

5.1. The Diversity and Conservation of Papua's Ecosystems

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THE TERM “ECOSYSTEM” refers to a biological community and its physical environment. Sir Arthur Tansley, an English botanist who was a pioneer in the study of plant ecology, coined the term in 1935 in recognition of the fact that a true understanding of ecological processes requires consideration of organisms and their habitats as a single, integrated system (Tansley 1935). Some ecologists extended this view and argued that the ecosystem should be considered the basic unit of ecological investigation (e.g., Evans 1956; Rowe 1961). Although modern ecology incorporates research on a variety of scales, from populations of single species, through landscapes and ecoregions, to the entire biosphere, the consideration of ecosystems as functional units has produced important insights into a range of important ecological processes, such as primary production, energy flow, and nutrient cycling. In this section we take a broad, ecosystem-level view of the Papuan environment. This level of analysis allows us to consider issues of biodiversity, conservation, and human well-being from a broader perspective than is possible when these issues are examined at smaller spatial scales. In this introductory chapter I comment briefly on some general concepts related to ecosystem classification, diversity, services, and conservation, and consider how these concepts can be applied to the management and preservation of Papua's ecosystems. In the following twelve chapters, experts provide overviews of the ecology, organization, and conservation of Papua's most important ecosystem types.

First, a comment on terminology. In ecology, as in many other scientific disciplines, terminology is both a blessing and a burden. When clearly defined and applied, specific terms unambiguously convey meaning and permit relevant debate. Unfortunately, ecological terms are frequently used in contexts other than those in which they were originally applied, without appropriate definition or clarification. Such misuses of terminology obscure meaning and can result in vigorous debates that create much heat while shedding little light on the issues under discussion. The term “ecosystem” is used frequently and in a wide variety of contexts without formal definition. In this volume we use the term to classify specifically delineated parts of the environment and all biological organisms that inhabit them. For example, lower montane forest is a particular ecosystem type that encompasses the physical structure of a mountain (e.g., bedrock, soil) found between roughly 650 and 1,500 meters elevation and all of the flora and fauna living within this structure (Chapter 5.10). It is distinct from the alpine ecosystem type typically found at higher elevations and the lowland forest ecosystem type found below. We do not use the term “ecosystem” to refer to the habitat occupied by a particular

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species, as this term is highly-species specific: the habitat of one species may include many ecosystem types (e.g., many bird species), while another species might only be found in one particular subset of an ecosystem type (e.g., a tree species limited to a particular soil type).

Ecosystem Classification

One of the complications that has long plagued ecosystem ecologists is the difficulty in identifying the boundaries of an ecosystem. Sharp lines can rarely be drawn that delineate the extent of a particular ecosystem type or contain all relevant ecological processes and interactions (Whittaker 1970). Even boundaries that initially appear to be clearly delineated are revealed upon careful examination to be porous and dynamic. For example, at first glance few ecosystems would seem to be more clearly distinct than the abutting marine and terrestrial ecosystems found along coastlines around the world. However, closer investigation reveals that energy and nutrients flow between these ecosystems, organisms move back and forth between them, and that the health and stability of one can profoundly effect the other. These interactions make categorization of ecosystems as discrete entities somewhat artificial. For the purposes of description, we have classified Papua's ecosystems into twelve broad categories. Nevertheless, it is important to remember that these classifications are simplifications made to facilitate discussion, and that in reality ecosystems are highly interconnected and interdependent.

The principle division of aquatic ecosystem types is based on water salinity, and two major categories are typically considered: saltwater (or marine) and freshwater ecosystems. Various ecosystem types are defined in each of these broad categories based on physical features such as substrate, temperature, water depth, and dominant vegetation type (Smith and Smith 2003). In this chapter we consider four major categories of aquatic ecosystems in Papua: coral reefs, seagrass ecosystems, mangroves, and inland water ecosystems.

The world's major terrestrial ecosystem types (often referred to as biomes) are classified by vegetation type, which is largely dependent on rainfall and temperature (Whittaker 1970). Within these biomes, separate ecosystems can also be defined according to the composition and structure of the plant community. We follow this convention by considering six distinct vegetative formations (i.e., ecosystems) within the tropical forest biome, following a roughly altitudinal gradient from coastal ecosystems to alpine vegetation. We also consider the extensive monsoon grassland and savanna ecosystems found in plains and deltas of the great rivers in southern New Guinea. Finally, we discuss the unique and little-known cave ecosystems of Papua.

Ecosystem Diversity in Papua

Many of the terrestrial ecosystem types discussed in this section are further subdivided based on dominant vegetation, altitude, soil type, and degree of human

disturbance. The wide array of ecosystem types found in Papua helps to explain why this is an area of such high biodiversity and a major center of endemism in many distinct taxonomic groups. From the reefs that contain the most coral species in the world to the cryovegetation communities growing in the ice and snow atop its highest mountains, Papua's ecosystem diversity creates a wide range of ecological conditions, each of which supports a highly specialized community of flora and fauna. Some ecosystems are fairly well characterized and understood (e.g., seagrass ecosystems, coastal vegetation), while others are scarcely known and the diversity and ecological interactions contained therein have yet to be discovered (e.g., cave ecosystems). Yet the uniqueness, complexity, and diversity of each of these ecosystem types is abundantly clear, and helps to make Papua one of the most biologically important regions on earth (Supriatna 1999).

Papua's high diversity of terrestrial ecosystems is largely due to its wide altitudinal range (Figure 5.1.1). Accurate measures of the extent of different ecosystem types in Papua are difficult to calculate, both because of difficulties in classifying ecosystems and complications in recognizing these ecosystem types on images obtained through remote sensing. However, based on general land cover classifications (Hansen et al. 1998) and recent Landsat 7 ETM+ imagery of Papua (1999–2000), the extent of broad land classes can be mapped (Figure 5.1.2). Anal-

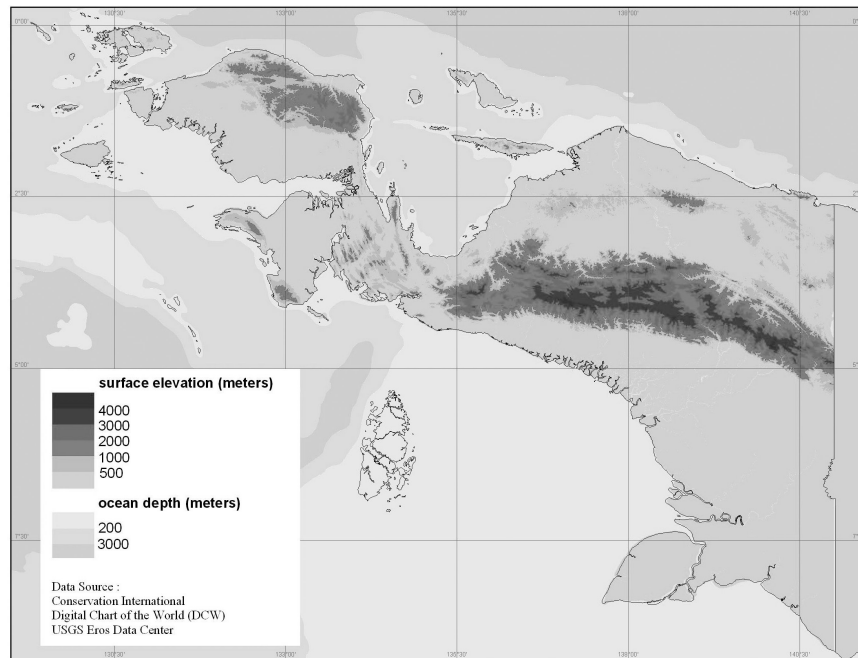


Figure 5.1.1. Surface elevation and ocean depth in Papua. The wide range of altitudes leads to a diversity of ecosystem types.

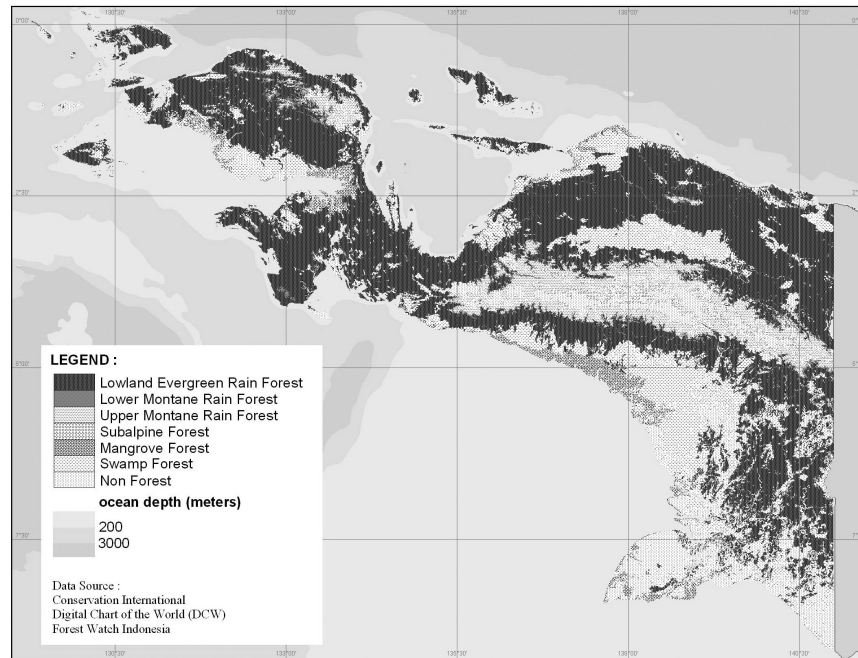


Figure 5.1.2. Forest cover in Papua. The picture is an interpretation of Landsat 7 ETM+ imagery of Papua, using a combination of images acquired in 1999 and 2000.

Source: Forest Watch Indonesia–Conservation International–Ministry of Forestry.

ysis of the resulting map provides estimates of the extent of each major land class in Papua. When forests are broadly defined to include all land cover classes with greater than 10% tree or shrub canopy cover, roughly 85% of Papua was forested in 2000 (Table 5.1.1). Over 60% of these forests were lowland evergreen forests (51% of Papua's total area), making Papua home to the largest remaining tracts of lowland tropical evergreen forest in Indonesia. Large areas of mangrove forest (15,124 km², 4.3% of forested land), swamp ecosystems (68,312 km², 19.5% of forested land), and montane forest (36,032 km², 10.3% of forested land) are also found, in addition to several other ecosystem types, each of which comprise more than 1% of forested area in Papua (Table 5.1.1).

The distribution and diversity of ecosystem types across the island of New Guinea are similar to those found in Papua (Figure 5.1.3). Due to differences in data quality and forest classification, figures for New Guinea are not directly comparable to those from Papua. However, analyses show that in 2000 the island of New Guinea was overwhelmingly forested, containing almost 657,000 km² (82% of the land area) of broadleaf forest and woodland (Table 5.1.2). For this reason New Guinea is considered one of the world's three great lowland tropical rainforest Wilderness Areas (Mittermeier et al. 2003).

Table 5.1.1. Major land classes in Papua

Land classes	Area (km ²)	% of forested land	% of total land
Mangrove forest	15,124	4.3	3.6
Swamp	7,465	2.1	1.8
Swamp brush	10,559	3.0	2.5
Swamp forest	50,288	14.3	12.1
Lowland evergreen rainforest	213,627	60.8	51.3
Lower montane rainforest	8,658	2.5	2.1
Upper montane rainforest	27,373	7.8	6.6
Subalpine forest	4,266	1.2	1.0
Brush	4,490	1.3	1.1
Savanna	9,298	2.6	2.2
Total forest cover	351,147		84.4
Bare ground, rice paddies, transmigration settlements	64,982		15.6
Total land area	416,129		100.0

Numbers may not accord perfectly with data listed in other chapters in this section due to differences in habitat classification and methods used to estimate the extent of each habitat type. Listed are estimates from Interpretation of Landsat 7 ETM+ imagery of Papua, using a combination of images acquired in 1999 and 2000.

Source: Forest Watch Indonesia–Conservation International–Ministry of Forestry.

THE IMPORTANCE OF ECOSYSTEM

DIVERSITY FOR PAPUAN FAUNA

Landscapes containing several ecosystem types have higher species richness than equivalent areas containing only a single ecosystem type (Figure 5.1.4). Thus Papua's high ecosystem diversity helps to explain the high diversity found in a number of taxonomic groups of flora (Section 3) and fauna (Section 4). In addition, many vertebrate species rely on more than one ecosystem type, often utilizing different ecosystem types for breeding, nesting, and foraging. For example, several species of sea turtles feed in open oceans and seagrass ecosystems, but rely on coastal beaches to lay their eggs (Chapter 4.6). Similarly, many species of mammals, insects, and birds breed in mangrove forests but live and forage mainly in adjacent terrestrial or marine habitats (Chapter 5.4). Greater Melampittas nest in cave ecosystems but forage daily in nearby forest ecosystems (Chapter 5.13), and many other bird species utilize several forest types at a variety of altitudes during their normal life cycles (Chapter 4.9). Therefore, preservation of the full complement of ecosystem types in Papua is necessary both to preserve its high biodiversity and to provide the habitat requirements for a number of threatened vertebrate species.

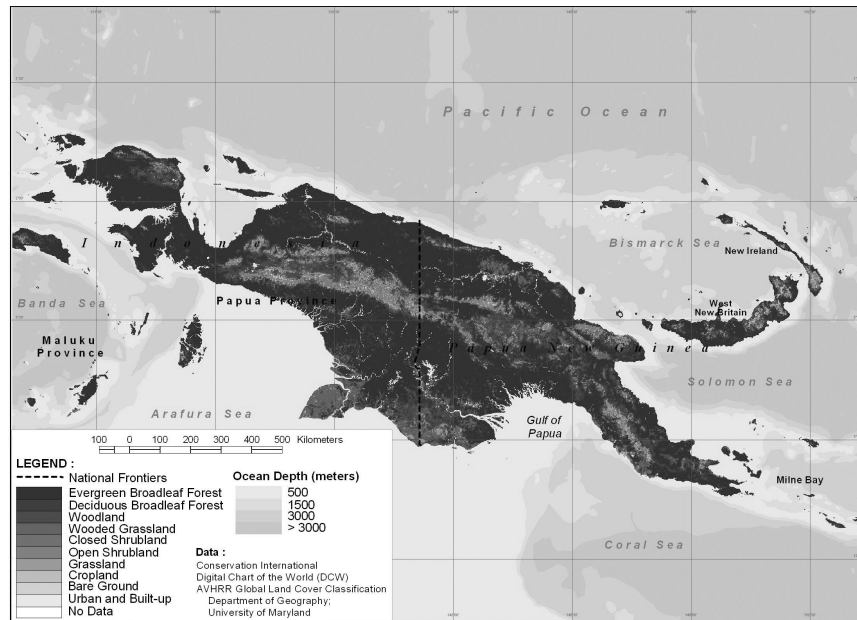


Figure 5.1.3. Forest cover in New Guinea. The picture is an interpretation of Landsat 7 ETM + imagery of Papua, using a combination of images acquired in 1999 and 2000.

Source: Forest Watch Indonesia–Conservation International–Ministry of Forestry.

Table 5.1.2. Major land classes in New Guinea

Land classes	Area (km ²)	% of land area
Evergreen broadleaf forest	540,418	67.3
Deciduous broadleaf forest	12,130	1.5
Woodland	104,369	13.0
Wooded grassland	82,196	10.2
Closed shrubland	1,745	0.2
Open shrubland	16,254	2.0
Grassland	35,668	4.4
Cropland	6,359	0.8
Bare ground	4,358	0.5
Urban and built-up area	75	0.01
Total land area	803,572	100.0

Land classes in this table are different from those presented in Table 5.1.1.

Source: Hansen et al. (1998).

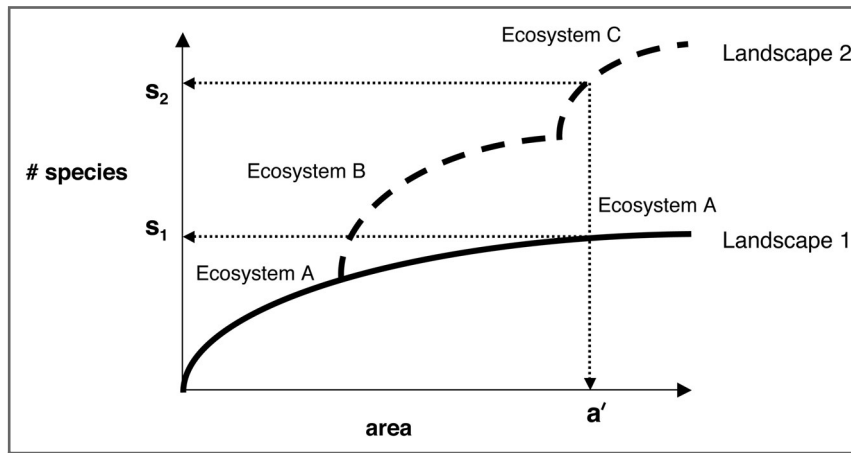


Figure 5.1.4. Schematic diagram of species richness and ecosystem diversity. The graph shows species-area curves for two landscapes. Landscape 1 (solid line) is comprised of a single ecosystem type (A). As more area is sampled the total number of species recorded increases, but slope decreases as an increasing proportion of the total species richness of ecosystem A is recorded. Landscape 2 (dashed line) is comprised of three ecosystem types (A, B, C). The species-area curves for the two landscapes are equivalent as long as sampling is confined to ecosystem A. However, as sampling begins in ecosystem B the species-area curve in Landscape 2 increases sharply as many new species are recorded in this new ecosystem type. Sampling of ecosystem C results in another rapid increase in total species richness in Landscape 2. This schematic shows that for any sampling area (e.g., a') species richness is higher in landscapes containing multiple ecosystem types than in landscapes comprised of a single ecosystem type (e.g., $s_2 > s_1$).

INTERACTIONS AMONG ECOSYSTEM TYPES

As is the case in many subjects within ecology and conservation biology, the more we learn about ecosystems the more we realize how connected and interdependent they are. As noted above, classification of ecosystems into discrete “types” masks the fact that there are many important interactions among them. For example, seagrass ecosystems provide an important functional link and buffer between reefs and mangrove ecosystems (Chapters 5.3 and 5.4) and forest ecosystems provide key nutrient inputs into aquatic and cave ecosystems (Chapters 5.5 and 5.13). This interdependence means that when one ecosystem is damaged it can have strong and often unforeseen effects on adjacent ecosystems. For example, uncontrolled clear-cutting of forest not only negatively effects forest ecosystems; the resultant erosion can also lead to detrimental siltation of downstream aquatic ecosystems (Chapter 5.5) and sediment deposition that can cause major harm to coral reefs (Chapter 5.2). Similarly, the smoke resulting from large-scale burning of lowland forests and peat swamps can have effects on other ecosystem types. For instance,

the fires that occurred in Sumatra and Kalimantan in 1997 led to red tide phytoplankton blooms that caused large-scale death of coral reefs in the Mentawai Islands (Abram et al. 2003, 2004) and Bali (van Woesik 2004). We are only beginning to understand the complexity of interactions among ecosystem types, but these examples warn us that degradation of one ecosystem can have broad cascading effects on other ecosystems.

Papuan Conservation: An Ecosystem Perspective

Conservationists address questions across a broad range of spatial scales. Each of these approaches can yield valuable insights and have important implications for the preservation of biodiversity. Here I briefly consider some of the issues relevant to conservation of entire ecosystems. I consider the services provided by Papua's ecosystems, discuss research into the relationship between biodiversity and ecosystem function, assess the representation of different ecosystems in Papua's protected areas network, and consider the implications of an ecosystem perspective on Papuan conservation issues.

ECOSYSTEM SERVICES

The earth's ecosystems provide a wealth of services necessary for human health and well-being, many of which are taken for granted or severely undervalued. Such services include purification of air and drinking water, reduction in the severity of droughts and floods, generation and preservation of soils and soil fertility, pollination of crops, nutrient cycling, climate stabilization, carbon sequestration, control of infectious disease, and erosion protection (Daily 1997; Krebs 2001). The relatively new field of natural resource economics has helped to raise awareness of the immense financial value of ecosystem services (Balmford et al. 2002, 2003; Balmford and Whitten 2003; Costanza 1991; Costanza et al. 1997; James, Gaston, and Balmford 1999; Peet 1992; Chapter 6.5), but the true benefits and costs of ecosystem services and their loss are rarely incorporated into decisions about natural resource management, particularly in developing countries. The financial costs associated with loss of ecosystem services resulting from degradation are rarely (or never) fully offset by those perpetrating the degradation, and the social and health costs are frequently disproportionately paid by people in lower economic groups. For example, the health costs alone associated with the Indonesian forest fires in 1997 have been estimated at 145 million U.S. dollars, with the majority of morbidity and mortality falling upon the poorest people in the region (Barber and Schweithelm 2000). Similar fires burn almost yearly and those who profit financially from these ecological disasters are not held accountable.

Papua's ecosystems provide environmental services of immense local, regional, and global importance. For example, Papua's forests maintain water quality and prevent soil erosion for numerous local communities. Regionally, Papua's mangroves serve as important breeding grounds for endangered vertebrates and commercially important marine invertebrates, sequester pollutants and environmental

contaminants, protect against coastal erosion, and can even serve as physical barriers protecting humans from tsunamis (Alongi 2002; Danielsen et al. 2005). More broadly, Papua's extensive forests and seagrass ecosystems serve as globally important sites of carbon sequestration that help to ameliorate global climate change. Therefore sound management and conservation of Papua's ecosystems will ensure that the valuable environmental services they provide will enhance human health and well-being for future generations.

DIVERSITY AND ECOSYSTEM FUNCTION

Because ecosystems provide such a wide range of services crucial to human health, substantial theoretical, empirical, and experimental work has addressed the relationship between diversity (or, more specifically, species richness) and ecosystem function. Although the theoretical roots of this discussion go back decades (MacArthur 1955; May 1972; Statzner and Moss 2004), the unprecedented extinction rates resulting from human degradation of natural ecosystems have made this issue one of considerable practical relevance in recent years (Cameron 2002; Kinzig 2001; Loreau et al. 2001, 2002; Naeem et al. 1994; Schwartz et al. 2000). Examination of this topic is complicated by several issues. First, until recently, unusually contentious academic debate over the role of biodiversity in ecosystem functioning has polarized discussion, hampered important syntheses, and created skepticism towards this important work among the general public (Mooney 2002; Naeem et al. 2002). Happily, recent collaborative syntheses have reduced these tensions and identified important new directions of investigation (e.g., Loreau et al. 2001; Hooper et al. 2005). Second, there are different measures of ecosystem function relevant to human well-being, including primary and secondary productivity, stability, resistance to invasion, and resilience, and there is little reason to expect that these different characteristics will be affected by biodiversity losses in similar ways (Hooper et al. 2005; Loreau et al. 2001; Schwartz et al. 2000). Third, multiple mechanisms may be responsible for observed relationships between diversity and ecosystem function (Loreau et al. 2002), highlighting one of the frequent difficulties ecologists face in attempting to infer processes from patterns. Finally, much of the recent experimental work has focused on studying the effects of manipulation of small-scale systems with relatively low species richness (e.g., McGrady-Steed et al. 1997; Petchey et al. 1999; Thébault and Loreau 2003; Tilman 1999). As most applied conservationists are primarily concerned with complex, large-scale systems, the practical relevance of insights gained from the study of much simpler systems is debatable on several grounds (e.g., Aarson 1997; Carpenter 1996; Hooper and Vitousek 1997; Huston 1999; Huston and McBride 2002; Rosenfeld 2002; Strivastava and Vellend 2005).

From a conservation standpoint, the key question is related to ecological redundancy (Lawton and Brown 1993; Rosenfeld 2002): are all species in an ecosystem necessary to sustain normal function, or can most ecosystem services be provided by a small subset of species (i.e., are many species functionally redundant)? It is unlikely that there is a universal relationship between diversity and ecosystem

function across all ecosystem types and functions (Hooper et al. 2005; Naeem et al. 1994). Some studies indicate that there are relatively high degrees of ecological redundancy and that substantial losses in biodiversity may have limited effects on the provision of certain ecosystem services, especially at small temporal and spatial scales or when environmental variability is relatively low (Hooper et al. 2005; Loreau et al. 2001; Schwartz et al. 2000, but see Rosenfeld 2002). However it should be noted that these studies typically use a limited definition of ecosystem function (often restricted to the effects of biodiversity loss on plant biomass), and many restrict their analyses to examining the effects of biodiversity loss within one trophic level. At larger temporal and spatial scales and in changing environments the number of species required to maintain ecosystem services increases (Hooper et al. 2005; Loreau et al. 2001, 2002). Research has now largely shifted away from focusing on simple indices of species richness to attempting to identify key functional species or groups that have disproportionate effects on ecosystem services (Loreau et al. 2001; Naeem and Wright 2003; Rosenfeld 2002).

There is debate over the extent to which biodiversity-ecosystem function studies have direct relevance for conservation biology (Hector et al. 2001; Lawler et al. 2001; Schwartz et al. 2000; Srivastava and Vellend 2005). The lack of universal support for a direct link between biodiversity and ecosystem function has led some to suggest that widespread use of this linkage as a justification for conservation goals is unwise (Krebs 2001; Lawler et al. 2001; Schwartz et al. 2000). Others acknowledge this point but argue that interactions between biodiversity and ecosystem services can provide useful additional arguments in support of conservation (Hector et al. 2001). It has also been suggested that although research on the relationship between biodiversity and ecosystem function has had limited conservation applications to date, this area promises to provide important insights into conservation policy in the foreseeable future (Lawler et al. 2001; Srivastava and Vellend 2005). While there is much debate in academic circles on how reduction in species richness or loss of key functional groups will effect the function and stability of ecosystems (and the pertinence of these debates to more applied conservation issues), the vast majority of ecologists agree that these losses will increase susceptibility to invasion by exotic species (and presumably also pathogens), reduce environmental services, and negatively impact the biosphere (Hooper et al. 2005; Loreau et al. 2001; Schläpfer et al. 1999). Therefore, as ecologists work to identify which species and functional groups are irreplaceable, a precautionary approach to biodiversity preservation should serve as a broad governing theme in conservation management in Papua.

THE PAPUAN PROTECTED AREAS NETWORK

The Papuan protected areas network encompasses approximately 66,500 km² of terrestrial habitats. The major ecosystems are not equally or proportionately represented within Papua's protected area system (Table 5.1.3). The most well protected land cover classes are lower montane forests and subalpine forests, with over 45% of each ecosystem type found within formally protected areas. However, lowland

Table 5.1.3. Representation of Papuan land classes in protected areas

Forest cover classes	Area (km ²)	Nature Reserve		Wildlife Reserve		National Park		Nature Recreation Reserve		Total	
		km ²	% land cover	km ²	% land cover	km ²	% land cover	km ²	% land cover	km ²	% land cover
Mangrove forest	15,124	718	4.7	1,508	10.0	2,122	14.0	1	0.0	4,349	28.8
Swamp	7,465	51	0.7	617	8.3	474	6.4	0	0.0	1,142	15.3
Swamp brush	10,559	38	0.4	1,963	18.6	591	5.6	0	0.0	2,592	24.6
Swamp forest	50,288	106	0.2	7,171	14.3	2,397	4.8	1	0.0	9,675	19.2
Lowland evergreen rainforest	213,627	12,539	5.9	11,309	5.3	6,785	3.2	296	0.1	30,928	14.5
Lower montane rainforest	8,658	2,216	25.6	974	11.2	777	9.0	0	0.0	3,966	45.8
Upper montane rainforest	27,373	2,317	8.5	2,171	7.9	4,042	14.8	0	0.0	8,531	31.2
Subalpine forest	4,266	47	1.1	355	8.3	1,523	35.7	0	0.0	1,925	45.1
Brush	4,490	211	4.7	276	6.2	388	8.6	0	0.0	875	19.5
Savanna	9,298	0	0.0	1,237	13.3	1,346	14.5	0	0.0	2,583	27.8
Total	351,147	18,242	5.2	27,581	7.9	20,445	5.8	298	0.1	66,567	19.0

Unforested lands are excluded. GIS analysis of protected areas map overlaying Landsat 7 ETM+ imagery of Papua, using a combination of images acquired in 1999 and 2000.

Source: Forest Watch Indonesia–Conservation International–Ministry of Forestry.

evergreen forest, by far the most dominant ecosystem type in Papua (61% of land area), is proportionately the least well represented in protected areas, with only 14.5% of this ecosystem type occurring within currently designated parks and reserves. This is a source of major concern as lowland forest is the ecosystem type most likely to suffer heavy degradation from uncontrolled human development, logging, and mining. In other parts of Indonesia almost all lowland forest found outside protected areas has disappeared or been severely degraded (Fuller et al. 2004; Holmes 2002; Jepson et al. 2001; van Schaik et al. 2001; World Bank 2001), with substantial losses even occurring within protected areas (Curran et al. 2004). Although this trajectory of habitat loss is far from inevitable in Papua, we would be well advised to consider the worst-case scenario that few forests in Papua will exist in their present state outside protected areas at the end of the 21st century. Under this scenario the current protected areas network in Papua is unlikely to be sufficient to protect the full complement of species, ecological processes, and ecosystem functions that is found there today. Assessment of this possibility will require careful consideration of the representation of ecosystem types within the current Papuan protected areas network, the prospects for maintaining connectivity between ecosystems, and the potential effects of global and regional climate change on the spatial distribution of ecosystems.

ECOSYSTEM-BASED CONSERVATION APPROACHES

Numerous strategies are currently employed and championed by scientists, conservation organizations, and government agencies involved in natural resource management. The widely-publicized "Biodiversity Hotspots" approach advocates prioritizing severely threatened areas of high species richness and endemism (Myers et al. 2000). Other strategies suggest that preservation of large wilderness areas that are ecologically intact and sparsely populated represent important opportunities for biodiversity conservation (Mittermeier et al. 2003). Some have argued that conservation efforts should focus almost exclusively on landscapes that are largely unaltered by humans (e.g., Myers 1980; Noss 1991), while others embrace the conservation potential of the careful management of lands that have already been substantially impacted (e.g., by development or logging, Fimbel 1994; Fimbel et al. 2001; Frumhoff 1995; Johns 1983; Marshall et al. 2006; Meijaard et al. 2005). Integrated conservation and development projects promise simultaneously to protect biodiversity and promote human well-being, health, and poverty alleviation (Goodwin and Swingland 1996; McShane and Wells 2004; Salafsky et al. 2001), while others suggest that the most effective way to conserve wildlife and habitats is strict protection and exclusion of most local people from protected areas (e.g., Terborgh 1999). Numerous campaigns have focused on the conservation of single species or specific taxonomic groups (e.g., Mittermeier et al. 2005; Stattersfield et al. 1998) and others work to preserve ecosystems, ecoregions, or functional landscapes (Hudson 1991; Noss 1996; Pressey et al. 1993; Woinarski et al. 1996). Each approach has strengths and limitations (Bonn and Gaston 2005; Kareiva and Marvier 2003; Kiss 2004; Young 1999; Orme et al. 2005; Possingham

and Wilson 2005), and it is likely that the most favorable conservation outcomes will result from careful application of a broad portfolio of conservation tactics and strategies.

Although a range of conservation strategies have applicability to Papua, the fact that Papua's ecosystems provide services of local, regional, and global importance strongly suggests that ecosystem-level conservation approaches are particularly warranted. The specific goals of ecosystem-based conservation plans will need to be carefully considered within the Papuan context, but the five basic goals of ecosystem management proposed by Grumbine (1992, 1994) provide a useful point of departure. Ecosystem management should strive first to protect sufficient habitat to ensure the long-term viability of populations of all native species; second, to represent all native ecosystem types across their range of natural variation within protected areas; third, to manage ecosystems on spatial scales that are sufficiently large to maintain important ecological processes (e.g., disturbance regimes, hydrological processes, nutrient cycles); fourth, to create ecosystem management plans for sufficiently long time scales (e.g., centuries) to permit evolutionary change; and fifth, to allow for human use and occupancy at levels that do not result in ecological degradation (Grumbine 1992, 1994). Ecosystem-based conservation plans in Papua are likely to be complicated to devise and even more challenging to implement effectively. Political support will need to be generated at all levels of government, ecosystems will need to be legally defined and delineated, consensus among diverse ethnic groups will need to be reached, and effective mechanisms to monitor the success of conservation interventions will need to be implemented. Ultimately, conservation efforts in Papua will not be successful unless such large-scale conservation issues are tackled.

Papua, and New Guinea more broadly, is a region of global biological significance. It includes the highest summit in Oceania, the only equatorial glaciers in the Pacific, the most extensive and diverse mangrove forests in Indonesia, and one of the world's largest remaining tracts of lowland tropical forest. Human population density in Papua is low. Rates of forest loss and remaining forest cover in Papua are encouraging when compared with many other areas in the tropics. Papua also is home to extensive and highly-diverse reefs that remain largely undamaged, at least in comparison to those in western Indonesia and many other parts of the world. However, threats to these ecosystems exist and will likely increase over time. We should have no illusions that protection of Papua's ecosystems will be easy or simple. Despite unprecedented investment in conservation, efforts to protect Indonesia's other lowland forests have largely failed (Curran et al. 2004; Fuller et al. 2004; van Schaik et al. 2001; Whitten et al. 2001). Our current conservation strategies have proved inadequate in the face of the legitimate and pressing demands of Indonesia's poorest citizens and the greed of illegal logging bosses. Papua presents one of the few remaining opportunities for proactive conservation action in Indonesia. Avoiding the fate of the rest of Indonesia's once-vast tracts of lowland forest will require a level of political will that has thus far

proved difficult to generate in other parts of the country. But the stakes are too high for us to let Papua quietly go the way of Sumatra and Borneo. The fate of Indonesia's last great wilderness area, and the people who rely on it, hangs in the balance.

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