantings often do not thrive and many plantings have failed in Asia (e.g. Erftemeijer & Lewis 1999; Primavera & Esteban 2008). Sea front plantings undertaken in KG have only been partially successful, costing lost money and time. There are numerous reasons for failure, but planting into too deep water is a common cause. This is of particular concern on eroding sections of the KG coast, where water may be too deep even at the front of existing forests. Sediment trapping/wave breaking structures may be needed and although these are being discussed and trialled in KG, they are unproven on a broad scale and inevitably expensive. Stabilising the front of eroding, but functional mangrove forests (e.g. Figures 9 – 12) might need only wave-breaking structures, but extension of the forest may need structures that actively trap sediment.

3. Mangrove fronts can be somewhat deceptive. In many discussions, the mangrove front is divided into two categories: ‘eroding’ and ‘accreting’. ‘Accretion’ areas seem to be judged from whether a muddy drape can be seen in front of the mangrove. However, mud is typical outside the mangrove and it is possible that places with mud in front of the mangrove are not actively accreting. The muddy area may be stable or even has suffered a measure of erosion (i.e. it has been scoured or is narrower and steeper than it would be). Mud flats too have a distinct ecology that is lost with trees, including as habitat for migratory wading birds which can be seen on the KG coast.

   Success in mangrove planting should not be assumed if mud is present outside the mangrove. In fact, planting often fails even on accreting mudflats (Erftemeijer & Lewis 1999), although sometimes this is due to non-water depth reasons such as insect attack. Suitable conditions are likely to foster natural regeneration eventually, but it is sometimes possible to plant mangrove seedlings at slightly greater mean water depth than in nature, as has been done in KG. Establishment and early growth are the most sensitive stages and planting may assist in passing through these stages, but there are limits.

   It remains unlikely that generating a 200 metre extension to the front of the existing mangrove (as discussed in KG) is possible, on what is mostly a non-accreting coast with rising sea level. Achieving the desired 500 metres outside the dykes in their existing position seems highly unlikely, with only minor exceptions of areas in Kien Luong and Ha Tien where the dyke travels inland around large hills.

4. It is important to note that colonising mangrove seedlings basically need two things: tidal water that is not too deep for too long on relatively consolidated sediment and a relative lack of water movement, which varies between species. *Rhizophora* plantings may fail in open water relative to *Avicennia* or *Sonneratia* because the seedlings do not bend with the waves as do other two species. There is a partially successful *Rhizophora* planting at the front of the mangrove in Kien Luong where wave energy is low. Seedlings near the existing mangrove are surviving best, with mortality increasing greatly with water depth to apparently close to 100%.

5. The net treed mangrove area in KG is smaller than the gross mangrove habitat due to aquaculture and to a lesser extent to unforested and largely unproductive ‘wasteland’ thickets (e.g. Figure 20 is a bad example). The best way to build biomass is within the existing mangrove. This is not discussed as much as seaward extension, but there are advantages. Firstly, protection where plants are already established will rapidly add to biomass and carbon stored, as productivity is high. This is particularly so as the forests are relatively young in most places. Secondly, plant establishment in non-forest areas is easier within the existing mangrove both in planting and in natural regeneration.
6. This may be an adjunct to attempts on the sea front, notwithstanding there are greater ownership questions arising. As carbon gain is likely more reliable and faster than outside the mangrove, it follows that this is a better way of increasing the carbon value of the forest.
7. Most restoration proposals focus on planting, although this is not always necessary. As noted, there is a biomass deficit from cutting and restoration in places will occur naturally with protection. Also, there is great potential in natural regeneration in areas not currently forested if tidal conditions are enhanced. This includes existing and former aquaculture ponds and degraded land. Regeneration is not limiting as evidenced by the number of seedlings and saplings (Figure 21). Mangroves establish and grow rapidly in good conditions and it is clear that this is the case in KG.
8. It is apparent that the occurrence and rate of natural regeneration in former ponds is good where suitable conditions exist. This is shown in Figure 22, where a breach of a wall immediately south of Hon Queo canal has reintroduced tidal flow, resulting in natural mangrove regeneration. The intervening period of a maximum of about 39 months has resulted in regeneration sufficiently large to be visible by remote sensing.

   Figure 23 shows young natural regrowth of *A. alba* at Vam Ray, in a abandoned aquaculture pond. Tidal flow is sufficient to instigate regeneration, which is rapid. Such regeneration is relatively low in biomass, similar to *A. alba* forest at the front of the mangrove, but will build over time. The advantages in natural regeneration are that it is low in resources compared to planting and that natural biodiversity is generated. The disadvantage compared to planting is that in good sites plantation growth is often faster.
9. It is recommended that the potential for assisted natural regeneration be investigated in activities aimed at enhancing mangrove growth within the existing area. In some cases, reinstituting tidal flow through dykes or bunds may be needed, but this is relatively easy. Thickets of *Acanthus*, *Acrostichum* etc may be suppressing regeneration where there is
10. *Rhizophora apiculata* has been the species of choice for plantings within the mangrove area. Planting within the existing mangrove, including in ponds, has been more successful than sea front plantings and *Rhizophora* plantings generate fast biomass, as a result of fast growth rates and dense timber. However, the plantings may have lower biodiversity than natural forests.

Figure 20: Degraded mangrove with unused aquaculture ponds, Kien Luong. Note a lack of tree cover and the eroding front of the mangrove. Erosion appears apparent even where mud extents out to sea (left of picture) (Image: Google Earth). The thickets in the non-treed areas may be suppressing regeneration.

Figure 21: *Sonneratia caseolaris* seedlings, Vam Ray. Regeneration is present throughout the mangrove.

Figure 22: Natural regeneration following reintroduction of tidal regime to ponds, Hon Queo (Image: Google Earth).

Figure 23: Young natural regeneration of *Avicennia alba* in former pond, Vam Ray

6. Summary and prospects

Considerable information on the mangrove vegetation of KG and its biomass has been gained, which is significant on a coast where little was known of the mangroves. There are notable mangrove biodiversity and biomass values remaining, albeit in a much reduced area. Many of the values have been outlined in the sections above, with more detailed biodiversity work being done by Dr Norm Duke. Erosion, clearing and cutting are addressed because of the impact on present and future biomass, even though a fuller erosion assessment is being done.

A central task was to assess carbon stores as a step towards gauging the feasibility of valuing KG's mangrove forests under the REDD scheme. This has been done, with both positive and negative conclusions. Firstly, some of the mangrove area supports good biomass forest, with a prospect nearly everywhere of further biomass and thus carbon gain with time and protection. Although not directly assessed so far, it is fair to conclude that primary productivity (the generation of biomass) is high in keeping with the tropical location and that soil stores of carbon would be considerable.

The negative aspects relate to the small area and the lack of security for the remaining mangrove, as these are so important to the amount of carbon stored now and in the future (the potentially tradable asset). The mangrove vegetation is mostly a thin strip, with long edges subject to natural and human pressure. Coastal erosion, the conversion of mangroves to aquaculture and the cutting of sizeable trees continue, with implications for the carbon store. They, and other 'edge' factors, such as cyclonic storms impacting the sea fringe, are magnified in a long and narrow strip. There is also a question over the variability of the vegetation over small distances, which is partly inherent to the sea fringe mangrove that making up much of what remains and partly due to human agency, making expanded biomass calculations more difficult.

The gross remaining mangrove area clearly has a much lower biomass than it might, due to the area of aquaculture ponds, 'waste' areas and heavily cut forests. The mangrove is too narrow nearly everywhere to meet biomass, protection and policy goals. Further, it is often shrinking. Reinstatement and restoration of forests for any reason enhances the value of the vegetation for other purposes, too. Shoreline protection and carbon storage, for example, go hand in hand.

The reduced area and lowered biomass within some of the gross mangrove area are problems for carbon valuation, but also reasons to do seek funding. Steps to secure the existing mangrove vegetation and to expand its gross area and biomass follow from both the need to address mangrove loss and the evident potential to increase biomass. However, revaluing of the ecosystem services provided versus conversion is needed in policy decisions at various levels - erosion and storms are not intentional, but it is a question of choice between aquaculture and mangrove retention.

Further assessment might be made if the biomass figures are expanded spatially via remote sensing, but it seems unlikely that the small and insecure carbon store in KG could generate UN-REDD funding directly, even if single small project funding is possible. However, the UN-REDD country programme for Vietnam is in a planning stage and avenues for small and fragmented mangrove areas within the whole-country approach may be possible. The planted *Rhizophora* blocks are relatively easy to account for, as the area is clear by remote sensing and the growth rates and biomass are simpler and better known than in a more complex natural forest. However, valuing natural forests as well is desirable if it leads to protection and restoration, even though more difficult technically. The biomass figures and observations in this report are a starting point.

Approaches that recognise the future carbon storage and climate change mitigation value of restoring forest biomass will be the most effective in KG (including so-called REDD+ mechanisms). It is advisable to note many of the problems to overcome and possibilities available on a local level outlined in this study. Other carbon-based funding opportunities may be available, but again are best likely to be stated in terms of enhancing mangrove biomass as well as protecting what remains. The issue of protection decades into the future needs to be addressed to gain security for the carbon. The cutting shown in Figure 6, for example, shows how immediate the impact on standing biomass can be. The small area, in the vegetation, complicated tenure situation and great pressure suggest a fine grained approach at the Forest Protection Management Board level is probably required.

Much more could be said on the needs for restoration and regeneration planning, but a full treatment is outside the scope of this report. However, a number of points towards the end of mangrove restoration and biomass increase have been made in general terms as they pertain to protecting and increasing the biomass. Mangrove biomass increase is easier and most certain within the existing mangrove area rather than to seaward, ignoring ownership and competing land use factors. Facilitated natural regeneration as a cost-effective measure is easier within the existing mangrove area, by reinstituting tidal flow or removal of thickets suppressing regeneration. It can be observed in KG, albeit with lower biomass gain than plantings.

However, the possibility of total or partial failure of ocean mangrove plantings does not negate the need to attempt to extend stable mangrove vegetation to protect dykes and to generate biomass benefits. However, careful planning, which may include the erosion data and site-specific water depth surveys in places, is advised before embarking on planting. Trials are being done in KG by GTZ and DARD towards establishing mangroves on the eroding coast using built structures. It is worth remembering the basic needs for mangrove seedlings; sediment trapping is likely needed as well as wave breaking where the water is now deep.

Appendix 1: Rapid survey assessment methodology

1. Introduction

The task was to relatively rapidly determine some key biodiversity and biomass characteristics of mangrove stands, including species composition, tree density, tree height and diameter and the cover of the canopy. The basic unit is a plot of sampled trees, although it is desirable to record other information, such other mangrove species in the stand of mangroves, whether the coast is eroding or accreting and tree cutting. A data sheet is attached.

There is always a need to trade the amount of information gathered against the time it takes both in the field and later in compiling and analysing the data. Hence, this approach takes some minor short cuts over what may be possible in setting up permanent plots, although the basic methodologies for measuring diversity and biomass may be similar. There are numerous ways to achieve similar ends and other approaches (e.g. plot design) or measurement techniques can achieve the same end, if the sampling is sufficient and consistent enough.

Components can be left out or adapted (i.e. plot width) if needed. One issue is the minimum size of trees to sample. In most situations, very small (thin) trees and saplings add only small amounts to the stand biomass, depending on the size and density of bigger trees. Many biomass studies do not sample trees below a diameter of 5 or 10 cm, which is too low for many mangrove forests. The minimum diameter might be set by the published or calculated allometric equation(s) used. For Kien Giang, a minimum of 2 cm is preferred.

Typically, sampling of ground cover of seedlings, small species or pneumatophores is not done in a rapid survey approach, may be in fuller treatments. The methodology outlined here estimates of seedling density, which have to be converted to biomass by calculation. This component is of low importance, because the biomass involved is not great.

2. Plot location and establishment

2.1 Introduction

The intention was to sample the variety of vegetation present in an area and ultimately across Kien Giang Province. In a rapid approach, sampling cannot be completely random, so pre-sampling information to identify the range of vegetation present is desirable, followed by sampling a representative sample or samples within those categories in a ‘stratified’ approach.

Selection of the sample localities (including GPS coordinates) should be done prior to heading to the field from aerial photography (available from ‘Google Earth’ if no other imagery is available),

In Kien Giang province, the main mangrove areas are narrow, so one plot may be enough, but if the mangrove area is relatively wide and the vegetation changes away from the water, then one or more extra plots should be done to sample the range of vegetation. For example, there may be one plot at plot 30 metres from the sea in an *Avicennia* forest and another one parallel to it 80 metres from the sea in a more mixed vegetation with increased species diversity at the rear.

The basic unit of measurement is a 2.5 metre wide plot laid out approximately parallel to the shoreline (Figure 1). The aim is to sample around 30 trees of greater than 1.3 metre height within the plot, meaning the plot length will vary depending on the density of the trees. Where there are many dense trees, the plots will be shorter in length than when the trees are scattered. Such a method is generally faster than laying out a plot of a fixed size, as the plot is effectively laid out as the work progresses.

2.2 Locating and setting out a plot

1. Select plot location by relatively randomly selecting a starting point within the broad vegetation area selected. In most of the frontal forests of Kien Giang a distance of approximately 30 metres from the sea edge is often good.
2. Record a plot name that makes sense, along with the locality, brief description of the site (current width of mangrove, height, tree species, condition etc) in the 'Site' box on the data sheet. Permanent marks can be left to mark the plot if needed.

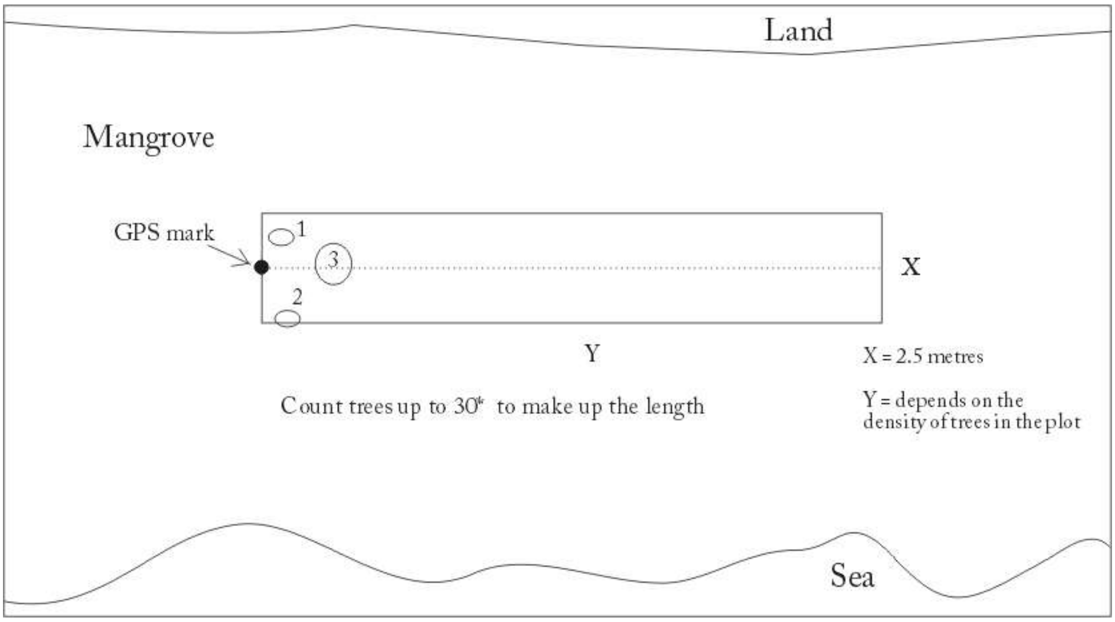

Figure A1: Basic plot layout

3. Take a GPS reading at the end of the plot, noting which end of the plot it is. Record the locality in digital degrees using the WGS84 datum on the data sheet. Also record the 'Mark' number from the GPS on the data sheet. ***Recording the locality accurately is vital***.
4. Lay out a measuring tape parallel to the sea shore. Initially, a distance of 25 – 30 metres is usual, and more tape can be laid out if the plot exceeds this distance.

5. Use a 2.5m pole laid perpendicular from the tape to indicate the width of the plot. The pole is moved along the tape as you progress from tree to tree.
6. Measure the girth, height and species of trees taller than 1.3 metres within the plot, moving along the tape progressively (i.e. trees 1, 2, 3 etc in Figure 1). Data are recorded on the data sheet until about 30 trees have been recorded, finishing on an even metre[5]. Notes on measurement are given in Section 3 (below).
7. After measuring all trees, record the length of the plot measured on the tape on the data sheet. Include all trees within the last metre of tape, even if makes the total more than 30. ***It is very important to record the tape distance to allow calculation of the plot area.***
8. If a tree overlaps the edge of a plot, it is included ONLY if more than half of its trunk is in the plot area (i.e. measure the distance to the centre of the trunk). If some stems of a multi-stemmed tree are in the plot and some outside it, then only include the stems within the plot area.
9. Where trees have multiple stems, record each stem separately, using the same line on the data with a line between the readings for girth and height (e.g. 12.5/4.5/10.3). Note the number of stems in the comments. Record the heights of all stems if they differ, or just one if they are the same.
10. *Nypa* (Dừa nước) is difficult to measure in the same way as trees and should be recorded separately in the *Nypa* recording box on the data sheet. Each clump of *Nypa* within the plot should be measured for the number and heights of living leaves (if fully extended) and the number of dead bases and whether they have been cut.
11. Estimate the canopy cover above the plot, using a canopy densitometer or other method. This includes all leaves and branches covering the sky in a vertical projection. A canopy densitometer is likely the easiest and cheapest field method.
12. Record the species and stem diameter of the top of the stump of cut trees in the plot in the 'cut stump' section of the data sheet.
13. Collect and dry specimens of any trees not known, with a code to record them on the sheet. Photographs are needed as well.
14. Take photographs along the plot tape both ways and other photos of the forest and take notes about the forest and any other plant species seen in the area.
15. Data are later entered to an electronic version of the data sheet for calculation.

2.3 Seedling, small shrub recording

At the beginning and the end of the transect and at 5 metre intervals, record the species, number and

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[5] Measuring 30 trees is arbitrary, seeking a balance between information and time taken in a rapid survey. More can be done. Where trees are all of a similar size, such as *Rhizophora* plantations, fewer trees may suffice.

approximate height of seedlings in a 1m x 1m square, along with the number and approximate height of *Acanthus* (Ô rô) and mangrove ferns (Ráng). Each stem of *Acanthus* and any tree seedlings are to be counted separately, but the whole clump only of mangrove fern is counted along with its height. There are enough 'boxes' for 10 samples on the data sheet, but add more below if needed.

3. Measurement techniques

3.1 Tree height

Tree height should be determined with as much accuracy as feasible (not just in whole metres, but in fractions such as 5.5 m). Up to 4 – 5 metres, a height pole is the best method (taller poles are available). Trigonometric methods or a dedicated height meter are best for taller trees, but can be estimated as closely as possible if no measuring equipment is available.

The 'height' of leaning trees should be measured along the trunk, or for taller trees with a lean >10% the lean recorded and used to adjust trigonometric height calculations if this approach is being used. Good height data is especially important for biomass calculations for species without specific allometric equations.

3.2 Tree girth/diameter

Trunk diameter is used in biomass calculations, but girth is often easier to measure in the field using a small tape measure. Trees are measured at 1.3 m above the ground[6], unless the trunk is misshapen at that point or a branch emerges. In those cases, the trees are measured at the point immediately above the obstruction. For *Rhizophora*, measure above the highest prop root, except where an isolated prop root is formed well above the main group of roots, in which case measure immediately above the main prop roots. It is important to be consistent in the height of measurement on the trunk.

3.3 Canopy cover

Estimating the canopy cover may assist with remote sensing applications and ongoing productivity although is not directly applicable to biomass calculations used in this project. There are numerous ways to estimate the Leaf Area Index (LAI) of a canopy, but most use specialist equipment, such as a LAI meter or hemispherical camera plus software. A light meter can also be used to determine relative illumination on a sunny day.

In this rapid project, an estimation of the canopy cover was made by a canopy densitometer. The simplest design can be made from piece of approximately 2.5 cm diameter duct pipe of about 30 cm length with cross hairs added at one or preferably both ends using fine wire threaded evenly across the diameter of the tube (Figure 2). More elaborate and easy to use designs are available for purchase or construction.

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[6] Many studies use the conventional 'Diameter at breast height' (DBH) at 1.3m, although it is convention rather than essential. In this case, applicable allometric equations use this height and it is important to be consistent.

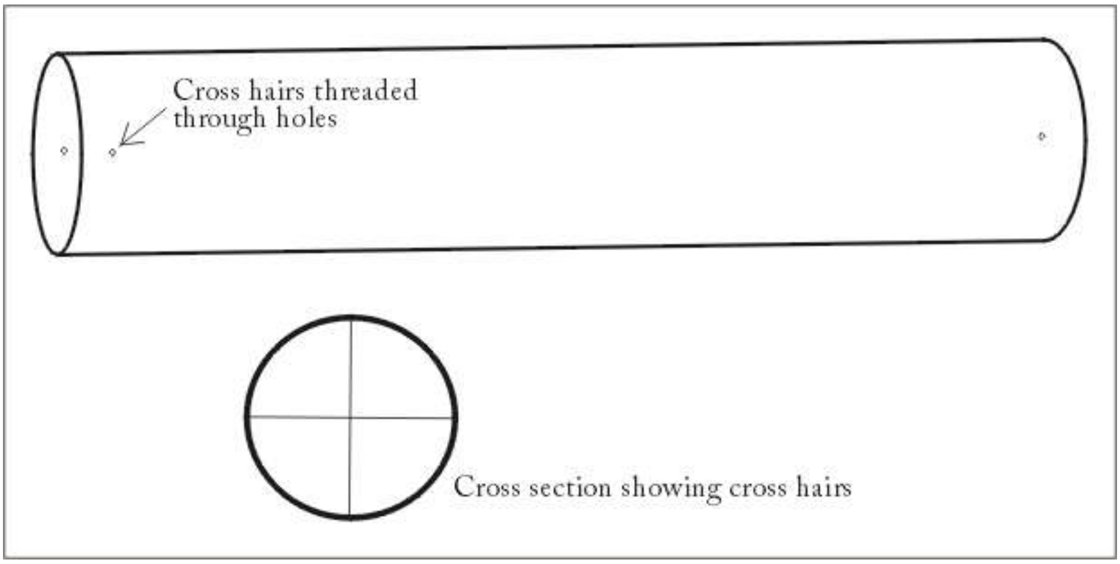

Figure A2: Schematic diagram of canopy densitometer

The densitometer is held vertically and whether the cross hairs are exactly on a leaf, branch (including tree trunk) or sky is recorded. Readings are taken every 50 – 100 cm along the length of the transect for about 50 readings. This number should give a reasonably good estimate for a rapid survey, but more readings increase accuracy.

Readings should be only be taken within the vegetation type of the transect, but can extend beyond it. The technique requires some practice to hold the tube vertically and to focus on the small point of the cross hairs, but is otherwise quick and simple. Windy conditions require extra effort to wait until a fixed point is available. Figures can be simply converted to % cover.

4. Basic equipment list

- GPS
- digital camera
- Data sheets, pencils, indelible marker etc
- Durable tags or tape if the plot location is to be marked
- Tape measure (30-50m)
- 2.5 metre pole for determining plot width (duct pipe of 2 – 2.5 cm diameter in two sections of 1.25 metres with a join on one end is easy)
- Tape for measuring tree diameter or girth
- Equipment such as canopy densitometer for estimating canopy cover
- Clinometers, hypsometer or other height measuring equipment (ideally)
- Compass (optional, helps determine alignment of plot)
- Plastic bags for plant specimens

Date:	Site:
Collectors:	Plot number:
GPS (WGS84):	Linear length of 2 metre wide plot:

Tree height and girth

Tree No.	Species code	Girth (cm) (not *Nypa*)	Height (m)	Comments (such as tree health, cutting of particular species etc)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

***Nypa* recording**

Height	Number of fresh fronds	Number of cut or died back bases	Total

Cut stump count

Species	Diameter at top of cut (cm)	Species	Diameter at top of cut (cm)	Species	Diameter at top of cut (cm)	Species	Diameter at top of cut (cm)

Tree and Shrub seedling counts and height (for *Acrostichum* record the number only; include *Acanthus* as a 'seedling')

Seedling species	Height (cm)	Seedling species	Height (cm)	Seedling species	Height (cm)	Seedling No.	Height (cm)	Seedling species	Height (cm)

Canopy transect (% vertical cover)

Category	Count along transect	Total
Leaves		
Branches		
Sky		

Comments (Other mangrove species observed within the general area of the mangrove stands and other observations, such as proximity to villages, plantations of mangroves etc.)

Appendix 2: Summary plot data

Plot Number	Latitude	Longitude	Species code	Number of individuals (genets)	Total	Number of stems (ramets)	Area of plot (m^2)	Density of individuals (genets m^{-2})	Density of all stems (ramets m^{-2})	Cut stump spp.	Cut stump No.	Cut stump mean diameter (cm)	Total density (ramets plus cut stems m^{-2})	Canopy leaf cover (%)	Mean height (m)	Mean diameter (cm)	Quadratic mean diameter of plot (cm)
AB1	9.84694	104.94062	AA	22	22	28	55.0	0.40	0.51	AA	3	8.33	0.56	68.80	4.86	3.10	4.10
AB2	9.84655	104.94128	AA	21													
			A sp.	1						AA	11						
			BS	1						BS	2						
			RA	8	31	33	57.5	0.54	0.57	RA	2	4.50	0.87	68.60	4.83	4.70	6.40
AB3	9.87088	104.97385	AA	25													
			LR	1													
			RA	2													
			SC	1	29	33	60.0	0.48	0.55	AA	6	4.08	0.65	76.00	5.78	5.34	6.40
AB4	9.85402	104.96217	RA	16	16	38	72.0	0.22	0.53	RA	9	2.60	0.65	81.40	10.30	10.06	10.40
AM1	9.74711	104.87122	RA	11	11	21	86.0	0.13	0.24	RA	25	1.64	0.53	65.00	8.00	6.34	6.70
AM2	9.53154	104.83546	AA	6													
			CZ	7													
			EA	17						AA	1						
			HT	1						CZ	3						
			Unknown	5	36	43	60.0	0.60	0.72	EA	3	12.29	0.83	62.71	10.54	6.64	
AM3	9.53408	104.83669	RA	13	13	22	44.0	0.30	0.50	RA	28	6.00	1.14	41.67	9.49	6.66	8.40
AM4	9.74716	104.87127	RA	6	6	8	40.0	0.15	0.20	RA	36	1.68	1.10	75.51	9.66	7.16	
AM5	9.77021	104.87538	AA	16													
			AM	4													
			B sp.	4						AA	2						
			EA	4						AM	1						
			RA	2						RA	3						
			TP	2	32	62	60.8	0.53	1.02	TP	2	6.70	1.15	73.00	3.60	3.00	6.20
HQ1	10.13116	104.85294	AA	14													
			AM	2						AA	3						
			BS	3						BS	2						
			EA	12						EA	3						
			RA	1	32	33	88.0	0.36	0.38	RA	1	7.80	0.48	80.00	3.80	3.43	7.50
HQ2	10.13137	104.85301	AA	4													
			AM	2													
			BC	3													
			BS	1						AA	2						3.90
			EA	9						AM	1						

HQ2	cont		RA	13						EA	4						
			XM	1	33	33	80.0	0.41	0.41	RA	1	4.60	0.51	82.00	3.80	3.70	
HT1	10.3284	104.52444	AA	11													
			CT	2													
			EA	15													4.10
			RA	2						AA	5						
			XG	2	32	50	52.5	0.61	0.95	EA	2	4.25	1.09	ND	4.97	4.53	
HT2	10.32861	104.52428	AA	8													
			B?S	1													
			EA	1													
			HT	1													
			LR	6													
			RA	15													6.20
			SO	1						AA	1						
			TP	1						RA	1						
			XM	2	36	40	125.0	0.29	0.32	TP	2	6.25	0.35	ND	3.60	3.02	
HT3	10.41126	104.4943	EA	7													
			HT	3													
			LL	1													6.00
			LR	6													
			RA	1													
			Senna sp.	1						EA	2						
			SH	5	24	72	100.0	0.24	0.72	L sp.	6	5.56	0.80	ND	2.09	2.38	
HT4	10.29279	104.54616	AA	9													
			BC	2													
			RA	5													
			SA	2	18	18	40.0	0.45	0.45	RA	3	2.50	0.53	ND	4.81	8.07	
KL1	10.19879	104.686	AA	1													
			AM	3						AA	1						3.90
			BC	6						BC	2						
			RA	15	25	27	95.0	0.26	0.28	RA	4	8.02	0.36	ND	7.69	8.27	
KL2	10.15653	104.65202	AA	2													
			AM	5													
			BC	1													
			SA	1						AA	3						
			TP	6	15	26	76.3	0.20	0.34	AM	1	4.25	0.39	ND	5.30	5.05	
KL3	10.1768	104.60205	CT	1													2.60
			EA	13													
			LR	5													
			RA	6	25	85	62.5	0.40	1.36	RA	1	4.00	1.38	ND	2.47	2.34	
KL4	10.24265	104.5867	AA	3													
			RA	18	21	23	67.5	0.31	0.34	RA	10	4.20	0.49	ND	8.17	7.80	12.00

KL5	10.24247	104.58677	AA	35	35	45	60.0	0.58	0.75	AA	1	6.50	0.77	ND	4.93	4.13	
KL6	10.21344	104.70622	AA	25													
			AM	6													
			RA	2						AA	5						
			SC	2	35	36	82.5	0.42	0.44	RA	2	3.86	0.52	ND	4.11	3.12	9.20
KL7	10.19689	104.59390	EA	5													
			LR	1													
			RA	14													
			SA	3	23	23	18.0	1.28	1.28	RA	5	6.40	1.56	ND	3.97	3.61	
KL8	10.19689	104.59390	EA	9													
			LR	1													5.80
			RA	14	24	24	12.0	2.00	2.00	RA	6	4,2	2.50	ND	3.94	3.28	
VQ1	10.03051	105.05767	AA	26													
			NF	1						AA	3						
			SC	6	33	38	170.0	0.19	0.22	SC	1	17.80	0.25	83.05	6.80	10.40	
VQ2	10.05141	105.03752	AA	23													2.90
			BG	2						AA	17						
			SC	6	31	37	90.0	0.34	0.41	SC	3	10.53	0.63	65.57	4.60	6.80	
VQ3	10.05176	105.03759	NF	22	22	::	110.0	0.20	::			::	::	::	::	::	9.00
VQ4	10.03846	105.04967	AA	18													
			NF	1						AA	3						5.50
			SC	12	31	35	130.0	0.24	0.27	SC	4	28.80	0.32	ND	7.20	10.30	
VR1	10.09772	104.95416	RA	8	8	9	60.0	0.13	0.15	RA	2	11.50	0.18	::	9.90	13.40	
VR2	10.09773	104.954375	AA	12													
			RA	3													
			SC	15	30	36	55.0	0.55	0.65	SC	3	18.10	0.64	72.50	6.60	5.60	4.20
VR3	10.09840	104.98798	SC	20						NF	c. 70						
			NF	8	28	30	125.0	0.22	0.24	SC	2	8.05	0.24	72.55	10.80	14.20	
VR4	10.09736	104.98298	SC	19	19	20	138.8	0.14	0.14	SC	10	14.46	0.22	ND	8.80	13.60	
VRy1	10.16960	104.82706	AA	22													
			AM	2													4.00
			BS	1						AA	2						
			SO	2	27	35	107.5	0.25	0.33	EA	1	5.33	0.35	58.06	4.90	5.10	
VRy2	10.16145	104.83316	AA	6													
			RA	20						AA	3						3.50
			RM	3	22	23	65.0	0.34	0.35	RA	1	5.88	0.35	61.54	3.80	4.59	
VRy3	10.21163	104.78127	RA	19													
			SC	1	20	20	109.0	0.18	0.18	RA	2	5.40	0.20	82.60	11.20	12.32	
			AA	28													15.00
VRy4	10.21078	104.78185	AM	1													
			RA	2	31	31	52.0	0.60	0.60	AA	4	1.38	0.67	69.40	6.40	6.80	

VRy5	10.21117	104.78215	AA	3													
			AM	2													13.20
			BC	1													
			EA	28													N/A
			SO	1	35	82	66.0	0.53	1.24	EA	6	4.00	1.33	78.00	7.40	6.70	
VRy6	10.17551	104.82266	AA	15													
			AM	16													
			EA	1													13.20
			RA	1	33	57	77.5	0.43	0.74	RA	1	2.00	0.75	74.50	4.70	5.30	
VRy7	10.17582	104.82266	AA	7													14.10
			AM	9													
			BC	1													
			EA	4													
			RA	5													
			XG	3	29	37	130.0	0.22	0.28	NONE	NONE	::	0.28	ND	5.56	6.28	7.40
VRy8	10.22457	104.721505	RA	23	23	23	48.0	0.48	0.48	RA	7	5.71	0.63	ND	10.37	7.45	
VRy9	10.22648	104.7274	AA	17						AA	7						
			AM	1	18	18	42.0	0.43	0.43	SO	1	6.20	0.57	ND	4.27	6.95	15.50
VRy10	10.22452	104.750659	AA	3													
			AM	2													14.00
			EA	5						?LA	1						
			RA	26	36	36	30.0	1.20	1.20	RA	1	3.40	1.27	ND	4.47	4.36	
				Means/ totals:	**911**	**1219**	**2772.8**	**0.43**	**0.57**		**302**	**6.96**	**0.70**	**71.07**	**6.22**	**6.42**	

Code	**Locality**
AB	An Bien
AM	An Minh
HT	Ha Tien
HQ	Hon Queo
KL	Kien Luong
VQ	Vinh Quang
VR	Vam Rang
VRy	Vam Ray

Code	**Species**				
AA	*Avicennia alba*	HT	*Hibiscus tiliaceous*	SH	*Scyphiphora hydrophyllacea*
AM	*A. marina*	LL	*Lumnitzera littorea*	SO	*Sonneratia ovata*
BC	*Bruguiera cylindrica*	LR	*L. racemosa*	TP	*Thespesia populnea*
BG	*B. gymnorhiza*	NF	*Nypa fruticans*	XG	*Xylocarpus granatum*
BS	*B. sexangula*	RA	*Rhizophora apiculata*	XM	*X. moluccensis*
CT	*Ceriops tagal*	RM	*R. mucronata*		
CZ	*C. zippeliana*	SA	*Sonneratia alba*		
EA	*Excoecaria agallocha*	SC	*Sonneratia caseolaris*		

Appendix 3: Allometric assessment of Kien Giang mangrove data

3.1 Introduction

The conversion of tree size data (trunk diameter and sometimes height) into estimations of biomass and carbon content requires the application of allometric equations. The derivation of equations that describe the increase in biomass with increasing plant size depends on a so-called allometric relationship between the growth of one part of an organism and another part or whole of the organism.

Given the correct equation, easily measured parameters, such as tree diameter, can be entered into the applicable equation to estimate parameters that are difficult to measure, such as the biomass of a tree. This is typically applied to above ground biomass (AGB), but equations can estimate root weight (RW) as an indicator of below ground biomass (BGB) if the sampling and analysis is done. It is possible to partition various parts of the tree biomass using different equations, such as for leaves, trunk etc, but for this project the total biomass only is being calculated as this relates most directly to stand biomass purposes.

In the case of trees, individuals of a range of sizes are cut and weighed and a regression of the weight against stem diameter and/or other variable(s) produces an equation that describes the relationship between the measured and weight. Allometry in mangrove vegetation has been practised for some time and there are numerous studies showing the applicability of the approach (Saenger 2002; Komiyama *et al.* 2008).

Previous equations are used as some are available and because of the difficulty in producing new equations in the absence of good laboratory facilities. Allometric equations can be derived for specific species (and may be applicable to the genus) and these ‘specific’ equations usually require only one measurement parameter (typically stem diameter). ‘Common’ equations can also be derived for groups of trees, usually those occurring within a particular forest type, with obvious advantages of wider applicability than specific equations. Common equations must include more measured parameters than specific equations to better fit the variation in form of numerous species, typically adding height and/or wood density to trunk diameter.

Stem diameter, tree height and dry wood density are the key parameters in determining tree biomass in the absence of detailed specific measurements (Chave *et al.* 2005; Komiyama *et al.* 2008). Wood density measurements can be problematic, because published figures do not necessarily specify to what degree the wood has been dried, as drying for timber purposes may only be 12% or 15% moisture content.

This is a rapid exercise, so there are some short cuts, including:

- Trunks were mostly assumed to be circular in cross section in the field. Only rarely was a trunk adjusted as for the most part this is close to the fact at 1.3m height, although two measurements were made from asymmetrical cut stumps routinely.
- Calculation of diameter from circumference may lead to slight overestimation in basal area.
- Each stem of multiple stemmed trees were treated as a separate stem for biomass calculations.

- Assumptions in the common equation that wood density is consistent between sites are made, although it is possible there are small variations (Komiyama *et al.* 2005).
- A correction factor to remove bias in regression estimates (e.g. Komiyama *et al.* 2005) has not been made to the Dr Nam equations, but the general indication is adequate as the factor is minor.
- Trees sampled by Dr Nam in *Ceriops*, *Lumnitzera* and *Rhizophora* are all planted, although this should not affect the form of the trees.

3.2. Calculation of biomass

3.2.1 Woody tree biomass

Specific allometric equations have been derived in Vietnam for *Avicennia alba*, *Ceriops zippeliana*, *Lumnitzera racemosa* and *Rhizophora apiculata* (Nam pers. comm.). An equation for *Rhizophora apiculata* in Ca Mau (Tan 2002) agrees well with that of Nam, but the Nam equation is used for consistency. These equations will be applied in KG. Allometric equations for *Avicennia* spp. and in particular *Rhizophora* spp. usually agree strongly (Saenger 2002; Komiyama *et al.* 2008).

Two common equations for mangrove species are available (Chave *et al.* 2005; Komiyama *et al.* 2005). The equation of Komiyama *et al.* (2005) is used for the remaining species, as the authors have calculated wood density figures for important species, such as *Sonneratia caseolaris*. Other sources vary considerably in their figures. Equations for some minor species, such as *Bruguiera* spp., have been derived outside of Vietnam (Clough & Scott 1989), but it is simpler to apply the Komiyama equation to these. Wood density is as given in Komiyama *et al.* (2005) or if not listed derived from a very conservative application of data from World Agroforestry Centre (2010). *Excoecaria agallocha* is taken to be 400 kg m^{-3}, for example.

Care in interpretation is required. For example, the common equation of Chave *et al.* (2005) generally gives a higher value than that of Komiyama *et al.* (2005) and there is variation between both common equations and specific ones for *Avicennia* and *Rhizophora*. There are always additional potential sources of error in biomass estimation (e.g. Sala & Austin 2000; Chave *et al.* 2004). Other sources of information on mangrove growth in Vietnam and elsewhere in Asia are judiciously included for comparison. Komiyama et al. (2005) includes an equation for root biomass, but has to be used carefully. The equations used include:

- For *Avicennia*: $AGB = 0.1292*D^{2.4137}$ (Nam pers. comm., 2010)
- *For Ceriops*: $AGB = 0.2079*D^{2.407}$ (Nam pers. comm., 2010)
- For *Lumnitzera*: $AGB = 0.075*D^{2.3721}$ (Nam pers. comm., 2010)
- For *Rhizophora*: $AGB = 0.3482*D^{2.2965}$/Root weight = $0.0122*D^{2.4959}$ (Nam pers. comm., 2010)
- Komiyama general: $AGB = 0.251*\rho D^{2.46}$/ Root weight = $0.199*\rho D^{2.22}$ (Komiyama *et al*. 2005)

Where D = trunk diameter in centimetres (at 1.3m above ground or immediately above the bulk of prop roots in *Rhizophora*); H = tree height in metres; ρ = wood density (dry weight/volume) in t m^{-2}.

Root weight (RW) is estimated using the equations of Komiyama and Nam for *Rhizophora* (above). These equations estimate root biomass, rather than all the dead biomass derived from roots, litter fall or other source in the soil and as such may be conservative in estimating total ecosystem carbon stores.

The minimum diameter calculated for the equations is 5 cm for Komiyama, 2.9 cm for *Avicennia*, 3.2 cm for *Rhizophora* and 1.27 cm for *Ceriops*. Strictly, use of an equation should not be outside the range of trees sampled to derive it, but the error at the small end, especially for the Nam equations, is very minor. Extrapolation at the large end is more serious. In this study for simplicity, all small stems are included.

Conversion from biomass to carbon requires the biomass to be divided by carbon fraction. The carbon content of tree biomass is close to 50% (Gifford 2000), and this figure is often used, even though there may be minor variation between species (Chave *et al.* 2005). Nam (pers. comm.) has calculated a total carbon content of about 49% for *R. apiculata* and this value is generally used.

Conversion of biomass carbon content to its atmospheric CO_2 equivalent is by multiplication by 3.67, because carbon makes up only 27% of the CO_2 molecule. Hence, the CO_2 equivalent of a tree is about 1.8 times the dry biomass (3.67 x the carbon fraction of biomass of about 50%).

3.2.2 *Nypa* biomass

Nypa palms have an unusual anatomy, with a clumping habit from an underground trunk. More than one clump may eventually form. The tall leaves have a swollen base that arises at ground level and there may eventually be many leaves in a large clump. Allometric equations for trees are not applicable, nor are equations for more typical palms. As it seemed likely that some scaling (allometric) relationships do exist, a number of leaves from 1.2 m to 6.8 m were harvested, dried and weighed to seek relationships that may assist in estimating AGB. Totally frond (leaf) length, the length of the stem of the frond (rachis) and the diameter of the rachis at the point of lowest pinnule (leaflet) were tested. Unfortunately, ovens being turned off and then failing reduced the number of samples, but preliminary results were derived.

The derived equations are preliminary only in the absence of more sampling, but the best fits were total frond length ($r^2 = 0.96$) and rachis length ($r^2 = 0.967$), rather than rachis diameter ($r^2 = 0.875$) using Minitab statistical software. Frond length is the easiest to use in the field.

$\text{AGB} = 0.029 * (\text{total frond length})^{2.013}$

The number of intact and cut fronds per *Nypa* clump, plus their approximate height was recorded. All clumps were cut to a varying degrees and no general factor is applicable. The number of cut bases was counted, allowing an estimate of cut biomass within limits. One *Nypa* only plot (VQ3) was collected to be indicative of *Nypa* stand biomass stands. *Nypa* root weight was not estimated as it is even more specialised than for woody trees. *Nypa* fruit are large, but they were not included as they were rare at the time of sampling. A carbon content for Oil Palm leaves of 43.7% was determined by Syahrinudin (2005) and it is conservative to use a lower figure of 44%for *Nypa* than the usual assumed 50% in the absence of more detail.

Appendix 4: Notable associate tree species observed

Barringtonia acutangula (Chi c, Freshwater Mangrove, Wild Almond)

Barringtonia acutangula was found in two places within the mangrove near Vam Rang. It is a widespread typically a species of fresh to brackish swamps and thus may associate with mangrove edges (Giesen *et al*. 2006) and has been referred to as a 'freshwater mangrove'. However, it was found deep within mangrove vegetation in KG, possibly because the freshness of the flooding water on the central KG coast in the wet season means a brackish mangrove. It is a facultative mangrove in KG. The species has heavy timber which is used in construction and boat building and may be usefully planted in KG.

Cerbera odollam t [name given by local people in the field]), Sea Mango, Pong Pong Tree)

Cerbera odollam was seen as three or so mature trees (two on canals and on at the rear of a mangrove fringe at Vinh Quang), plus scattered seedlings in the mangroves of the central part of the province. It is likely that the brackish conditions encourage it. The characteristic fallen fruit were also seen. It is likely the species present is *C. odollam* because of a yellow collar at the base of the flow tube. This species is principally notable for its toxicity and medicinal value, although has medicinal and ornamental uses.

Instia bijuga (Gơ nước, Kwila, Merbau)

Instia bijuga is one of the most valuable timber trees of SE Asia and Melanesia, being traded as Kwila or Merbau. The timber is very strong and one of the most decay-resistant known (UNEP 2007). It is being heavily exploited in Indonesia and Papua New Guinea and formerly in Malaysia. Despite its value there has been little investigation of plantation potential (UNEP 2007).

Numerous small regenerating trees of *I. bijuga* were seen in scrubby mangrove edge vegetation on natural channels or canals in the Giang Thanh River system at Ha Tien. It was not observed elsewhere in KG, although it is recorded from Ca Mau (Hung & Tan 1999). It is not known how big it might grow in KG.

Mangrove Palms - *Nypa fruticans* (Dừa nước) and *)*

Nypa Palms are a unique salt-tolerant palm species with no above ground trunk, widely distributed in saline and brackish systems in the Indo-Pacific. They are typically included as 'core' mangrove species, although they often occur on the fringes. There are relatively large areas of *N. fruticans* in KG, such as planted in the Giang Thanh River system at Ha Tien. It is frequent in much smaller areas on the open coast, including some organised plantings and local planting in or at the edge of natural mangrove stands. This evidently includes the removal of other trees in favour of *Nypa* in small areas.

Nypa is favoured in this way because of the value of its fronds for thatching or other material, and as such has value. Virtually all the large *Nypa* seen in KG had been cut and usually repeatedly so. The fruit are another source of above ground biomass, which are harvested in some cases. *Nypa* grows in a clumping manner from a large branching underground rhizome and thus the harvest of fronds does not kill the overall plant. However, the biomass is usually kept below what would develop if there was not repeated cutting.

Phoenix paludosa is a palm forming dense clumps of stems and so reaches some size. It is an associate species of mangrove vegetation in drier places in many situations (Giesen *et al*. 2006), but is found well within the mangrove in the north of KG.

Hong (2000, in Geisen *et al*. 2006) cites an *Excoecaria-Phoenix* community in the upper mangrove edge on saline open coasts, so *P. paludosa* has been seen as a mangrove species at least faculatively in Vietnam. There is vegetation in Ha Tien at least that fits this community, given these species and associates such as *Ceriops tagal*, *Xylocarpus* spp. and *Heritiera littoralis* are present.

Literature cited

Alongi, D.M. (2009) *The Energetics of Mangrove Forests*. Springer, New York.

Alongi, D.M. (2002) Present state and future of the world's mangrove forests. *Environ. Conserv.* **29**(3): 331-49.

Cat, N. N., Tien, P. H., Sam, D. D. Binh, N. N. (2006) Status of coastal erosion of Vietnam and proposed measures for protection, Regional technical workshop presentation: *Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forests and trees?* 28 – 31 August 2006, Khao Lak, Thailand.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B. & Yamakura, T. (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* **145**: 87-99.

Chave, J., Condit, R., Aguilar, S., Hernandez, A., Lao, S. & Perez, R. (2004) Error propagation and scaling for tropical forest biomass estimates. *Philos Trans R Soc Lond B Biol Sci.* **29; 359**(1443): 409-20.

Chen, L., Zan, Q., Li, M., Shen, J. & Liao, W. (2009) Litter dynamics and forest structure of the introduced *Sonneratia caseolaris* mangrove forest in Shenzhen, China. *Estuar. Coast. Shelf Sci.* **85**(2): 241-46.

Christensen, B. (1978) Biomass and primary production of Rhizophora apiculata Bl. in a mangrove in southern Thailand. *Aquat. Bot.* **4**: 43-52.

Clough, B., Tan, D.T., Phuong, D.X. & Buu, D.C. (2000) Canopy leaf area index and litter fall in stands of the mangrove *Rhizophora apiculata* of different age in the Mekong delta, Vietnam. *Aquat. Bot.* **66**: 311-20.

Clough, B.F., Ong, J.E. & Gong, W.K. (1997) Estimating leaf area index and photosynthetic production in canopies of the mangrove *Rhizophora apiculata*. *Mar. Ecol. Prog. Ser.* 159: 285–292.

Clough, B.F. & Scott, K. (1989) Allometric relationships for estimating above-ground biomass in six mangrove species. *For. Ecol. Manage.* **27**(2): 117-27.

Erftemeijer, P.L.A. & Lewis, R.R., III (1999) Planting mangroves on intertidal mudflats: Habitat restoration or habitat conversion? *ECOTONE VIII Seminar: Enhancing Coastal Ecosystem Restoration for the 21st Century, 23-28 May 1999.* Ranong & Phuket, Thailand.

Giesen, W., Wulffraat, S., Zieren, M. & Scholten, L. (2006) *Mangrove Guidebook for Southeast Asia*. FAO and Wetlands International, Bangkok.

Gifford, R.M. (2000) *Carbon Contents of Above-Ground Tissues of Forest and Woodland Trees*. National Carbon Accounting System Technical Report No. 22. Australian Greenhouse Office, Canberra.

Hong, P.N. & San, H.T. (1993) *Mangroves of Vietnam*. IUCN Wetlands Programme, IUCN, Bangkok, Thailand.

Hung, H. A. & Tan, D. T. (1999) . Ca Mau Publishing House, Ca Mau.

Komiyama, A., Ong, J.E. & Poungparn, S. (2008) Allometry, biomass and productivity of mangrove forests: a review. *Aquat. Bot.* **89**: 128–37.

Komiyama, A., Poungparn, S. & Kato, S. (2005) Common allometric equations for estimating the tree weight of mangroves. *J. Trop. Ecol.* **21**(04): 471-77.

Komiyama, A., Moriya, H., Prawiroatmodjo, S., Toma, T. & Ogino, K. (1988) Forest primary productivity. *in* Ogino, K., Chihara, M. (Eds.), *Biological System of Mangrove*. Ehime University, pp. 97–117.

Kristensen, E., Bouillon, S., Dittmar, T. & Marchand, C. (2008) Organic carbon dynamics in mangrove ecosystems: A review. *Aquat. Bot.* **89**(2): 201-19.

McKenzie, N.J., Ryan, P.J., Fogarty, P. and Wood, J. 2000. Sampling, measurement and analytical protocols for carbon estimation in soil, litter and course woody debris. National Carbon Accounting System Technical Report No. 14. Australian Greenhouse Office.

Mazda, Y., Magi, M., Nanao, H., Kogo, M., Miyagi, T., Kanazawa, N. & Kobashi, D. (2002) Coastal erosion due to long-term human impact on mangrove forests. *Wetlands Ecol. Manage.* **10**(1): 1-9.

Ong, J.E., Gong, W.K. & Clough, B.F. (1995) Structure and productivity of a 20-year-old stand of *Rhizophora apiculata* Bl. mangrove forest. *J. Biogeogr.* **22**(2-3): 417-24.

Primavera, J. & Esteban, J. (2008) A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. *Wetlands Ecol. Manage.* **16**(5): 345-58.

Saenger, P. (2002) *Mangrove Ecology, Silviculture and Conservation*. Kluwer Academic, Dordrecht, Netherlands.

Sala, O.E. & Austin, A.T. (2000) Methods of estimating above ground net primary productivity. in *Methods in Ecosystem Science*. (Eds Sala, O.E., Jackson, R.B., Mooney, H.A. & Howarth, R.W.). Springer, New York**:** 488.

Snowdon, P. Raison, J., Keith, H., Ritson, P., Grierson, P., Adams, M., Montagu, K., Bi, H-q, Burrows, W. & Eamus, D. (2002) Protocol for Sampling Tree and Stand Biomass. National Carbon Accounting System Technical Report No. 31. Australian Greenhouse Office. pp. 65.

Syahrinudin (2005) *The Potential Of Oil Palm And Forest Plantations For Carbon Sequestration On Degraded Land In Indonesia*. Ecology and Development Series No. 28: Center for Development Research - University of Bonn, Goettingen, Germany.

Tan, D.T. (2002) Biomass of *Rhizophora apiculata* forest. in *Forest Science and Technology Research Report Results Period 1996-2000*. (Ed. Forest Sciences Institute of Vietnam). Agricultural Publishing House, Hanoi**:** 165-72.

UNEP (United Nations Environment Programme) (2007) *Tree Conservation Information Service:* Instia bijuga. Online: http://www.unep-wcmc.org/trees/trade/int_bij.htm. Accessed 24/02/2010.

UN-REDD (The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) (2010) *About REDD*. Website: http://www.un-redd.org/AboutREDD/tabid/582/language/en-US/Default.aspx. Accessed 24/3/2010.

Van Laar, A & Akça, A. (2007) *Forest Mensuration*. Springer, Berlin.

World Agroforestry Centre (2010) *Wood Density Database* .Online: http://www.worldagroforestrycentre.org/sea/Products/AFDbases/WD/asps/DisplayDetail.asp?SpecID=1464. Accessed 15/4/10.