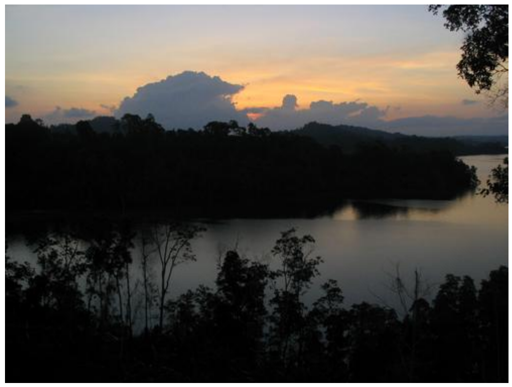
(*Revision* : 1.5)

A REPORT TO
THE NATURE CONSERVANCY



VEGETATION OF THE RAJA AMPAT ISLANDS, PAPUA, INDONESIA

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1 Summary

The Raja Ampat are a group of four large islands, and numerous smaller islands, off the western tip of the Bird's Head of New Guinea, administratively in Indonesian Papua province. The waters around the Raja Ampat have long been renowned as perhaps the most biodiverse marine area in the world, especially in terms of hard coral and fish species, confirmed by a number of recent studies and expeditions. The terrestrial resources of the Raja Ampat have received far less attention, despite it being a biogeographically rich and complicated area. The Nature Conservancy has had a marine conservation program in the area for a number of years, and has had plans to increase its terrestrial activities. This survey and mapping of the vegetation will provide some baseline data for these activities.

I made two trips to the Raja Ampat islands, the first visiting Batanta, Kofiau and Misool islands, the second focussed on Waigeo (Fig. 1). The islands are geologically complicated, having extensive karst, acid volcanic and ultrabasic rocks, have a number of high mountains, and have been assembled in their current position from several directions, and thus, a priori, the flora should be relatively diverse for substrate and biogeographic reasons. To the extent I was able, on short trips, I confirmed this high diversity of plants. Habitats ranged from submontane forest, via forest on karst and acid volcanics, to sago swamps and mangroves. The ultrabasic scrub vegetation of Waigeo (and surrounding islands) is unique and widely known for its endemic species. Each island was significantly different in its composition of habitat types, and as a whole the Raja Ampat are botanically extremely important and valuable, despite their relatively small size.

The conservation status and potential of the Raja Ampat are also unique in my experience in Indonesia. The population density of the islands is very low, being a mix of long-resident indigenous groups and fairly recent arrivals from Biak to the East and islands to the West. The traditional government system is still highly influential and coexists with Indonesian government structures. Logging over the past twenty years has been extensive, and almost exhaustive in the lowlands on deep, clay soils, but villagers are now wary of the promises of logging companies, and are preventing their entry into several key areas. Much of the land on the islands is rugged karst, and these areas have low timber potential and are physically inaccessible. Additionally, much of the prior logging was relatively light, searching primarily for large specimens of merbau (*Intsia* spp.). Hence the potential for the Raja Ampat to remain a relatively intact refuge for New Guinea species, including many endemics, is high. Working closely with local people, and searching for alternative livelihoods, will be the key to success.

Overall, I found the plants and vegetation of the Raja Ampat to be some of the most special and exciting of any I have examined and, considering the beautiful landscapes, and the proven marine riches, I believe the islands are an unparalleled natural wonder.

2 Introduction

The Raja Ampat islands (literally 'The Four Kings'; Figs. 1, 2) are situated off the Western tip of New Guinea, and have historically formed terrestrial stepping stones between New Guinea and islands farther West. Their flora is relatively unknown, and, while most similar to the New Guinea flora, has been found to contain both endemic elements and similarities with Maluku plants. Their dominant vegetation is primarily forest, and commercial operations have selectively logged much of the lowlands over the past 20 years. However, because karst and other rugged landscapes dominate much of the islands' area, much undisturbed forest remains. Prior surveys have concluded that the islands are extremely interesting both floristically and faunistically, and given their overall good condition are of great value for conservation. However, the terrestrial value of the Raja Ampat has been overshadowed by the very high diversity and near-pristine condition of the reefs and ocean between the islands. However, an integrated conservation strategy is vital for protecting the marine resources, and considered both above- and sea-level the Raja Ampat present an unparalleled natural site.

TNC has been working in the Raja Ampat area for several years, primarily on marine conservation. However, an expansion of the program to include more terrestrial concerns has been considered, and this report presents background data on the vegetation and plants of the islands. This survey can also serve as a beginning for any future ecoregional conservation assessments ('ECAs' of TNC) in New Guinea. I was able to make two trips (31 Oct.–7 Nov. 2004; 20 Mar.–1 Apr. 2005) to the islands, which included landfalls on Batanta, Kofiau, Misool and Waigeo. Wayne Takeuchi, one of the pre-eminant New Guinea botanists, accompanied a TNC expedition in 2002, and his (published) report (Takeuchi 2003) formed an invaluable starting point for my survey. Because the expedition was moving rapidly from reef to reef—it was predominantly a marine survey trip—Takeuchi was constrained only to visit sites near the coast. I therefore tried to concentrate on inland sites where possible (primarily during the second visit).

The goals of this survey were:

1. to provide descriptions of the vegetation types present on the islands,
2. integrating their classification with the work of previous authors,
3. to produce a vegetation map for the major islands of the Raja Ampat, to guide regional conservation planning and choice of future areas for TNC work,
4. to review plant species and biogeography of the islands,
5. to comment on the conservation value of the various islands.

3 Sources of Information

Despite the general paucity of information on the plants of the Raja Ampat, I was able to assemble a sufficient set of background information for mapping the vegetation.

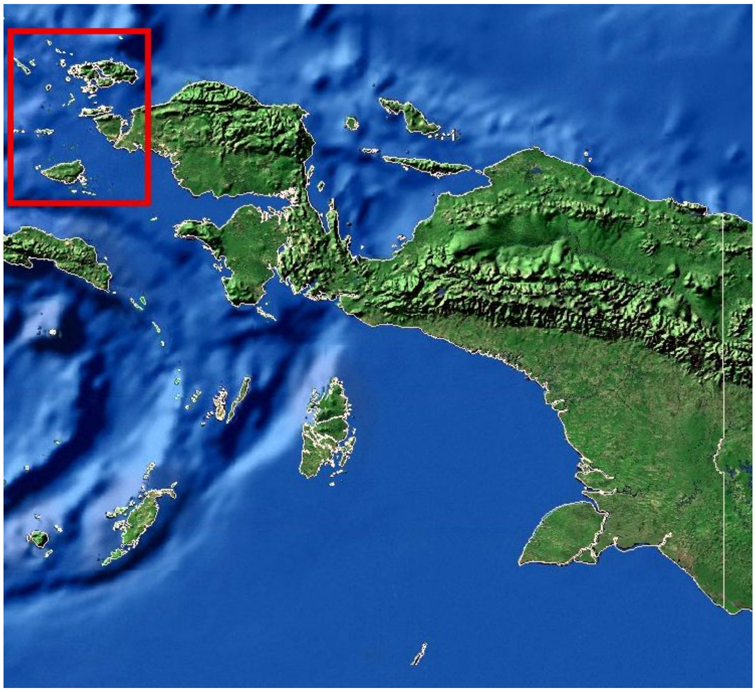

Figure 1: Overview map of the West Papua (New Guinea), showing the Raja Ampat archipelago. (Source: U. Texas Map Library)

3.1 Prior surveys

Takeuchi (2003) reviews the history of plant collecting in the Raja Ampat. Of particular note is the visit of Evelyn Cheesman, who stayed for many months (1938-39) at Waifoi on Waigeo, and wrote a book-length account, *Six-legged Snakes in New Guinea* (George G. Harray & Co.). We were all amazed when my guide and host on the Waigeo trip, Pak Henky, saw the pictures in this book (which Max Ammer had a copy of) and recognized his mother! The next major visit was by van Royen in 1954-55 (see van Royen 1960). Staff from Herbarium Manokwariense (Universitas Cendrawasih) made a collecting trip to Waifoi and Jensner (21 June–3 July 1997; Anonymous 1997). Sinaga (2002) studied ferns on Misool island in 2002. Conservation International funded a collecting and plot-making trip (3-15 April 2002; Farid and Yohanita 2003, de Fretes and Rachman 2005), also to the Waifoi area. Kesaulija (2003) studied ferns on the same trip. Takeuchi's 2002 trip (30 October–22 November) was mentioned above.

More general descriptions of New Guinea vegetation include Paijmans (1976), Johns (1982), Shea et al. (1982), Johns (1997). When published, Johns et al. (in press) will become the most comprehensive reference on New Guinea lowland vegetation.

3.2 RePPProT Landsystems

Throughout the latter part of the 80's, a large, British ODA funded project mapped the lands of the whole of Indonesia, as a resource for the transmigration programs going on at that time. In so do-

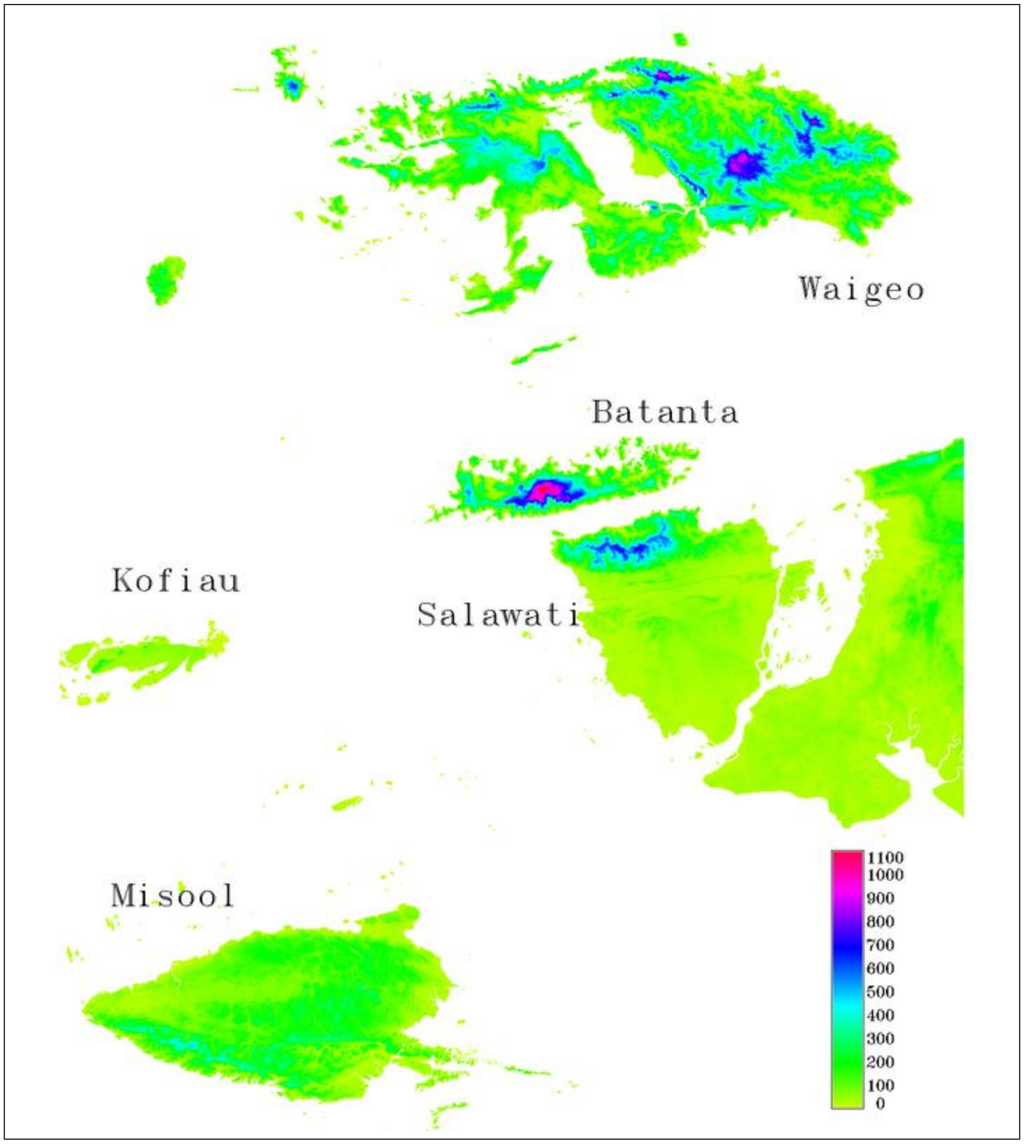

Figure 2: Overview map of the Raja Ampat, with elevations (m).

ing, the Regional Physical Planning Programme for Transmigration (RePPProT) project provided excellent background information for ecological studies in Indonesia. The maps they produced classed the ground into 'landsystems' – defined by combinations of geology, soils, macro- and micro-topology. Arial photographs were often used in mapping, sometimes interpreting geology from the vegetation. I was unable to obtain the original RePPProT report for the Raja Ampat, but was given a GIS version of the main landsystems. Unfortunately, the meaning of landsystem codes was not given in the shapefile database, but I located an early version of the report on microfiche at UC. Berkeley, and was able to interpret the landsystems from this. The RePPProT map was mainly used as a base geology map (see section 6.1).

3.3 Remote sensing

I acquired a series of Landsat 7 images from the University of Maryland archive. Four images covered the Raja Ampat entire area. These images were analyzed separately, since they had been pre-treated in different ways, and were taken on different dates. All were relatively cloud free. Also of great value was the NASA EarthSat MrSID file (S–52–00) for visual interpretation of forest types and landsystems (Fig. 3).

Figure 3: Sample of MrSID coverage: the Go peninsular area of Waigeo (S–52–00).

3.4 Field surveys

Ground-truthing a vegetation classification is vital. I was able to make two trips to the field. Traveling between the islands is necessarily time-consuming and expensive, especially to Misool and Kofiau. On the first trip I was able to join a previously planned mission by TNC Sorong staff to Kofiau and Misool. On the second trip, I chartered a small 'long-boat' and explored Waigeo. I was unfortunately not able to visit Salawati, which was a shame, since the extensive (logged) lowlands of southern Salawati are a distinct vegetation type.

On the first trip, I was accompanied by Julianus Thebu (jthebu@yahoo.com) (to Batanta), Ricardo Tapilatu (rtapilatu@tnc.org), Anton Suebu (asuebu@tnc.org), Yohanes Goram (johanes_goram@yahoo.co.uk), Andreas Muljadi (amuljadi@tnc.org), Uca, and Metha Ancelino (to Kofiau, Misool). On the second trip I was very grateful to be accompanied by Henky Goram, and Kris, elders of the Maya people of inland Waigeo. They opened the route, and opened my eyes in many ways.

Along the way, I kept careful notes and GPS positions. Unfortunately, I was not able (for reasons of time) to obtain a collecting permit, or to include collecting staff from UNIPA, and so (shamefully) did not make any plant collections. I did, however, take numerous plant photos. I also took systematic sets of pictures of 100 plant morphotypes in various sites, a method I have used on many surveys, and which I call PURIs (Photographic Ultra-Rapid Inventories). These sets of photos can be analyzed as if they were sample plots, to give measures of similarity between different locations, but on this survey, I simply used then to record the overlap in common, identifiable species between different sites.

3.4.1 Itinerary

30 October – 1 November 2004 Trip to Batanta with Julianus. Stayed at Yansawai. Climbed to 300 m, leaving from the bay behind the village. Heavily logged forest all the way except the last few 100 m, which were beautiful, and in which the bird-life was exuberant. Saw two large sharks in shallow waters near mangrove—great to see them. Forest dominated by 'matoa' (*Pometia pinnata*), *Celtis*, 'kayu besi' (*Intsia* sp.), 'nyatoh' (Sapotaceae spp.). Other taxa noted: *Artocarpus*, *Gnetum gnemon*, *Ficus*, *Canarium*, *Sterculia*, 'ketapang hutan' (*Terminalia*), 'belimbing' (*Koordersiodendron*), *Mangifera*, *Macaranga*, *Leea* (used as an important charm against evil spirits), *Podocapus*, *Mallotus*, *Alstonia*, *Ventilago*, *Blumeodendron*. I was accompanied by Yansens and Albertus.

3–4 November Kofiau. We stayed on Pulau Deer, but I took a hike on the main island, climbing the nearby solitary hillock. I was accompanied by Edy, Lazarus and Askenes. From the beach, we crossed an old log yard from 1979, still largely devoid of vegetation, up onto a limestone bench at ca. 30 m elevation. Much of Kofiau appears to be of this landform, perhaps uplifted coral. We passed a camp of 'Mario' from Belgium, who had stayed here for 1 month, studying birds. The hillock (UTM 52M 594040 / 9871168; 130 m tall) was unlogged above ca. 80 m, and was of volcanic rock. The forest was tall (30–40 m). I saw 'matoa' (*Pometia pinnata*), 'kayu besi' (*Intsia* sp.), 'kenari' (*Canarium*, 'pisang-pisang' (Annonaceae spp.), *Diospyros*, *Mangifera*, *Calophyllum inophyllum*, a Myristicaeae sp., *Dracaena*, *Syzygium*, *Semecarpus*. The forest was clearly Malesian in character. We descended and entered a patch of remaining tall forest on limestone bench (Fig. 12). At the generic level the forest had a very similar composition to the volcanic substrate.

5 November Left Kofiau, sailed for Misool. Passed several low islands with casuarina forest. Observed northern Misool low limestone plateau (near coast), and tooth-shaped karst hills behind. Passed into the amazing karst 'tail' off eastern Misool (Fig. 14). Stayed at a cultured pearl operation, and visited forest behind it on sandstone-derived soils. Species general different than those seen on Batanta and Kofiau. Unfortunately, no time to make a plot here.

6 November Visited several islands in this eastern karst tail. Stopped at one and explored forest on steep karst tower. Saw *Haplolobus*, *Hopea*, various Sapotaceae, a *Calophyllum*.

20 March 2005 Travelled from Sorong to Waifoi (Waigeo). Through the amazing limestone gateway into Menyalibit Bay. Stopped for a few minutes at Wassamdim, the administrative center on the west shore of the straits. Met the KaDis of Teluk Menyalibit, Daniel Goram. Pass Lepintol, in the southwest of Teluk Menyalibit. Several karst towers in the channel are covered in casuarina. Discuss the local geology: "katim ahar" (karst), and "katim matem" (volcanic), and "matok" (level lowlands).

21 March Climbed the Go isthmus behind Go village. Recently burned, and bare (Fig. 16). Metallic pebbles laying on surface of orange soil. Common shrubs seen: *Myrtella becarii*, and *Styphelia abnormis*. Small patch of forest remains at summit, with very dense, small trees (Fig. 15).

22 March To lowland swamp forest west of Kabilol village. Pass mangroves, *Nypa*-zone, and into sago swamp. Pass a work-crew of ca. 15 people from Kabilol, paddling a giant dug-out canoe to fell and extract a single tree for village buildings. Apparently, I am the first 'bule' to enter this river—it is made clear to me that this is an honor. Pass a sacred hill: no one must step foot on the shore, on pain of death from the spirits that live there. Reach another low ridge, and follow a series of low switch-backs. Dense 'damar putih' (*Vatica* sp.) trees at the base of the hills: recently fruited. Also many *Artocarpus*.

23–26 March To Gunung Nok (aka. Mt. Buffelhorn), behind Waifoi (Fig. 4). Accompanied by Henky, Kris, Daud and two others, whose names I forgot to record. Crossed low hills behind village, intact, stunted forest on ultrabasics (Fig. 17). Many *Dillenia* trees. Then cross wide alluvial basin of Bam river, very muddy. *Syzygium* (Fig. 9), *Vatica*, and *Pometia pinnata* are common, giant trees here. Up onto ridges of Gunung Nok. Camp near the old house-site of Cheesman. Hill forest, with *Nageia wallichii* (Fig. 10). Make a small tree plot (see Section 5.2.1). Return, travel to Wasamdin.

27 March Follow the Orobiai river east through the coastal karst range. Striking scenery! (Fig. 13). Many fruiting *Anisoptera* on lower slopes of karst. Kali (river) Sam heads north towards Warimak, following the back of the karst range. Through a large area of gardens, then into amazing lowland area of *Agathis* trees (Fig. 8). Rocks poorly weathered, soil very acid, almost peaty. Wai Sos ('woman's river') heads east-south-east, towards Yengsner on the coast. Turn north, leaving the river, climb to 310 m, heading north towards the wide peak of Mt. Danai (known locally as 'Bongsale'). Route, via $-0.07497°$ S, $130.66964°$ E; farthest point: $-0.27533°$ S, $130.96822°$ E. No one recently has been up there, although in old days the hunters would go everywhere. Stories of many birds-of-paradise, fields of pineapples guarded by snakes and a tiger or two. June/July are the dry months—the best time to try the mountain. This whole area was amazing—a great sense of wilderness.

27–28 March Circumnavigation of Pulau Gam. Boatmen: Herman and Otis. Stop in at several karst canyons (Fig. 11). Pass through the narrow Kaboi strait. Visit Yenwaupnor, where a film crew shacked up in a hut in a garden and filmed many birds. Now acting as a eco-tourism site. I asked to be taken to the forest, but all forest was secondary and gardens, for a long way. Not recommended for eco-tourists looking for undisturbed forest. Forest was on interesting level limestone bench (raised reef?), as at Kofiau. I pointed out 'gaharu' (*Aquilaria* sp.), and the local guide (Nico) was very excited. Stopped in at Papua Diving resort, and had a long, interesting chat with Max Ammer. Crossed to Batanta, to Yansawai.

29–30 March Attempted to climb to highest point on Batanta, leaving from behind Yansawai. Accompanied by Lodek, Yan, and James. Climb through mixed steep lowland limestone ('cockpit country' type) and volcanics. Heavily logged. Find a few big trees left (Fig. 7). At ca. 300 m the slope steepens and we climb on steep limestone. At new ridge (750 m), the landscape becomes razor-sharp karst boulders. Nearly impassible. No water. Forest stunted and submontane in character, with dense tree-ferns. Camp here, and decide to turn back the next morning, knowing we are kilometers from the summit. The accessible route must be from the south, via the volcanic slopes. Set off immediately for eastern Batanta. Spend last night at uninhabited bay. The island is strikingly uninhabited. Much of it has been logged, but it is all still forested. Amazing!

4 Physical Factors

4.1 Geology

Waigeo and Batanta sit on the Tosen micro-plate (Pacific in origin), which also supports Halmahera. Misool and Salawati sit on the main Kemun block of the Bird's Head (an Australian plate). Recent reconstructions by Robert Hall's group (Royal Holloway) have the Tosen block originating as a mid-ocean archipelago, being far from any mainland at 50 My, then approaching its current position from the ENE, then due E, as the main Papuan plates approached from the S. The Pacific plates are sliding alongside and over the relatively stable Australian plates, causing deep underwater troughs. At 10 My, Waigeo was where Biak now is, and only assumed its present position in the last 2 My. This recent arrival explains the high number of endemic animals found on Waigeo and Batanta (such as the Waigeo maleo, and the red and Wilson's birds-or-paradise), and possibly the absence of cassowaries from Waigeo, which is curious given its current proximity to the mainland.

Waigeo and Batanta are predominantly Tertiary oceanic basaltic rocks, overlaid with the Tertiary Waigeo and Dajang limestones. The long history of rapid movement as a small plate has led to a great variety of surface rocks. The volcanics are "basic to intermediate tuffs, agglomerates, lavas and dykes of of the Tertiary Dore Home and Batanta" formations, with trapped slivers of many other exotic rocks in the fault zones, all metamorphosed to a greater or lesser extent (RePPProt 1986). Ultrabasic rocks are also common, adding to the diversity of substrates. The ultrabasics hold significant nickel deposits, and there are plans to mine the Go isthmus. The tailings from such an operation would devastate the ecology of the shallow Menyalibit bay.

Salawati and Misool, on the other hand, are primarily Australian in origin, and less uplifted. The mountains of northern Salawati are Tertiary volcanic in origin, with areas of uplifted Jurassic sandstone. The plains to the south are recently uplifted Quaternary sediments (mudstones). The hills of southern Misool are classified by RePPProt as acid silicaceous metamorphics (KMM landsystem; Table 1), and Jurassic acid sedimetary rocks by the geology GIS layer we acquired (of unlabeled origin). I observed layered, deformed sandstone on the hill just south of the pearl farm, but did not visit the main hills to the southwest, and have included the KMM landsystems in the general volcanic class. In the north of Misool, the limestone uplands are Jurassic, while the low northern rim are recently-uplifted (Quaternary) reefs. Kofiau is primarily these same recently raised reefs, with a few hills of Tertiary volcanics.

4.2 Landforms

Apart from geology, the landforms (Table 1) capture the general physiognomy of the land. On Waigeo, the three major landforms are SKS, APR and BMI. SKS is areas of sharp ridge and valleys on weathered volcanic rocks (see the description of van Royen's trek from Selogof to Kabare and back; van Royen 1960). BMI is like SKS in physiognomy, over ultrabasic rocks. APR is a system of steep tooth-shaped karst towers, nearly inaccessible to climb. Batanta is mainly SKS and MAR, another, less towering limestone formation. Both formations contribute to the deep bays on the north shore of Batanta. Salawati has low hills and valleys in the north on a variety of geologies, and flat plains in the south. The plains overlay oil and gas deposits, and gas flares mark the extensive petroleum industry developed on the island. Misool also contains large ares of the very inaccessible APR landform, hence the little explored nature of its interior.

4.3 Rainfall

There is little climate data for the area, but in general we can expect that rainfall falls off the farther one goes from the Papuan mainland. Hence, Batanta and Salawati will be wetter than the other islands. Mainland rainfall is 1.5–3.0 $m.y^{-1}$, while a station on Saunek (Waigeo) recorded 1.5 $m.y^{-1}$. Mainland sites have 1 dry month (mean < 0.1 m), while Waigeo has 2–4. The wettest months are April to September.

5 Vegetation Types

The majority of the study area is some form of 'New Guinea lowland forest,' which has received less attention from botanists than montane forest (Johns 1982), and I have had to initiate its subdivision, based on field observations. Some of these subdivisions (between submontane, upland, lowland and alluvial forest on the same substrate) do not occur at clearly defined floristic boundaries, and are added primarily as indicators that forest composition does turn over between the lowlands and uplands. The turnover of species between substrates can be more clear, especially between karst and volcanic soils.

As is always the case with mapping vegetation from GIS and remote sensing (RS) data, some classes observed in the field are not easy to detect in RS layers, and similarly, some variation in RS layers is not easy to interpret given even extensive field observations. A one-to-one mapping is seldom possible, and I have provided a cross-walk table (Table 2) to assist this comparison.

As I was not able to make collections, most of the species names are drawn from Takeuchi (2003): where I saw a common plant, and was sure of the genus, I have assumed it was the species referred to in his report. Please refer to that report for more details on species composition.

5.1 Submontane forest

While no areas of the Raja Ampat are higher than 1,000 m, the proximity of their mountains to the ocean (the 'Masenehebung effect'), means that pseudo-montane vegetation appears at much lower elevations than would be found inland. The character of the vegetation I saw on Batanta at 700 m, and the descriptions of the top of Gunung Nok by van Royen (1960), indicate a sub-montane type vegetation, and I have assigned land above 700 m to this class. The sub-montane zones, while being relatively species-poor, are likely to have the highest proportions of endemic and new species.

5.1.1 Submontane forest on volcanics and acid metamorphics [1]

Van Royen (1960) describes the woody species on top of the Gunung Nok (Fig. 4): *Evodia* sp., *Rhodomyrtus trineura*, *Drimys piperita*, *Elaeocarpus* sp., *Rhododendron cornu-bovis* (a new species), *Melastoma* sp. and *Rapanea* sp. The relatively large area of high elevation forest on Mt. Danai will surely have a strong montane character, although there may be obvious inter-digitation of lower forest types in the valleys and coves with sub-montane forest on the ridges. We would expect substantial areas of *Lithocarpus*-dominated forest. It is unlikely that there would be *Araucaria* or *Nothofagus* at such low elevations. This mountain is perhaps the highest exploration priority for future trips.

Figure 4: Gunung Nok on Waigeo with sub-montane forest at the top.

Figure 5: Submontane forest on karst (class 2), nearly impossible to pass through.

5.1.2 Submontane forest on karst [2]

The character of the forest at 700 m on karst at Batanta was definitely sub-montane. Tree ferns abounded, and there had been a near complete turnover of understory plants from farther down (as assessed by the PURIs; section 3.4). From observations of the island from a distance, a semi-permanent cloud belt had its base also at 700 m. It is interesting to note that the best indicator species of karst, an emergent palm (*Gulubia costata*), was visible (with binoculars) all the way up to the top of the Batanta mountains, indicating that this particular species has a very high tolerance for climatic conditions. According to the geology layers, areas on Batanta above 700 m contain both limestone and volcanic soils; climbing the mountain from the volcanic (southern) side would offer interesting comparisons of forest on these two substrates.

Because of the moister conditions, it is probable that fire plays less of a role in the vegetation dynamics of submontane forest on karst than on karst at lower elevations.

5.2 Lowland and hill rain forest on dry land

Lowland forest in New Guinea is generally Malesian in character, but without the striking dominance by dipterocarps that is seen farther west. The dominant genera include: *Pometia, Intsia, Terminalia, Vatica, Dillenia, Canarium, Anisoptera, Cryptocarya, Syzygium, Ficus, Celtis, Semecarpus, Koordersiodendron*, and various Sapotaceae (Paijmans 1976; Johns 1982). Smaller species of tree come from the genera *Diospyros, Myristica, Calophyllum*. As in any rain forest, extensive local habitat-related and climate-related variation in composition occurs, which we are far from understanding. I have divided this general lowland forest by elevation zone (above and below 300 m), and by general substrate (volcanic, limestone and sandstone). These classifications should be read as suggestions of the likelihood of significant compositional change, rather than as having been unequivocally demonstrated. In general, the trees become smaller as one increases in elevation, and ridge/valley variation becomes more pronounced. Fagaceae and Lauraceae and *Elaeocarpus* also become more dominat at higher elevations, while *Terminalia* becomes less dominant. It is likely that moisture relations play a greater role in species turnover between sites than substrate chemistry (ultrabasic rocks excepted), and this is borne out by the similarity of lowland forest on deep soils on flat limestone, and on weathered volcanics. In general, forests at higher elevations and farther inland will be moister than those right on the coast.

5.2.1 Hill forest on acid volcanics and metamorphics [3]

I encountered these forests above 300 m on Gunung Nok, and on Gunung Danai. A good indicator species appears to be *Nageia wallichiana* (syn. = *Podocarpus wallichianus*; Fig. 6). The forest was still of tall stature (ca. 30 m) on the ridges, up to ca. 500 m. On Gn. Danai, I found *Hopea* trees at 400 m, and there were many figs and *Elaeocarpus*. At 350 m on Batanta mountain, I fould a few large *Intsia* trees that had escaped the chainsaw (Fig. 7). The composition of these forests is not distinct from those on volcanics and acid metamorphics at lower elevations, so see below (section 5.2.3) for more information.

5.2.2 Hill forest on limestone and karst [4]

I encountered these forests on the slopes of the main Batanta peak, above a belt of richer, more deeply weathered volcanics. In character, they were moister than forests lower down, with extensive moss at even 400 m. On the steep slopes, the canopy was generally broken and fairly open. As with the forests on volcanics, this mid-elevation class has been added mainly to indicate of species turnover between lower and higher forests. See section 5.2.4.

5.2.3 Lowland forest on acid volcanics [5]

This forest type describes the most extensive lowland vegetation on Waigeo. Where the soils are well weathered, and the forest is tall, these areas have been extensively logged. The dominant

Figure 6: *Exocarpus latifolius* (Santalaceae) and *Nageia wallichiana* (Podocarpaceae), showing striking convergence of both leaf and fruit morphology.

species and genera on these weathered soils include: *Intsia bijuga, Koorderiodendron pinnatum, Pometia pinnata, Terminalia* cf. *copelandii, Celtis, Ficus, Dysoxylum, Myristica, Alstonia scholaris, Gastonia serratifolia, Morinda citrifolia* and *Trema cannabina* (Takeuchi 2003). I also saw plenty of *Vatica ressak, Endospermum, Calophyllum, Pternandra, Prunus, Flindersia*, and several Lauraceae spp. An *Aquilaria* species ('gaharu') was also fairly abundant.

However, in the basin of the Orobiai river, a second forest type was common: dominated by *Agathis labillardieri*, with a peaty, mossy understory (Fig. 8). This type seems to occur on the hardest volcanic rocks that are resistant to weathering, and was frequently found by the riverside. Along the river's edge, *Cerbera odallum*, *Maniltoa* and *Syzygium* were common.

5.2.4 Lowland forest on limestone and karst [6]

The scenery associated with this forest type is often awesome, and the species composition will vary greatly between karst islands (Fig. 14), shallow soil raised bench (Fig. 12) and limestone valleys (Fig. 11). On the former, a very xerophytic vegetation is found, marked by the striking emergent palm (*Gulubia costata*). Other common species on these islets (and probably also on knife-edged, inland karst at low elevation) include *Pandanus* spp., *Exocarpus latifolius* (Santal.; Fig. 6), *Ficus* spp., *Nepenthes* sp., a Sapotaceae sp., *Aglaia* sp., *Hopea* sp. (the first record of a *Hopea* on Misool), *Glocidion* sp.

On level surfaces, with substantial development of a rich, dark-brown soil, the forest tends to a composition similar to that of lowland forest on volcanics. *Intsia* and *Pometia pinnata* dominate. However, on the lower slopes of some karst towers, the most common species is an *Anisoptera* species. In March 2005, all these trees were in fruit, and many fruits were found floating in the Orobiai river (Fig. 13).

Because of the ease with which limestone absorbs water, the forests on most of the limestone substrates will be frequently drought-stressed. At dry times of year, natural fires would always

Figure 7: Large *Intsia* tree in forest on volcanics at 300 m (class 4).

Figure 8: Riparian forest with *Agathis* on Waigeo volcanics (class 5).

have been common, and many limestone areas showed signs of burning (e.g., north side of the Orobiai canyon). The fire frequency is probably much higher now, due to active fire-setting, and the even greater likelihood that logged forest will burn.

5.2.5 Lowland forest on sandstone [7]

These forests dominate much of Salawati, but the only place I saw them was in the southeast of Misool. It was clear that the species composition was significantly different from forest on volcanics and limestone, but I did not see enough to characterize it, beyond recording the presence of some Sapindaceae, *Macaranga*, Burseraceae, several *Syzygium* spp., *Cinnamomum*, *Diospyros*, and several Fabaceae. From this limited selection, it appears these forests may be reminiscent of forests on richer substrates to the west.

5.2.6 Forest on alluvium and residual plains of sandstone or volcanics [8]

It was on the alluvial soils of Waigeo that I saw the tallest, most impressive forest in the Raja Ampat. Staff from CI and the Bogor herbarium (de Fretes and Rachman 2005) established two plots in this forest, and recorded high densities of: *Spathiostemon javense, Hopea novoguinensis, Homa-*

Figure 9: Large *Syzygium* tree in alluvial forest

Figure 10: *Pometia pinnata* in lowland forest at ca. 150 m

lium foetidum, Mallotus floribundus, Pimelodendron amboinicum, and *Vatica ressak*. *Elatostema* and *Piper* were very common in the understory.

5.2.7 Lowland forest on ultrabasics [9]

At ca. 300 m on the Go isthmus, we found small patches of forest in the valleys and coves, while on the ridges was open scrubland. The trees in these forest patches were dense and short, and included *Calophyllum* and *Dillenia* species (Fig. 15). On lower slopes, behind the village of Waifoi, a taller forest occurred, also dominated by two species of *Dillenia* (Fig. 17).

5.3 Grassland, scrubland, open ground

5.3.1 Scrubland on ultrabasics [10]

This is the famed 'ultrabasic scrubland' of Waigeo and Kawe (Figs. 16, 18). Orange bare soil dominates the view, with patches of (nickel-rich) metallic pebbles. The shrub species include: *Ploiarium sessile, Gymnostoma rumphianum, Ixonanthes reticulata, Decaspermum bracteatum* and *Myrsine rawacensis*. I was especially struck by the near identical distribution of *Myrtella beccarii* and *Styphelia abnormis*; wherever there is a patch of the former, the latter is also present—

Figure 11: A fertile valley on limestone, Waigeo.

Figure 12: Lowland forest on limestone bench, Kofiau.

Figure 13: The canyon of the Orobiai river (forest class 6).

Figure 14: Karst pinnacles rising from ocean, Misool.

they would present a fascinating study in competitive (non-)exclusion! I searched in vain for *Dodonea viscosa*, reported to be here, which I have seen in Mexico and Hawaii! Two *Nepenthes* species were found, one growing in the open, and the other in the more protected forest patches.

Fire is clearly a dominant driver of these ecosystems, as with karst. Fire scars were everywhere, and large patched of the hillside above Go were black.

5.3.2 Savanna and grasslands on non-ultrabasics [11]

The only areas of real savanna are those along the Kasim and Waitama rivers in Misool, and were characterized by *Melaleuca leucadendron, Eucalyptus* cf. *papuana, Baeckea frutescens, Decaspermum bracteatum, Melastoma malabathricum*. The grasses are *Ischaemum barbatum*, *Rynchosporum rubra* and *Imperata conferta* (Takeuchi 2003). These savannas are similar in composition to

Figure 15: Short forest of small trees in cove on Go isthmus.

Figure 16: Open scrubland on ultrabasic rocks, Go isthmus.

those on the mainland, at Bomberai.

Some of the open land seen on the Landsat is forest converted to garden. Every village we visited had associated, slash-and-burn gardens, planted with bananas, root crops (*Ipomea, Dioscorea, Manihot* and various Araceae species), chilli peppers, and tree crops.

5.4 Lowland rain forest on wet land

5.4.1 Freshwater swamps and sago swamps

Behind the mangroves and before the alluvial forest, there are, in some places, well-developed swamps, dominated by sago palms (*Metroxylon sagu*). The dominance by sago is probably a result of active management by humans, as sago has long formed the main starch source for local people. Numerous other species were still present in the sago swamp at Kabilol. The riverbanks were dominated by a striking, spiny species of *Osmoxylon* (Araliaceae).

Sago palms were also seen to be planted in 'sub-optimal' habitats, like a strip behind the mangroves on Kofiau.

5.4.2 Mangroves [12]

The Raja Ampat lack large sediment-producing rivers that generate wide, zonation-rich mangrove areas. However, mangrove forests have formed on some of the larger rivers (Gam, Kasim on Misool, and Kabilol on Waigeo), and contain a sequence of *Rhizophora mucronata, Ceriops tagal, Bruguiera gymnorrhiza* (Takeuchi 2003). I saw only scattered *Nypa fruticans* on the Kabilol (Fig. 20). On not-beach shores throughout the islands, a mangrove margin is usually present, consisting mainly of *Rhizophora*. As usual, the mangrove areas in the Raja Ampat, though limited in extent, have a unique spectral signature on the Landsat images, and were fairly easy to extract.

Figure 17: Lowland ultrabasic forest behind Waifoi, with some xerophytic character. Dominated by *Dillenia*.

Figure 18: Open scrubland on the Go isthmus. Note the *Nepenthes*. Metal nodules are found on the soil surface.

5.5 Beach forest

On the sand and coral rubble 5–10 m back from the beach there is a distinctive plant association that includes *Calophyllum inophyllum, Hibiscus tileaceus, Pandanus tectorius, Terminalia catappa, Thespesia populnea, Colubrina asiatica, Pongamia pinnata, Ximenia americana*. Most of these species are widespread throughout Malesia and the Pacific islands, their seeds being dispersed by sea. This formation was too narrow to attempt to map, but can be assumed to be present wherever sandy beaches are present. In some places, a beach forest of *Casuarina equisetifolia* also develops (Takeuchi 2003), and I saw an example of it on Pulau Weeim, half-way between Kofiau and Misool.

6 Mapping

6.1 Methods

After carefully examining the Landsat images by eye, and with an unsupervised classification, I determined that it would not be possible to use the spectral signature to differentiate among the important forest sub-types in mature forest. My general approach to mapping was therefore i)

Figure 19: *Nypa* palms just downstream of sago swamps.

Figure 20: Mangroves at the Kabilol river.

to use the RePPProT-derived geology layer to differentiate major substrate-based closed forest classes, ii) add DEM information to model the effect of elevation, and iii) use the Landsat image to indicate open and mangrove forest classes. In detail my method was:

1. I imported four Landsat tiles from the Univ. Maryland archive (http://glcfapp.umiacs.umd.-edu): accession numbers 025-555 (107/061, 1990-12-31, TM), 025-561 (108/060, 1991-11-15, TM), 025-562 (108/061, 1991-11-15, TM), 040-651 (107/060, 2001-07-06, ETM+). All images were taken by EarthSat, were orthorectified to UTM/WGS84, and were offered as GeoCover, GeoTIFF images.

2. I downloaded Space shuttle SRTM files from NASA (N00E129, N00E131, S01E130, S02-E129, S02E131, S03E130, N00E130, S01E129, S0 1E131, S02E130, S03E129, S03E131), and patched them together.

3. I obtained a coastline shape file, and a RePPProT landsystem shape file, and a geology shape file from GIS resources at TNC. The origin of the files was unknown. The coastline was projected onto UTM and overlaid the Landsat images perfectly. The geology layer was obviously created from a far lower resolution map, and was used only for interpretation. The RePPProT layer was of a suitable scale, but was severely distorted (a simple x-y shift would not align the layer).

4. Because of the large areas of water between the islands, I created four working regions (Waigeo, Batanta and Salawati, Misool, and Kofiau), to conserve disk-space and increase the rate of analysis. SRTM, Landsat, RePPProT and coastline layers were clipped to these regions, the latter two having been converted to raster layers. All the following steps were repeated for each region.

5. I filled the gaps in the DEM using curvilinear interpolation, and cut the ocean noise out using the coastline layer.

6. I orthorectified the RePPProT layer using the island coastlines as control points. I produced a simplified, geology-based landform classification from the various landsystems in the overall region (Table 1).

7. I performed a supervised, maximum-liklihood classification of the Landsat layers (Bands 1, 2, 3, 4, 5, 7), training on a) Mangrove, b) open areas, c) general forest, d) cloud, e) cloud shadow, f) ocean, g) shallow reef. Each tile was treated seperately, and the subsequent classifications were patch into one image where two tiles occurred in one region. Separate raster layers were made of the 'open' and 'mangrove' classes, and the 'open' class was split into ultrabasic and non-ultrabasic rasters.

8. Separate raster layers were made for the various geology classes at $>$ 700 m ('mountain') and $>$ 300 m ('hill').

9. Layers were assembled by overlaying rasters (top to bottom): 'Open' layers, 'Mountain' layers, 'Hill' layers, mangrove, base/lowland layers.

10. Neighbourhood smoothing (de-speckleing) was implemented using the modal class of a 9-pixel window.

11. Images were produced of the resulting maps (Figs. 22, 21, 23, 24).

12. The vegetation GIS data was exported as: i) GeoTIFFs (UTM), ii) Erdas Imagine rasters, iii) Shape files. The GeoTIFFs can be viewd with most image viewers.

7 Plant Biogeography

The plants of the lowland forests of New Guinea have primarily arrived from the west over the past 2–10 My, while the indigenous Gondwanan flora tends now to dominate the uplands of New Guinea. In addition, it appears that the Gondwanan element is most speciose in the southern parts of New Guinea, with the Malesian elements most diverse in the northern, accreted terranes (Heads 2001). Johns (1997) considers Waigeo to belong to a separate phytogeographic region from the rest of the Bird's Head, and its geological history would tend to support such a division. Batanta might also be considered to belong to the same region. The only plant species that we know to be endemic to the Raja Ampat is *Rhododendron cornu-bovis*, first collected by van Royen from Gg. Nok. We expect that the uplands of both Waigeo and Batanta will produce many more endemic and new species with further exploration. Again, a long expedition to Mount Danai, in the wet and/or flowering season, is a high priority.

The floristic affiliation of Salawati is likely to be close to the lowlands of the Bird's Head mainland, and fewer of the species are likely to have restricted ranges and be endangered. The plants of Misool, which is separated by large ocean distances, but which is on the same plate as the Bird's Head, is likely to be a mixture between the Papuan flora and the Ceram flora. When all islands are taken together, the diversity of the Raja Ampat is likely to be extremely high: Waigeo/Batanta (oceanic terrane with endemics) *plus* Salawati (Papuan lowlands) *plus* Misool (Ceram-influenced). Add to this biogeographic mix the nearly incomparable range of habitats (swamp, lowland rain forest, karst, ultrabasic, submontane...), the total plant diversity of the Raja Ampat *per unit area* may be among the highest of anywhere in the world!

8 Animal Notes

While not an experienced bird watcher, I saw several species of bird-of-paradise, and the calls of many more were pointed out to me, on both Waigeo and Batanta. Pak Henky was frequently critical of the bird-catching business that was apparently quite developed on Waigeo, and warned the villagers he talked to that the birds would disappear if this kept on. Various species of parrots and parakeets seemed to be the primary birds traded. I saw plenty of cassowary droppings on Batanta, and the population seemed to be in good shape, according to the locals. Iwein Mauro (iweinmauro@gmail.com) has spent many days on Waigeo (and Kofiau?) studying the birds, and should be consulted with bird-related questions. As far as hunting went, pig was the primary quarry, and everyone on Batanta and Waigeo claimed that they were easy to catch, although I never saw or was offered wild pig-meat. On Kofiau, the extensive logging near Pulau Deer was seen as the cause of a reduction in the density of pigs.

9 Human Impacts and Conservation

The intact social organization (especially the adat council of the Maya people of Menyalibit Bay), the general cessation of logging activities, and the low population density, make the terrestrial resources of the Raja Ampat less threatened (currently) than any other comparable area in Indonesia I have seen. This does not mean the areas is without threat though:

- The most serious threat now appears to be the possible nickel mine on the Go isthmus, which would devastate both the rare open shrubland habitat on ultrabasic soils, and the marine ecology of Manyalibit bay.
- Serious fire is part of the historical disturbance regime on karst and ultrabasic substrates, but now, with the large areas of degraded forest, a huge, devastating fire is possible on any of the islands. There is little that can be done to guard against this possibility, but the threat might be used constructively in arguing against further logging.
- Renewed logging would reverse the current course of forest regeneration, and could have significant negative biodiversity impact. The primary target species extracted here are the two *Intsia* spp. (Fabaceae), which occur at lower densities than the bundle of dipterocarp species extracted from Sundaland forests. Hence the general damage to the forest during logging is lower here than elsewhere in Indonesia. The sustainable re-harvesting cycle however is still likely to be at least 35–50 years, and re-logging before then will lead to a general degradation of the populations of the target species, and of general structure of the forest. As

above, the greatest threat to logged forest is fire. The areas that have been logged are patchy, and include:

- Most of northern Batanta, below ca. 300 m, on volcanics.
- Almost all of the south Salawati plains, and much of the low hills in the north of Salawati.
- Coastal plain areas of Waigeo on deep, weathered soils, derived from either volcanics or limestone (class 8, brown on map), and up into the hills on the south of Gam island. The large interior of the eastern part of the island appears not to have been logged, despite the valuable stands of lowland *Agathis*.
- The raised reef limestone in the coastal north of Misool, but not the vast area of interior inaccessible karst. I did not see the hills in the south, on acid metamorphics, but expect that logging has occurred there.
- Probably the whole of lowland Kofiau: limestone plains on raised reefs.

The villagers now seem to have effective veto power on the re-entry of commercial logging operations and should be the target for conservation awareness activities. They already are resistant to the commercial loggers, because they have seen numerous cases of villages admitting the loggers, losing their fresh water, their hunting and their general sense of a pleasant place, and being paid a pittance in return.

One of the keys to successful terrestrial conservation in the Raja Ampat, as in most places, is developing alternative livelihoods for the locals. The key concern appeared to be raising money for school fees which are extremely high here on the island (Rp. 2,000,000 per year for SMA: eternal shame on the thieving teachers!). There appears to be plenty of food: sago is abundant within Menyalibit Bay, fish are still easy to catch, there is plenty of fertile land for gardens. However, cash crops are not as simple, and access to markets is poor. One villager at Waifoi asked about sustainable teak plantations—he had heard that people will pay a premium for well-managed teak. As in the Adelbert mountains of PNG, there is a possible solution in the development of fair-trade markets for choice good. Fair-trade pearls would be the obvious choice in the Raja Ampat. Significant research and testing is needed to move activities in this direction.

10 Suggestions for Further Study

Our assessment of the terrestrial resources of the Raja Ampat has just begun. Here are a few concrete suggestions to most effectively increase our knowledge:

- Conduct a thorough study of the logging history and extent on the major islands. This could be done best by a boat-based circum-navigation of the islands, short shore trips, and questioning of local villagers. Some use could be made of Landsat images, but the logging has been fairly light in some places, and does not register clearly in these images. Acquiring other satellite image products (ASTER, SPOT) may help. This survey would be very useful for assessing the risk of re-logging, determining exactly the habitats in the Raja Ampat with commercially viable timber stands, and quantifying the overall 'naturalness' of the islands.

- Develop the authorization and infra-structure for continued plant collecting programs in the Raja Ampat. The area is so rich that it is a crime to go there and not collect (a crime that I committed). Plant collecting is relatively simple, and any TNC (or CI) terrestrial trips should entertain the possibility of making collections.
- Conduct a survey of the ethnicity and origin of all villages on the islands. There are significant land disputes raging on the islands, some of these between 'traditional owners' (e.g., the Maya people of Waigeo), and recent new-comers (e.g., the Biak peoples in some Waigeo coastal communities). While not wishing to play off different peoples against each other, knowing accurately who lives where and what they claim to be their own will be vital to developing community-sensitive conservation plans.
- Take an expedition to the summit of Mount Danai on Waigeo. This mountain has extensive areas at high elevation, is likely to be loaded with endemics, and has yet to be visited by a scientific expedition. Access will be easiest from the Orobiai, along the route I tried.
- Try (for the third time) to reach the summit of Batanta's highest mountain. For the same regions as for Mt. Danai, there are likely to be significant botanical finds here.

11 Conclusions

Of all the places I have travelled in the tropics, the Raja Ampat islands felt like the most biologically and socially intact, despite the extensive logging that has gone on in the past. The key to this is the relatively low population pressure, combined with the islands' isolation. While the α-diversity of plants may be lower than on the mainland, the β-diversity within islands (due to habitat diversity) and the γ-diversity among islands (due to historical reasons), make the overall diversity, the endemicity, and the probability of finding new species extremely high. There is no doubt in my mind that the above-ground resources demand far more attention than they are now getting, and combined with the proven undersea resources make the Raja Ampat one of the most amazing biological sites anywhere in the world.

12 Acknowledgments

First, I want to thank Marcy Summers for inviting me to participate in this exciting project, and for her support and patience (!). I would like to thank the outstanding logistical support offered by the Bogor and Jakarta TNC Offices, particularly Tiene Gunawan, Agus Salim, Sofie, and Jerry. In Sorong, thanks to Ricardo 'Ricky' Tapilatu, Yohanis Goram, Anton Suebu, Fery Liew (PHKA), Yulianus Thebu (WWF), Irdez Azhar (CI) and Muhammad Farid (CI). Thanks to Yance de Fretes (CI) and Ismail Rachman (BO) for providing a report on plots in Waigeo. Max Ammer welcomed us to his Papua Diving resort and shared much information. Thanks in particular to our companions

on the road and villages that made us welcome (mentioned above in section 3.4.1). I thank also PHKA in Jakarta and Sorong for providing permission to enter the protected areas of the Raja Ampat. My apologies to those inadvertantly ommitted from this list.

13 References

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Table 1: Landforms common in the survey area, by area in the three major island groups (ha); from RePPProT (1986). Note that we did not have access to the original descriptions and some classes lack notes. We are, however, confident of their placement in geological categories.

Name	Code	Description	Waig.	Bat.-Sal.	Mis.
Amban	ABN	Hard reef limestone hills	-	-	3336
Amiri	AMR	Small steep hills over basalt	394	1877	8607
Apriri	**APR**	Limestone round-top, towers	77236	-	78636
Bami	**BMI**	Outcrops of ultrabasic rock within SKS. Broad round ridges. Stunted vegetation	43970	511	-
	GBO		-	3792	-
Igomu	IGM	Atop SKS. Massive blocky areas of karst, dipping northward, with smooth appearence	-	4972	10727
	IKN		3598	-	1087
Kajapah	KJP	Intertidal swamps of mangrove and nipah	3540	5315	8249
Klasafet	**KFT**	Low, rolling interfluves and vallies on sedimentary rocks.	1768	1	30182
Kemun	**KMM**	Acid silaceous metamorphic mountains	6107	2142	44931
	KWS		-	199	5937
Mar	MAR	High hills and ridges on calcareous sediments	-	12957	-
Mariam	MRM	Coalescent alluvial plain of braided rivers	14092	3598	-
	PGO		-	1454	-
Puting	PTG	Alluvial flats, coastal	94	-	550
Rumberpon	RBN	Raised reefs, shallow soils	127	1053	286
Saukris	**SKS**	Strongly dissected, simple ridge systems over basic volcanic rocks	185165	57011	-
	SMT		-	53547	-
	STL		-	86765	-
	STS		-	7975	-
	SWA		8020	-	7619
Waibu	WBU	Steep sided parallel ridges on hard sedimentary rock	-	6908	-
	YTP		-	30284	-

Table 2: Cross-walk between vegetation classes observed, vegetation classes in map, and other researchers' classifications.

<table>
<tr><th>Vegetation observed</th><th>Mapped vegetation</th><th>van Royen (1960)</th><th>Takeuchi (2003)</th></tr>
<tr><td>Submontane, acid</td><td>(1) Submontane volcanic</td><td rowspan="2">Submountain</td><td rowspan="4"></td></tr>
<tr><td>Submontane karst</td><td>(2) Submontane karst</td></tr>
<tr><td>Hill, acid</td><td>(3) Hill volcanic & acid metamorphic</td><td rowspan="7">Lowland, riverine, & coastal forest</td></tr>
<tr><td>Mid-elevation karst</td><td>(4) Hill limestone/karst</td></tr>
<tr><td rowspan="2">Lowland, acid</td><td>(5) Lowland volcanic & acid metamorphic</td><td rowspan="4">(Pl, Hm) Lowland forest on deep soil</td></tr>
<tr><td>(7) Lowland sandstone</td></tr>
<tr><td>Lowland karst</td><td rowspan="2">(6) Lowland limestone</td></tr>
<tr><td>Lowland flat limestone</td></tr>
<tr><td>Alluvial forest, Low-elevation forest on non-limestone residual plains, Sago swamps</td><td>(8) Plains (on mixed non-limestone substrate) and alluvium</td><td>(Pl, Hm) Lowland, (Wsw) Swamp, (B) Littoral</td></tr>
<tr><td>Ultrabasic forest</td><td>(9) Ultrabasic forest</td><td rowspan="2">Xerophytic</td><td rowspan="2">(W, HsCp) Ultrabasic scrub & forest</td></tr>
<tr><td>Ultrabasic scrub</td><td>(10) Ultrabasic scrub</td></tr>
<tr><td>Grassland, Savanna, bare soil</td><td>(11) Open land, grassland, savanna (non-ultrabasic)</td><td></td><td>(SaMl) Savanna</td></tr>
<tr><td>Mangroves</td><td>(12) Mangroves</td><td>Mangroves</td><td>(M) Mangroves</td></tr>
</table>

Table 3: Data used in vegetation mapping

Code	Class	RePPProT	DEM	Image class
1	Submontane forest on volcanics & acid metamorphics	KMM, SKS, AMR	elev. > 700 m	forest
2	Submontane forest on limestone	IGM, IKN, ABN, APR, RBN, MAR, SWA	elev. > 700 m	forest
3	Hill forest on volcanics & acid metamorphics	KMM, SKS, AMR	700 m $>$ elev. > 300 m	forest
4	Hill forest on limestone	IGM, IKN, ABN, APR, RBN, MAR, SWA	700 m $>$ elev. > 300 m	forest
5	Lowland forest on volcanics & acid metamorphics	KMM, SKS, AMR	elev. < 300 m	forest
6	Lowland forest on limestone	IGM, IKN, ABN, APR, RBN, MAR, SWA	elev. < 300 m	forest
7	Lowland forest on sandstone	WBU, KFT, KWS, GBO, STS	elev. < 300 m	forest
8	Alluvium and flat plains on sandstone/volcanics	PTG, KJP, STL, PGO, SMT, MRM, YTP,		forest
9	Forest on ultrabasics	BMI		forest
10	Open scrub on ultrabsics	BMI		open
11	Savanna and grassland	not BMI		open
12	Mangrove			mangrove

14 Digital Complements to this Report

1. Digital vegetation maps of Waigeo, Batanta/Salawati, Misool, Kofiau, provided as:
   - Arc shape files
   - ERDAS Imagine files
   - GeoTIFF files
   - JPEG images

   All layers are provided as UTM/WGS84 projected maps.

2. GPS waypoints from field surveys: `webb_waypoints.txt`.

15 Vegetation Map Images

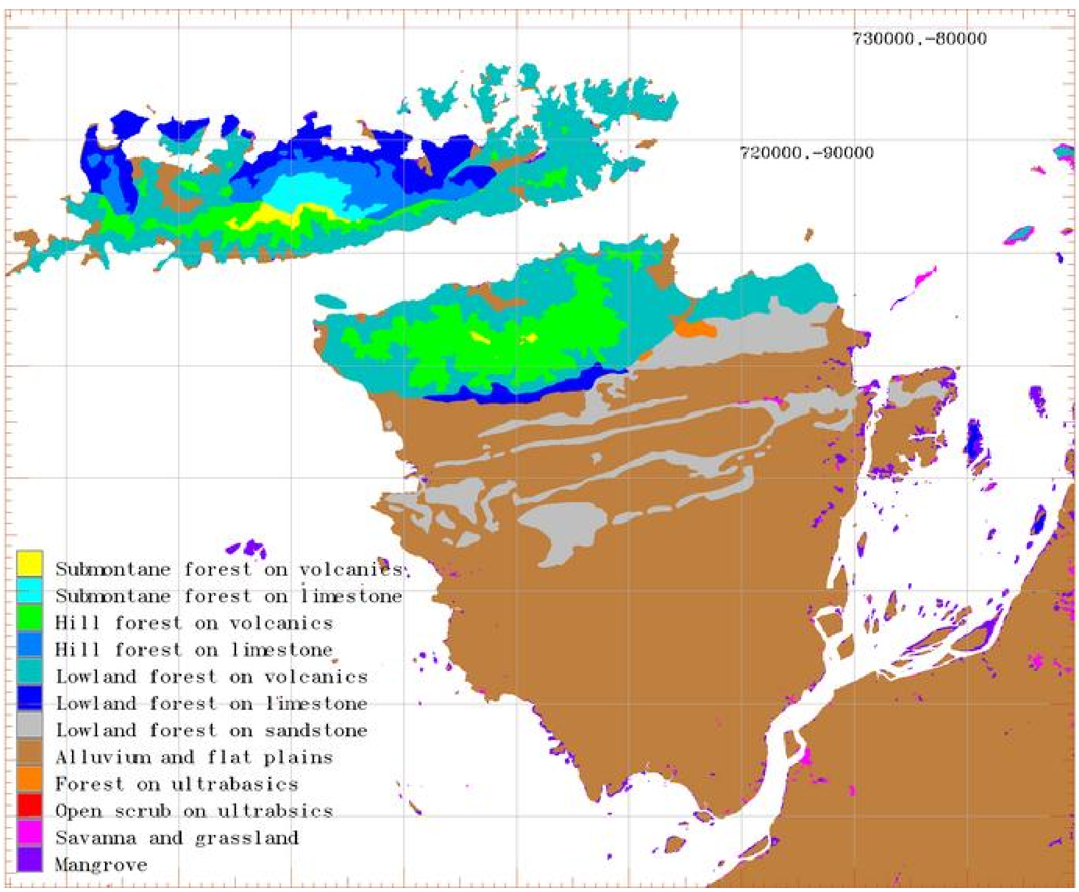

Figure 21: Vegetation map of Batanta and Salawati islands. Grid is 10 km, UTM projection and alignment (two UTM reference points given).

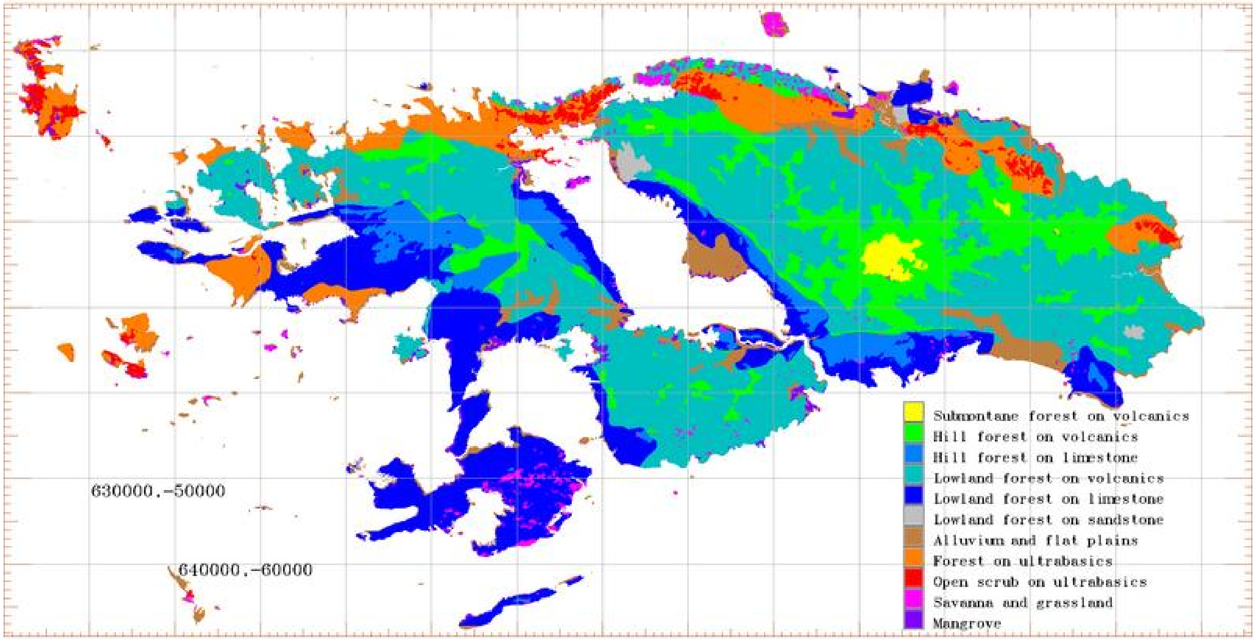

Figure 22: Vegetation map of Waigeo island. Grid is 10 km, UTM projection and alignment (two UTM reference points given).

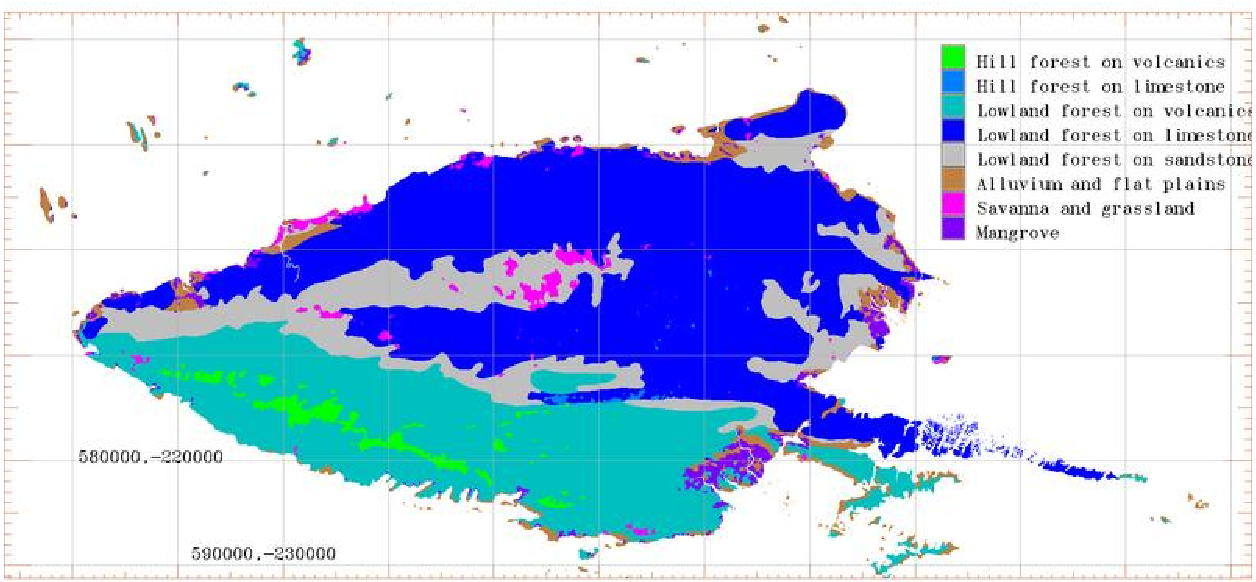

Figure 23: Vegetation map of Misool island. Grid is 10 km, UTM projection and alignment (two UTM reference points given).

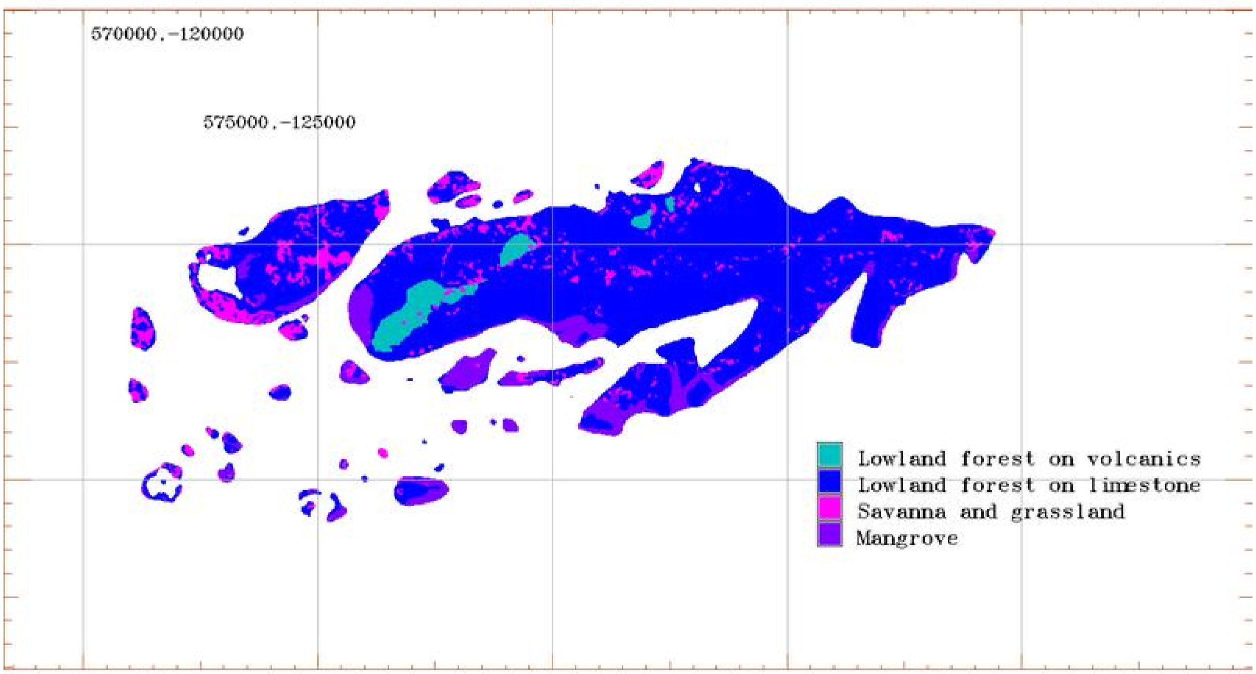

Figure 24: Vegetation map of Kofiau island. Grid is 10 km, UTM projection and alignment (two UTM reference points given).