PAPUA NEW GUINEA COUNTRY STUDY ON BIOLOGICAL DIVERSITY

edited

by

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Cover Photograph

Papua New Guinea is renowned for the diversity and splendour of its coral reefs. These provide a wide range of direct and indirect use benefits to coastal communities, and have a number of potential future uses, including possible medical applications (Bob Halstead).

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CHAPTER 6

STATUS OF BIODIVERSITY IN PAPUA NEW GUINEA

Introduction

Papua New Guinea probably harbours more than five percent of the world's biodiversity within some of the world's most biologically diverse ecosystems. Many of these organisms are endemic; that is, they are found only in Papua New Guinea or on the island of New Guinea. This chapter reviews the status of knowledge of Papua New Guinea's biodiversity from a taxonomic perspective, for example, by group of organism. Chapter 7 reviews the extraordinary range of environments which exist in Papua New Guinea. Many of the same processes that have promoted the evolution and maintenance of Papua New Guinea's biodiversity have also provided the diversity of habitats that we see today, so there is some overlap between Chapters 6 and 7.

The term "diversity" (or biological diversity) means many things, and many measures have been proposed to quantify diversity (Cousins 1991; Holloway and Stork 1991; Vane-Wright et al. 1991). At least four major types of diversity measurement can be recognised:

- **species richness** – the absolute number of species in a given area;
- **a combination of species richness and abundance** – taking account of rarity and balance within the species found in a given area;
- **genetic heterogeneity** – variability within species; and
- **taxonomic distinctness** – incorporating an historical (evolutionary distance) component.

This chapter focuses on species richness because very few data are available for the other categories for Papua New Guinea.

This chapter is based heavily on Volume 2 of the *Papua New Guinea Conservation Needs Assessment* (Beehler 1993), which should be referred to for more detailed background, discussion, and bibliographies. We have also gathered data from the staff and libraries of the University of Papua New Guinea, Papua New Guinea University of Technology, Wau Ecology Institute, Christensen Research Institute, Bishop Museum, and elsewhere.

In many cases, summary data are available only at the level of the island of New Guinea. In some cases, specialised collecting or analysis techniques have been applied only in the western half of the island of New Guinea, so data from Irian Jaya must be extrapolated to Papua New Guinea. In Chapters 6 and 7, the term New Guinea will be used to include the island of New Guinea and associated smaller islands, including all of Papua New Guinea (the region called Papuasia by botanists). Moreover, the Papua New Guinea biota cannot be understood in isolation because much of the biota is shared with Irian Jaya, the Solomon Islands, and Australia.

Status of Biological Knowledge

The many institutions interested in Papua New Guinea's terrestrial biodiversity have organised over 100 expeditions to areas throughout the country (Frodin and Gressitt 1982; Allison 1991). These areas were generally chosen on the basis of their biological interest (for example, high diversity, high endemism, and interesting geography). Although major gaps remain in coverage (especially in marine environments), knowledge of Papua New

Guinea's biodiversity is much better than that of many other tropical countries. Papua New Guinea is much better known than Irian Jaya for most (but not all) organisms – a factor which complicates analyses of endemism and distribution patterns.

Frodin and Gressitt (1982) presented an excellent history of the terrestrial biological exploration of New Guinea, extended for botany by Stevens (1989) and Frodin (1990), so only the major elements will be repeated here. Biological exploration of New Guinea by Western scientists started in the mid-1800s. The earliest expeditions collected relatively few specimens, however, and these specimens usually have relatively non-specific locality data. These expeditions provided the first specimens of many species that are endemic to New Guinea, but more comprehensive collections must be consulted to understand distribution patterns. The major period of exploration by foreign-based scientists occurred from about 1920 to 1950. Some of the most important work was associated with the first (1933-34) through seventh (1964), and especially the third (1938-39) Archbold Expeditions. Starting in the 1950s, local scientific institutions began to be built in Papua New Guinea and a great deal of research was done by scientists in residence at those institutions. Various government departments, especially in agriculture, fisheries, forestry, and public health, developed research programs and scientific collections. The Lae Herbarium, now part of the Forest Research Institute, stands out as a major, world-class centre for botanical studies. Universities were developed at Port Moresby and Lae, with field research stations at Motupore Island and elsewhere. In 1961, the Bishop Museum established a field station at Wau. This evolved into the independent Wau Ecology Institute in 1972 and continues to be a centre of biological research and conservation programs. Because of sampling intensity, Wau has become one of the best known places in the country for terrestrial biodiversity. The recent establishment of the Christensen Research Institute near Madang has dramatically increased knowledge of marine biodiversity.

The result of the activities in biological research in New Guinea is a host of resources within Papua New Guinea, and at major international research centres (especially Sydney, New York, London, Leiden, Honolulu, Canberra, Boston, and Bogor). Overall, a very large body of data exists, but it is scattered through scientific literature (journals and books) that has accumulated over the last 200 years and collections located around the globe. For example, it has been estimated that some 200 000 reptile and amphibian specimens (Allison 1993) and 450 000 plant specimens (Stevens 1989) exist from New Guinea. Bringing these data together in a modern information management system is a major challenge, but it is possible and will provide the knowledge base for resource management (Miller 1993). However, even a comprehensive compilation of existing knowledge would still have major gaps, so additional sampling and research is desperately needed. Even for plants, the overall density of sampling remains poor and is one of the lowest in the Malesian botanical region (Stevens 1989; Frodin 1990). The tremendous geographical diversity in Papua New Guinea requires adequate samples on which to base 'analysis of variation within and amongst species to correctly define those species. Increasing the absolute knowledge of Papua New Guinea's biota will be accomplished only by improving in-country scientific infrastructure (especially collections) and human resources.

The gaps in existing biological knowledge include the following (see the Conservation Needs Assessment for more details): many areas within Papua New Guinea have never been adequately sampled (see map and list in Chapter 7); many organisms that are small in size or live in habitats that are difficult to sample have been inadequately collected (especially fungi, soil invertebrates, and some marine invertebrates); and many of the most diverse organisms have never been subjected to modern taxonomic analysis (especially some insects and marine invertebrates).

How can Papua New Guinea fill these gaps in knowledge of biodiversity? The most important step is to create an information management system within Papua New Guinea that can receive, manage, and disseminate biodiversity knowledge. Such a centre does not necessarily have to own and maintain all the data, but could serve a coordinating and networking role. Without such a centre, data that flow from national and international institutions is effectively lost. The processes of the Conservation Needs Assessment and this Biodiversity Country Study demonstrated how difficult it is to find biodiversity information on Papua New Guinea within the country. Additional processes needed are:

- strengthening national institutions involved in biodiversity and their human resources;
- collaborative projects with international research centres to make New Guinea data available; and
- additional field surveys, taxonomic research, and ecological research.

National Species Diversity, Endemism, and Status

Table 6.1 summarises knowledge of major taxonomic groups of organisms. Classification in the table generally follows Parker (1982) with the use of five kingdoms (Margulis and Schwartz 1988). Some artificial categories of convenience are used (for example, marine molluscs). Freshwater categories generally include brackish water dwellers. Because data are often available for New Guinea rather than Papua New Guinea, we have specified which figure is provided. For some marine invertebrates, faunal data are only available for specific regions (for example, Madang, Motupore Island, or the Torres Strait).

Endemism refers to species unique to a certain area. Endemism tends to follow biogeographic boundaries determined by geographic factors and evolutionary history. It is important to note that biogeographic boundaries do not correspond with the political boundaries of Papua New Guinea. The western half of the island of New Guinea is the Indonesian State of Irian Jaya. The island of Bougainville is part of Papua New Guinea, but is biogeographically most similar to the Solomon Islands. The same conflict between biogeographic and political boundaries arises across the Torres Strait between the southern part of Papua New Guinea and the northern tip of Queensland, Australia (Kikkawa et al. 1981). Another factor which affects apparent endemism is the level of study which has taken place on particular taxonomic groups, for example, the relatively visible bird species are well-documented, whereas only limited information exists on many invertebrates. Thus, some organisms are known only from a particular place simply because they have not yet been identified elsewhere. At individual sites, high species diversity (absolute number of species) does not necessarily correlate with high numbers of endemic species. Additional information on species which are endemic to Papua New Guinea may be found in the Conservation Needs Assessment report and maps.

As noted previously, there is a vast literature on the biota of New Guinea, but it is scattered in an array of books and journals in many languages. Outside of the vertebrates, there are very few synthetic papers which review entire groups for any particular region of interest. We have used the Conservation Needs Assessment and literature that could readily be gathered to construct Table 6.1. We have not undertaken a detailed assessment of the scattered data in the taxonomic literature (for example, Papua New Guinea records within taxonomic studies on a world basis). This would produce a great deal of data and should be done, but it will be a time consuming activity. Ewers (1973) provides a window on a small part of the taxonomic literature. A search of the computer database version of Biological Abstracts showed some 4 000 papers on biology (including ecology and some medical subjects) of New Guinea from 1970 to 1994, an average of some 166 titles per year. This is, in fact, an underestimate, because it under-samples the taxonomic literature (for example, New Guinea records within monographs covering larger areas). There is also a vast number of additional records that are found only in collections and have never been mentioned in the literature. These, too, could be compiled into a very useful database by gathering data from the collections in Papua New Guinea and combing the major museums and herbaria of the world for Papua New Guinean specimens.

Viruses, Bacteria, and Algae

Very poor data are available for unicellular organisms such as viruses and bacteria outside of those with direct economic importance in agriculture (Shaw 1984; Muthappa 1987) and the health of humans and domestic animals. Algae, both freshwater and marine, are poorly documented beyond a few studies (especially Vyverman 1991a, 1991b).

Fungi

Shaw (1984) listed 2 390 fungi from Papua New Guinea. Hawksworth (1994 personal communication) suggests a ratio of 1:6 between vascular plants and fungi. Using a conservative estimate of 15 000 vascular plants yields an estimate of 90 000 fungal species. Lichens, which are symbiotic combinations of fungi and algae, were reviewed by Streimann (1986) and Lambley (1991). Bryophytes, the mosses and liverworts are the subject of active research that has not yet been synthesised (Grolle and Piippo 1984; Piippo 1994).

Protozoans

Protozoans are almost entirely unstudied, with the exception of marine foraminifera, which have been censused at Motupore Island (57 species – Haig 1979) and Madang (182 species – Langer 1992).

Plants

The vascular plants probably include 15 000 to 20 000 species of ferns and flowering plants. There is a recent list of genera (Hoeft 1992), but modern species-level treatments exist for only a small portion of the flora (for example, Womersley 1978; van Royen 1980; Henty 1981). Most of Papua New Guinea is within the region covered by the ongoing Flora Malesiana project. The overall status of knowledge of plants has been reviewed recently by Johns (1993), Stevens (1989), and Frodin (1990). Orchids are particularly diverse, with well over 3 000 species (van Royen 1979; Howcroft 1992). Seagrasses and seaweeds are important in marine ecosystems.

Invertebrates

Knowledge of the taxonomy and distribution of invertebrates in the New Guinea area is much less focused than is the case for vertebrates. The information to a large extent reflects the interests of individual taxonomists who have worked on particular groups often in circumscribed areas. The marine invertebrates, other than molluscs and crustaceans, are very poorly known. Some groups have been studied at Motupore Island and Laing Island, and many are now under study at Madang, but much remains to be done. A large number of animal phyla are represented by marine invertebrates that are effectively unknown in Papua New Guinea but are probably major components of the marine biodiversity. The situation can be illustrated with corals, based on studies in progress at Madang by D. Potts and colleagues.

The total number of coral species in Papua New Guinea is unknown although about 300 species have been reported. No established coral taxonomist has worked extensively in New Guinea, and serious scientific collections, suitable for assessing biodiversity, are extremely limited. The only intensive study of a single site by an experienced coral taxonomist listed 285 living species from Motupore (Veron and Kelley 1988). On the north coast, four collections have been made near Madang (J. Oliver in 1988; B. Hoeksema in 1992; J. Pandolphi; and D. Potts in 1994); an extensive study at Laing Island is now being published (Claerebout); and largely undescribed collections have been made by geologists working on uplifted fossil reefs of the Huon Peninsula. Veron (1993) recognises more than 650 reef-building coral species in the entire central Indo-Pacific region (northern Australia to Japan), based mainly on his own work in Australia, Japan and the Philippines. Most have ranges from Australia to Japan. Although he includes only one Papua New Guinean site (Motupore), it is likely that most of these species also exist in Papua New Guinea and that other undescribed species are also common. Thus, the total number of reef-building coral species in Papua New Guinea is likely to be at least 700 (D. Potts, personal communication, 1994).

Yet, coral biodiversity in Papua New Guinea may be much greater than 700 species. Despite their abundance, large size, and geological and biological importance, coral taxonomy is very poorly known. The world has only seen about 25 serious coral taxonomists over the last century, and most of these have been geologists more concerned with fossils than living forms. Species recognition is notoriously difficult even for experts, and especially in the most diverse genera and families (for example *Acropora, Montipora, Porites*, and Faviidae). There has been a strong tendency to group morphologically similar forms into a relatively small number of highly variable species with cosmopolitan distributions (for example, nearly 300 species of world *Porites* were described before 1900, but only about 30 are now accepted). Recent genetic work demonstrates that species names are not being applied consistently in adjacent localities and that some presumably widely distributed "cosmopolitan" species may consist of suites of locally endemic species (Potts, in preparation). Independent taxonomic studies of the same individual corals using live tissues, genetics, micromorphometrics, and traditional skeletal morphology show that the traditional characters have the least ability to discriminate species consistently (Potts et al. 1993). For these and other reasons, it seems likely that future coral taxonomy will recognise many more species than at present, and that many will be endemics restricted to local regions such as Papua New Guinea. Thus, total Papua New Guinean coral biodiversity may exceed 1 000 reef-building species, with a similar number of smaller, cryptic, often deepwater species of non-reefbuilders (which have never been seriously collected anywhere in Papua New Guinea).

Studies of other invertebrate groups, such as sea pens (Pennatulacea), nudibranchs, and crustaceans indicate that the Madang lagoon and vicinity may have the highest species richness of any site in the world. Hoeksema (1993) found this was also true for mushroom corals (Fungiidae). He found 36 of the 42 species previously described worldwide, and also described a new species. It is also likely that other species exist in the area. Moreover, as with corals, genetic data are calling into question the entire concept of shallow water "cosmopolitan" species in many invertebrate groups (for example, jellyfish — Greenberg et al., in press).

Other faunal studies on marine invertebrates include sponges (25 common species from Motupore Island — Kelly Borges and Bergquist 1988), various coelenterate groups (Bismarck Sea — Bouillon 1984; Bouillon et al. 1986; Pages et al. 1989), sea anemones (18 species in Madang vicinity — Fautin 1988), octocorals (83 species from Bismarck Sea — Verseveldt and Tursch 1979), and echinoderms (177 species from Torres Strait — Clark 1921).

Some work has been done on marine crustaceans (crabs, etc.), but much work remains to be done. Morgan (1988) reported 198 species of marine and freshwater decapod crustacea from the Madang region. Marine molluscs are probably better known than most other invertebrates because of the popularity of their shells with collectors. However, the existing knowledge is superficial and does not penetrate the very high diversity that exists in Papua New Guinea. A popular guide to shells of Papua New Guinea includes 950 species (Hinton 1979), but there are more than 800 prosobranch gastropods (snails) alone in New Guinea (Wells 1990), 268 of which are found at Motupore Island (Signor et al. 1986). Ongoing studies of nudibranchs in Madang Lagoon have recorded at least 600 species and are expected to reach an eventual total of 700-800 species (T. Gosliner, personal communication).

The status of terrestrial, freshwater, and brackish molluscs (mostly snails) was reviewed by Cowie (1993). Some 650 species have been described but they are in great need of synthetic revision and many species remain unknown.

Terrestrial and freshwater invertebrates other than insects and molluscs have been very poorly sampled and studied. Several recent studies include earthworms (at least 42 species — Easton 1984; Nakamura 1992), leeches (at least five species — Van der Lande 1994), flatworms (Sluys and Ball 1990), and onychophorans (seven species

– Van der Lande 1993). Freshwater decapod crustaceans (crabs, crayfish, etc.) include at least 87 species, with at least 31 endemic species (Eldredge 1993). Nematodes, except those that parasitise crops, livestock, and humans, are almost unknown in Papua New Guinea, although there must be a very large number of species. Freshwater rotifers include at least 135 species, all widespread outside Papua New Guinea (Segers and De Meester 1994).

Information on New Guinea insects and related terrestrial arthropods is in drastic need of collation, and the quality and quantity of knowledge is uneven for different groups. Generally, levels of diversity and of endemism are high amongst the insects. The New Guinea fauna is primarily derived from the oriental region, but Australian elements are present also, especially in southern savannahs. The general status of knowledge of insects in Papua New Guinea was reviewed by Miller (1993). The bibliography by Gressitt and Szent-Ivany (1968) has been the only broad attempt to synthesise knowledge of Papua New Guinean insects, although reviews exist for some groups (for example, flies in Evenhuis 1989). Given ratios of the New Guinea fauna to the world fauna for groups that are well known, rates of description of new taxa, and the size of the Australian insect fauna (CSIRO 1991), there may be 300 000 species of insects in New Guinea, but this figure may be high or low by 100 000 species. Despite the relatively small area, Papua New Guinea ranks twelfth amongst world nations in terms of endemism of large butterflies (Papilionidae, Pieridae, Nymphalidae, 56 of 303 species are endemic) (Sisk et al. 1994). The mites of New Guinea are very poorly known, but have the potential for being a megadiverse group.

Fishes

Existing knowledge of the fishes of New Guinea has been well synthesised in field guides (Allen 1991; Allen and Swainston 1993) and in a checklist (Kailola 1987-1991), but more research remains to be done. There are well over 3 000 fishes in the region, including over 300 found in freshwater. The native freshwater fish fauna is derived from the marine fauna, and primary freshwater ostariophysian fishes are absent with the exception of *Scleropages* spp. (Roberts 1978; McDowell 1981). All species naturally occurring in freshwater are either diadromous or descendants of marine families. This has been noted to have an adverse effect on species diversity and fish stock abundance resulting in low fisheries yields (Coates 1985). Of the 329 species occurring in freshwater in New Guinea (Allen 1991), 13 species are non-indigenous, and about 102 species are believed to have a marine larval stage and are relatively widespread outside New Guinea. This leaves 214 native fish species that are limited to freshwater, of which 149 (70%) are endemic to New Guinea. Two closely related families are unique to Australasia – Melanotaeniidae (Rainbowfishes) and Pseudomugilidae (Blue-eyes), and this fauna further differs to that of other continental tropical regions which are dominated by cichlids and primary division Ostariophysan fishes (carps, barbs, loaches, characins, and catfishes). The Ostariophysan assemblage is represented in New Guinea-Australia only by plotosid and ariid catfishes. All the freshwater fishes except the lungfish (*Neoceratodus*), bony tongues (*Osteoglossus*), and possibly galaxiids are considered to be derived from marine ancestors.

The freshwater ichthyofauna can be clearly divided into two zoogeographic regions. Freshwater bodies to the south of the central cordillera have an ichthyofauna closely allied with that of northern Australia, reflecting a former land connection. While several of those species with diadromous habits can be found in both southern and northern rivers, the fish permanently inhabiting freshwater in the north are invariably different species from those in southern water bodies. Apart from the land barrier formed by the central cordillera, northern rivers are much younger than southern rivers. Of those fish families common to both northern and southern rivers, species diversity is invariably lower in the north (Coates 1987b).

Amphibians

Of the three orders of amphibians, neither caecilians nor salamanders occur in Papua New Guinea. Frogs (Anura: five families) are well represented, with 197 species described at present, and new species being recognised as current research proceeds (Allison 1993). The five families are: Bufonidae (the introduced cane toad, *Bufo* *marinus*), Hylidae, Leptodactylidae, Microhylidae, and Ranidae (Allison 1993). Not all species are aquatic – a large number are forest dwellers which burrow beneath the surface, or live beneath the leaf litter. The majority of species are endemic to either Papua New Guinea or the island of New Guinea. A southern group having its origins from Australia can be recognised, as can a group of species originating from the Solomon Islands to the south-east of Papua New Guinea. The surrounding islands have, in general, a depauperate amphibian fauna in comparison with the adjacent mainland. Much taxonomic work remains to be done, and the rich variation in specialised habitat requirements which is already known, suggests that many more species are yet to be described. The only toad in Papua New Guinea (*Bufo marinus*) is a classic example of a poorly planned biological control introduction.

Reptiles

The reptilian fauna of New Guinea consists of representatives of all four main groups. The turtles and tortoises (Chelonia), number thirteen species in total, seven associated with freshwater and six with marine habitats (Allison 1993). Three freshwater species are endemic in the broad sense, of which one, *Chelodina parkeri*, is restricted to the Fly River system.

The bulk of the reptiles are lizards (Squamata) with approximately 195 species of lizards and 98 species of snakes (Allison 1993). Most of the lizard species (71%) belong to the family Scincidae with the Agamidae and Gekkonidae both represented by more than ten species. The overall endemism is about 60 percent. The snakes belong to seven families, all of which are shared with Australia. Among the snakes, the level of endemism is considerably less than that found for lizards. At least 32 species (33%) can be considered endemic to the island of New Guinea and northern Australia.

There are two described species of crocodile in Papua New Guinea – the New Guinea or freshwater crocodile (*Crocodylus novaeguineae*) and the saltwater crocodile (*Crocodylus porosus*). Both species are still found in relatively large numbers and are heavily exploited for hides and meat. However, freshwater crocodile populations along the south coast probably represent an undescribed species (Allison 1993: 165).

Birds

The birds of Papua New Guinea are relatively well studied compared to other animals (Beehler et al. 1986; Coates 1985, 1990; Osborne 1987), and show a high degree of endemism. To date, a total of 762 species of bird have been recorded from Papua New Guinea, of which 405 (53%) are endemics (Papua New Guinea Bird Society Checklist, in preparation). This figure is higher than some other recent figures (for example, 725 species in New Guinea – Beehler et al. 1986; and 740 species in New Guinea – Coates 1985-1990) because of the inclusion of vagrants, taxonomic changes, and additional islands covered. Of these endemics, 289 (39%) are confined to mainland Papua New Guinea and/or the D'Entrecasteaux group of islands. Sixty (8%) are endemic to the Bismarck Archipelago and/or Admiralty Islands with nine of these extending into the Solomon Islands. Thirty (4%) are endemic to the Solomon Islands. Thirty-eight species are shared between Papua New Guinea and Northern Queensland while the 357 non-endemics are generally more widely spread. On a world basis, Papua New Guinea ranks fifth in terms of the number of restricted-range bird species and seventh in the number of endemic bird areas as mapped by the International Council for Bird Preservation (Bibby et al. 1992).

Mammals

Papua New Guinea is impoverished in terms of the range of mammalian orders compared to South-East Asia (nine orders of mammals found there which are lacking in Papua New Guinea). At least two of the existing four mammalian groups – marsupials and rodents – show a high degree of endemism. However, with 187 indigenous mammals (Flannery 1990; Menzies 1991), the New Guinea region has only slightly fewer mammal species than Australia, although the surface area of the former is approximately ten percent that of Australia. In addition, some 24 marine mammals (cetaceans) and the dugong occur within Papua New Guinean waters (extrapolated from distribution maps in Jefferson et al. 1993).

Approximately 71 species of marsupials have been recorded from the New Guinea area, of which 60 (84%) can be considered as endemics (not occurring in Australia). Two species of monotremes occur in New Guinea and the long-beaked echidna (*Zaglossus*) is endemic to the island of New Guinea. Seventy-five bat species belonging to six families are known. Rodents, belonging exclusively to the Muridae, have radiated extensively in the New Guinea region.

Overall Species Diversity

Estimates of the total number of species in the world vary tremendously, especially because estimates of insects range from several million to fifty million. Briggs (1994) presented an estimate of 12 300 000 terrestrial species and 200 000 marine species. However, Briggs did not include fungi, which would number about 1 500 000 species (250 000 vascular plants x 6, following Hawksworth), yielding a world total for multicellular species of approximately 14 000 000.

What is the total number of species in Papua New Guinea? No exact figure can possibly be determined, but a very rough estimate can be derived in two ways. In some of the the better known groups of organisms (for example, flowering plants, and birds), about five percent of the world's species occur in New Guinea. This is remarkable in itself, given that New Guinea has less than one percent of the world's land area. Five percent of the putative world figure of 14 000 000 is 700 000. This is likely on the high side, because Briggs (1994) probably overestimates the number of insect species (Basset et al. 1995). Alternatively, working up from the species, numbers in Table 6.1 yield about 90 000 fungi, 20 000 plants, 5 000 invertebrates, 300 000 insects, and 4 000 vertebrates for something more than 400 000 species. However, this does not take into account the probably large, but totally unknown, numbers of nematodes and mites. A reasonable working estimate for total species numbers in New Guinea is in the range of 300 000 to 500 000 for fungi, plants, and animals. The major problems in this estimate come from the megadiverse groups – fungi, nematodes, insects, and mites. These statistics are for New Guinea as a whole – most of these species (probably at least two-thirds) will occur within Papua New Guinea, but it is impossible to guess how many.

If approximately 400 000 species occur in New Guinea, how many of these are endemic? Statistics vary tremendously between groups (see Table 6.1), from very low for many marine groups to fairly high for many vertebrates. Vascular plants are likely 60 percent endemic (Johns 1993). However, endemicity will be much lower for Papua New Guinea, because of biotic overlap with Irian Jaya, Australia, and the Solomon Islands.

Conservation Status of Species

Table 6.2 lists species that are legally protected or recognised as threatened by Papua New Guinean laws, CITES or the IUCN. Animals are organised by phylum, class, and order, then alphabetically by genus and species. IUCN status data come from Collar et al. (1994) for birds, and Groombridge (1993) for other animals. Important background information on IUCN status can also be found in Thornback and Jenkins (1982, mammals), Seri (1992, mammals), Groombridge (1982, reptiles), and Wells et al. (1983, invertebrates). The birds follow the new IUCN criteria (Mace and Stuart 1994; Collar et al. 1994): Extinct (Ex), Extinct in the wild (Ew), Critically endangered (c), Endangered (En), Vulnerable (V), Data deficient (D), and Near-threatened (N). The other groups follow the traditional IUCN categories (for example, Wells et al. 1983): Extinct (Ex), Endangered (E), Vulnerable (V), Rare (R), Indeterminate (I), and Insufficiently known (K). Marsupials listed as potentially vulnerable by Seri (1992; see also

Kennedy 1992:vi) were upgraded to vulnerable by Groombridge et al. (1993). Species in the IUCN categories classified as indeterminate, insufficiently known, data deficient and near-threatened are not included unless they are also listed by Papua New Guinea or CITES. Latin and English names generally follow Beehler and Finch (1985, birds), Flannery (1990, mammals) and Allen (1991, fishes). Three birds protected by Papua New Guinean law do not actually occur in Papua New Guinea – *Goura cristata, Circus melanoleucus* and *Astrapia nigra* (Coates 1985: 118, 304, 1990: 543, 546; Beehler, personal communication, 1994). Chapter 20 reviews national legislation, as well as international conventions and agreements that provide for the management and protection of Papua New Guinea's biological diversity (see also Seri 1992). The listing of entire higher taxa under CITES makes them rather difficult to tabulate – there are probably over 3 000 species of orchids in Papua New Guinea, all recognised under CITES Appendix II, although many remain unknown to science.

There is a considerable lack of concordance between the listings of Papua New Guinea, CITES, and IUCN – both in species included and their status. Except for the IUCN bird list (Collar et al. 1994), there is little or no current survey data backing up the listings. Except for the birds and marsupials, there has been very little consultation with managers or biologists in Papua New Guinea in formulating the CITES and IUCN lists. All the lists, especially the IUCN one, are very uneven and heavily influenced by information that is available opportunistically. While this can be useful, the taxa that are absent may simply be absent because of lack of information, not lack of conservation problems. Even for mammals, many of the listings are based on data that are over 20 years old (for example, comments in Seri 1992).

Care should be taken to promote opportunities for conservation through farming or ranching (Parsons 1991). For species that are endangered by habitat loss, the best way often to protect them in Papua New Guinea is to get local people to value the species and therefore the habitat. Thus, it is important that protected species listing and permitting processes are flexible enough to allow for the sale of individuals cultivated by appropriate means. The permit system that has worked for crocodile farming, should be considered for application to other organisms, including birdwing butterflies. Once a species has been listed as 'protected' under Papua New Guinean law, there does not seem to be an efficient mechanism for permitting trade (or delisting, if necessary). In summary, lists of threatened species are useful as a starting point, but need continual refinement based on modern field surveys and other assessments by experts.

According to the IUCN criteria applied in the Birdlife International World Checklist of Birds (Collar et al. 1994), 31 Papua New Guinean endemic birds are listed as threatened, including the Victoria Crowned-pigeon (*Goura victoria*), Southern Crowned-Pigeon (*Goura scheepmakeri*), New Guinea Harpy Eagle (*Harpyopsis novaeguineae*), and three species of Bird of Paradise. These are important species from the conservation standpoint, both as indicator and flagship species. A further 32 endemics are listed as near-threatened while 20 others are listed as data deficient, despite birds being the best known faunal group in Papua New Guinea. The status of monotreme and marsupial mammals in Papua New Guinea was recently reviewed by Seri (1992). However, comprehensive survey data are available for only a very few species of any animals. Even the best known threatened invertebrate species in Papua New Guinea, the Queen Alexandra's Birdwing Butterfly (*Troides alexandrae*[1]) and the Manus Green Tree Snail (*Papustyla pulcherrima*) have not been the subject of adequate status surveys (Miller 1993; Cowie 1993).

Creating a list of rare or threatened plants for Papua New Guinea would be very difficult. Many species are known from only one or a few collections. Their "rarity" relates more to lack of sampling or taxonomic attention than to actual conditions in the field. Some of the actual narrow endemics might be threatened by forestry or mining, but others are totally protected by inhospitable remoteness. The same problem applies to most invertebrates. Some orchid populations have suffered from overcollecting, and sandalwood and ebony may be endangered by overexploitation (J.R. Croft, personal communication, 1994).

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[1] It is worth noting that all the birdwing butterflies formerly placed in the genus *Ornithoptera* are now placed in the genus *Troides* (Hancock 1983; Miller 1987).

Role of CITES on Papua New Guinea's Biodiversity Endowment

Papua New Guinea signed the Convention on International Trade in Endangered Species (CITES) in 1976. Detailed data on the volume of export trade of CITES listed organisms by species or derivative product are not available for recent years. General data on the volume of export of crocodiles and butterflies are discussed in Chapter 12. In 1992, only 11.4 percent (8 464 specimens) of the butterflies exported through the Insect Farming and Trading Agency were CITES listed (P.B. Clark, personal communication, 1994). Most exports of CITES listed crocodiles and butterflies are from ranches, so presumably the trade is sustainable, but detailed data are not available. There is anecdotal evidence that illegal exports are taking place in regard to orchids (Kores 1977; Bandisch 1992), butterflies, reptiles, and birds, but no firm statistics are available. In some cases, it is clear that wildlife was exported from New Guinea without proper permits, but it is not clear if it originated in Papua New Guinea or Irian Jaya.

Ex-Situ Conservation Infrastructure

Organised *ex situ* conservation programs in Papua New Guinea are limited to a relatively few species. However, there are significant genetic resources maintained by various institutions (see also Chapter 12). The largest botanical garden is the National Botanical Garden in Lae (also the site of the national herbarium). Smaller botanical gardens exist at the University of Papua New Guinea (Waigani) and elsewhere. A major living collection of orchids is maintained at the Lipizauga Botanical Sanctuary, Mount Gahavisuka (Goroka). Germplasm collections of agricultural cultivars exist at various research sites around the country (for example, Bourke 1985; Levett et al. 1985; Sowei 1992). The Insect Farming and Trading Agency (Bulolo and elsewhere) maintains butterfly colonies and, along with Wau Ecology Institute, Christensen Research Institute, and Unitech, encourages butterfly ranching thoughout the country. Several small collections of captive vertebrates exist, with the largest at Wau Ecology Institute. Crocodile farms exist throughout the country. The Department of Agriculture maintains cultures of microbes for research and identification. Some species are maintained at zoos and botanical gardens outside of Papua New Guinea.

There are several significant collections of voucher specimens that are crucial to documenting biodiversity within the country (Frodin 1985; Sakulas 1985). The national herbarium is at the Forest Research Institute, Lae, but smaller herbaria are held at Wau Ecology Institute, Christensen Research Institute, University of Papua New Guinea, Unitech, and the Department of Agriculture. Two national insect collections exist at the Department of Agriculture (Konedobu) and at the Forest Research Institute (Lae). Smaller insect collections are maintained at Wau Ecology Institute, Christensen Research Institute, and various agricultural research stations. Vertebrate collections are maintained at the National Museum, Department of Environment and Conservation, Department of Fisheries, Wau Ecology Institute, and Christensen Research Institute.

Flagship Species

Flagship species are those which may serve to generate support for conservation action from which a broader component of biodiversity would benefit. Usually flagship species are endemic to the area, and often are threatened in a conservation sense. The uniqueness of the monotreme and marsupial mammals is such that a number of species could serve as flagship species (for example, *Zaglossus bruijni, Dendrolagus dorianus, D. goodfellowi,* and *D. scottae*). Another is the Dugong *(Dugong dugon)*.

The Victoria Crowned-Pigeon (*Goura victoria*), Southern Crowned-Pigeon (*Goura scheepmakeri*), Vulturine Parrot (*Psittrichas fulgidus*), and New Guinea Harpy Eagle (*Harpyopsis novaeguineae*) could draw attention to the effects of lowland rainforest destruction by logging. Birds of Paradise are recognised worldwide as being almost wholly New Guinean. The Ribbon-Tailed Bird of Paradise (*Astrapia mayeri*), Black Sicklebill (*Epimachus fastuosus*), Goldie's

Bird of Paradise (*Paradisea decora*), and Blue Bird of Paradise (*Paradisea rudolphi*) are all attractive and have international appeal.

Possible reptile flagship species include the turtle *(Carettachelys insculpta)*; the barred python *(Liaisis boa)*; Boelen's python *(Python boeleni)*; *Varanus salvadori*, probably the longest lizard in the world; *V. prasinus*, the green monitor, with its striking colourations; *Corucia zebrata*, an unusual skink species with a prehensile tail, which may be the largest skink species in the world; and frogs of the family Microhylidae, which are unusual in being terrestrial breeders with unusual habits.

Among fish, the Pseudomuqilidae (for example, *Pseudomuqil connieae*) and Melanotaenidae (for example, *Melanotaenia lacustris*), which are endemic to the Australia-New Guinea region, are obvious candidates for flagship species. A number of colourful coral reef fish species could attract attention to the extensive reefs of Papua New Guinea.

Flagship invertebrate species must include the birdwing butterflies (*Troides*, formerly *Ornithoptera*) and, in particular, *T. alexandrae* which is the largest butterfly in the world with a wingspan in excess of 25 centimetres. Other possibilities include the weevil *(Gymnopholus lichenifer)*, which has well-studied mutualistic relationships with a variety of plants and animals, and the Manus green tree snail *(Papustyla pulcherimma)*.

Population Status of Species at Risk

Because of the high biodiversity of Papua New Guinea and the logistical difficulties of field surveys, detailed information on population sizes, over time, is available for only a few species. Crocodiles are perhaps the best known example in Papua New Guinea (Goldstein 1991). Once threatened with extinction by hunting for the skin trade, they are now managed in the wild and also in captivity. Seri (1992) provided recent data on selected mammals, and the Conservation Needs Assessment provides additional examples and references.

Saltwater and freshwater crocodile populations declined during the late 1950s and 1960s, through indiscriminate hunting. In 1969, the *Crocodile Trade (Protection) Act* (Chapter 213) was implemented which, to protect breeders, placed a ban on trade in skins greater than 51 centimetres belly width. This halted any further decline in crocodile numbers, as indicated by a steady export level during the 1970s. The Act also allows for the control of the crocodile industry on a systematic basis. Regulations under this Act control crocodile farming and the purchase and export of skins. In 1981, a ban was placed on trade in skins smaller than 18 centimetres. This ban was established because Papua New Guinea was in a position to ranch crocodiles on a large scale. By 1984, although the number of skins exported was the same as in previous years, 30 percent were from ranched animals and consequently were of higher grade and greater size. Both species of crocodile are listed in Appendix 2 of CITES which means that they are regarded as vulnerable, but trading is allowed to continue. For many years, Papua New Guinea has been the only country allowed by CITES to trade in *C. porosus*. In 1982, extensive monitoring of both species commenced especially in the Ambunti District of East Sepik Province.

Invasive and Introduced Species

Non-indigenous species represent a major economic threat. Other than a few of the most important agricultural pests, data do not exist to address these issues in any detail. The recent report prepared for the United States (OTA 1993) provides ample examples of the problems and solutions.

The aquatic plants — water hyacinth (*Eichhornia crassipes*) and salvinia (*Salvinia molesta*) — have been major problems in the Sepik River and elsewhere, illustrating the damage that invasive non-indigenous species can cause, and the potential of biological control (see Box 6.1). Introduced freshwater fish provide another case study of positive and negative environmental aspects of introductions. The recent establishment of the apple snail in the Lae area (Laup 1991) also underscores the importance of pest exclusion and detection programs (Kanawi et al. 1994).

Other species have been introduced for biological control of agricultural pests and weeds. The early history of biological control introductions in Papua New Guinea is reviewed by Wilson (1960). Modern biological control programs against insects, snails, and weeds in Papua New Guinea are reviewed by Waterhouse and Norris (1987). While biological control programs can be very beneficial, poorly implemented programs can have serious impacts on non-target organisms (Howarth 1991).

Herington (1977) reviewed animal species that are known to have been intentionally introduced to Papua New Guinea for agriculture, hunting, and biological control. Some data on insect introductions for biological control was compiled by Wilson (1960) and Waterhouse and Norris (1987), but documentation for non-indigenous insects remains very poor. There has not been a thorough review of non-indigenous plants in Papua New Guinea, although many are included in the review of weeds by Henty and Pritchard (1975). Box 6.2 summarises non-indigenous animals in Papua New Guinea, but there is no comprehensive program for monitoring the presence of non-indigenous species. Therefore, general statistics on distribution, population sizes and rates of change, environmental impacts, as well as the effectiveness and costs of control measures, are not available.

Box 6.1: Invasive Aquatic Weeds: Salvinia (*Salvinia molesta*) and Water Hyacinth (*Eichhornia crassipes*).

Two aquatic weeds, *Salvinia molesta* and *Eichhornia crassipes*, are now widespread in the low-lying wetlands of Papua New Guinea. *Salvinia molesta* was first recorded in Papua New Guinea in 1977 at Wau, and on the Sepik River where it was probably introduced in 1971-72 (Mitchell 1978-1979, 1979). By 1979, salvinia covered 80 square kilometres and the physical impact of the weed was reflected in the decline in fish catches, crocodile hunting, and sago gathering, and also in the disruption to the lives of Sepik villagers. People in a number of villages were unable to reach markets to sell produce and children were prevented from attending school (Mitchell et al. 1980; Coates 1982, 1987a). A control program was instituted in 1979 (Thomas 1979), and physical, chemical, and biological control methods were tested (Thomas 1985). Biological control using the South American weevil *Cyrtobagous salviniae* was spectacularly successful (Thomas 1985; Laup 1985; Thomas and Room 1986). The initial development of the weevil population introduced in 1982 was nitrogen limited (Room and Thomas 1985, 1986a, 1986b), but once established on plants enriched with fertiliser, the populations became self-sustaining. By June 1985, the weevil had destroyed an estimated two million tonnes of weed which had covered 250 square kilometres. The local people have now resumed their former lifestyles (Thomas and Room,1986). *Eichhornia crassipes* was first recorded in 1962 when it was found near Bulolo in old gold mining dredge ponds. Despite warnings (Mitchell 1978-1979; Osborne and Leach 1984), it has become widespread throughout lowland areas of Morobe, Madang, and East Sepik Provinces, and has recently spread to the wetlands west of Port Moresby, in Central Province. It has also been reported from Manus, New Ireland, North Solomons, West New Britain, Eastern Highlands and Western Provinces (Laup 1986a). Attempts at biological control using the weevil *Neochetina eichhorniae* have produced some promising results. This weed now covers the majority of Waigani Lake and has severely disrupted the once productive fishery based on *Oreochromis mossambica*. *Pistia stratiotes* is widespread throughout the lowlands of Papua New Guinea, and although it is a weed in other parts of the world, it has not reached weed proportions here (Laup 1986b). The same is true of *Hydrilla verticillata* which has only been recorded near Wau, Madang, Port Moresby, and at Lake Kutubu (Leach and Osborne 1985).

Introduced Freshwater Fish in Papua New Guinea

Twenty-one species of freshwater fish representing 19 genera, 11 families, and all six continents have been introduced into Papua New Guinea for various reasons (West 1973; West and Glucksman 1976; Glucksman et al.

1976). The reasons include sport, aquaculture, ecological manipulation, control of pests, ornamentation, and improvement of subsistence welfare. Most introductions have been unsuccessful or were never released into the wild. Nine to eleven are thought to be established in Papua New Guinea (Allen 1991; Osborne 1993). Of the successful introductions, most have had a negligible impact as either food fishes or in the control of mosquitoes (Allen 1991). *Oreochromis mossambica* is an exception as it now provides the major subsistence source of protein to villagers living along the Sepik River, and it was, prior to infestation of the lake with water hyacinth, the basis of a thriving commercial fishery on Waigani Lake near Port Moresby.

Allen (1991) regards most of the earlier introductions as having had a negative impact through competition for space and limited food resources, or by feeding on the native species. Even the popular *Oreochromis mossambica* has adversely affected the environment, creating turbid conditions in formerly clean lakes and overcrowding the indigenous fauna because of its prolific breeding. On the positive side, the number of established introductions is relatively few, and Allen (1991) states that the Fly River appears to be free of introductions. Coates (in litt.), however, indicates that common carp (*Cyprinus carpio*) occur in the Fly River and, furthermore, that he recorded the climbing perch (*Anabas testudineus*) from the Fly River in 1985.

Four major negative effects may result from fish introductions in Papua New Guinea:

- **predation and competition** – introduced species can lead to a reduction in native fish diversity either through competition for a common resource or through increased predation pressure;
- **introduction of parasitic or pathenogenic organisms**, not previously found in the region, to native fish species;
- **stunting**, particularly in cichlids. (Introduced fish species may undergo explosive population expansion resulting in precocious maturity and reproduction. This, in turn, leads to a habitat filled with large numbers of small fish which encroach on the living space of indigenous species); and
- **environmental effects**, particularly in common carp and tilapine cichlids.

The introduced species may alter the habitat to such an extent through their activities that native species are unable to survive.

Two species of trout, *Salmo trutta* and *Oncorhynchus mykiss*, have been introduced into the highland regions of Papua New Guinea, with an introduction of *Salvelinus fontinalis* having been unsuccessfully attempted. Only *Oncorhychus mykiss* seems to have become established and widespread. Their potential impact, well-recognised in Australia and New Zealand, is as predators and competitors with native fish species, but as Allen (1991) notes, as most introductions have taken place above 2 000 metres in Papua New Guinea where there are few native fish species, their impact on other fish is likely to be minimal, but they will have an impact on other species and on general stream ecology.

The Cyprinidae dominate the ichthyofauna of other tropical regions and *Cyprinus carpio* has been widely introduced throughout the world. This species is well-established in the Sepik system in Papua New Guinea and is also found in certain Southern Province rivers. The species is known to increase water turbidity, and directly and indirectly destroy rooted vegetation. This is often accompanied by a decline in native fish populations and spread and build-up of carp populations (see Cadwallader 1978; Taylor, Coutney and McCann 1984).

The family Poeciliidae are live-bearing ovoviviporous fishes originating in Central and Southern America. Two species –*Poecilia reticulata* and *Xiphiphorus helleri* – are somewhat localised within the country, whereas *Gambusia affinis* introduced for its supposed ability to control mosquitoes, is more widely distributed. All three species have been recognised as having a detrimental effect on small surface feeding native fish species belonging to the genera *Melanotaenia*, *Pseudomugil*, *Craeterocephalus* and *Retropinna* in Queensland. Members of the same four genera also occur widely in Papua New Guinea (Arthington et al. 1981). Introduction of two or more poecilid species into the same water body would seem to have a synergystic effect upon the disappearance of small surface dwelling native species (McKay 1984). There is little evidence to support the view that poecilids are more capable of controlling mosquito populations than native surface dwelling species. The possibility that *Gambusia* may be associated with introduced parasitic species in Papua New Guinea is currently under investigation (see also Mungkaje 1986).

Introduction of the Mozambique tilapia, *Oreochromis mossambicus*, into Papua New Guinea is relatively well-documented (Glucksman et al. 1976) and appears to have been based upon 250 fish brought to Port Moresby in 1954 from either Malaya or Java. Within the next five or so years the species became established in rivers in the vicinity. At present this species is widely spread throughout the country with particular importance in the Sepik system (Coates 1985). In that river system, it has been shown to constitute between 30 to 50 percent of the weight of gill net catches. Recent studies in rivers in the Port Moresby region (Kawei and Menzies, unpublished; Hyslop, Mala and Soare 1994) have shown that this species in conjunction with the Gourami, *Trichogaster pectoralis*, make up the bulk of catches. In the lower reaches of the Angabanga River, *Oreochromis mossambicus* constituted between six to 90 percent of the fish catch by weight (Hyslop et al. 1994). The Mozambique tilapia was also noted by Berra et al. (1975) as the species collected from most localities in the Laloki River.

Nelson and Eldridge (1991) and Maciolek (1984) document introductions of Mozambique tilapia throughout the Pacific Basin and note its propensity to dominate native fish faunas and its poor acceptance as a food fish in various places including Kiribati, the Cook Islands, and Guam. In Fiji, the species is considered as a pest because of its tendency to dominate ichthyofaunas to the exclusion of native species and the trend towards stunted populations. Allen (1991) associates the species with increasing turbidity levels because of their feeding method, and domination of bottom space by nest building males. The ability of this species to switch its dietary habits according to its habitat means that it is very likely to compete with native fish species in a range of locations. Moreover, the response of the tilapia population to fluctuations in environmental conditions is to mature early and reproduce out of season resulting in a rapid build up of numbers which, because of limitations of food/space never attain significant size. The implications of this are twofold – tilapia rarely reach marketable size in sufficient numbers, and native species may be edged out because of pressure for food and/or space.

The family Belontiidae contains two species of gourami – *Trichogaster pectoralis* and *T. trichopterus*. The former is widely distributed, particularly in Central and Gulf Provinces. Two studies (Kawei and Menzies, unpublished; Hyslop et al. 1994) have shown this species to be extremely abundant in Southern Highlands Province rivers. Hyslop et al. (1994) quantified the contribution of *T. pectoralis* to the catch from the lower Angabanga River at between three and 82.5 percent by weight. In many places, especially in areas of swamp, this species in conjunction with *O. mossambicus* constituted the entire catch. Furthermore most individuals of both species were of small size (five to six grams), perhaps indicative of stunting.

The family Anabantidae is characterised by possession of an accessory air breathing organ, which enables species to tolerate low oxygenation and periods out of water. *Anabas testudensis*, the Indian climbing perch, has been introduced into Papua New Guinea from Irian Jaya and the spread of this species has been the subject of various press releases from the Department of Fisheries and Marine Resources. The earliest record of the species is from 1976 in the Morehead River. Present observations indicate that it is widespread throughout the Fly/Ok Tedi system and also the lower Strickland River. It seems to be particularly abundant in shallow weedy habitats (Hyslop et al., unpublished). Anecdotal evidence indicates that *Anabas* may cause the death of predatory fish species, file snakes and even crocodiles by becoming lodged in the pharynx of these species by means of its spines on the opercula and fins.

Several features are shared by introduced fish species in Papua New Guinea which increases their chances of survival and proliferation over those of indigenous species:

- **the lack of radiation/specialisation of the native ichthyofauna** ensures that introduced species which are often "generalists" can find a niche to establish themselves in the community;

- **superior environmental tolerance**: most successful introduced fish species are able to tolerate a wide range of conditions, such as low oxygen levels, via adaptations including accessory air breathing organs and tolerance of low levels of dissolved oxygen;

- **enhanced reproductive capacity allowing rapid population build up**: the Poecilidae are all live bearers (ovoviviporus) ensuring a high survival rate of offspring as young are produced at an advanced stage. High fecundity occurs. For example, a five kilogram carp may produce one million oocytes (Merrick and Schmida 1984). Early non-seasonal maturity and mouth brooding of eggs in tilapia and gouramis ensures good survival of offspring and fast increase in population size;

- **dispersal abilities**: carp, Mozambique tilapia, climbing perch and gouramis can survive out of water for some time if kept moist, allowing them to survive transportation between water bodies by humans. Others have high tolerance of salinity enabling spread between water bodies;

- **ecological adaptability**: opportunistic feeding behaviour and omnivory are typical of most introduced freshwater fish species in Papua New Guinea; and

- **aggressive behaviour**: gambusia and male oreochromis possibly harass other fish species.

The freshwater fish fauna of New Guinea is particularly susceptible to the effects of introduced fish species because of the lack of specialisation. Nine species of introduced fish are widely established in Papua New Guinea and, while there is limited direct evidence to substantiate the case, these species have resulted and are likely to result in loss of biodiversity in the freshwater ichthyofauna. Other prominent examples of deleterious effects from non-indigenous species in Papua New Guinea include the cane toad (*Bufo marinus*), the African giant snail (*Achatina fulica*), water hyacinth (*Eichhornia crassipes*), and salvinia (*Salvinia molesta*).

Box 6.2: Animals Introduced to Papua New Guinea (based on Herington 1977; Eldredge 1994).

Although general statistics on non-indigenous animals in Papua New Guinea are not readily available, there are data on the various species of molluscs, insects, fish, amphibians, birds, and mammals that have been introduced. The following summary is based on Herington (1977) and Eldredge (1994).

MOLLUSCS (Eldredge 1994; Mead 1961, 1979; Hadfield et al. 1993)

- Giant African snail (*Achatina fulica*), introduced during Japanese times; well-established.
- Predatory snail (*Gonaxis quadrilateralis*), New Britain, New Ireland; status unknown.
- Predatory snail (*Gonaxis kibweziensis*), status unknown.
- Predatory snail (*Euglandia rosea*), introduced in 1958.
- Freshwater snail (reported as *Pomacea lineata*, but probably *P. canaliculata*).
- Unidentified pearl oysters (probably *Pinctada maxima*), 7 000 shells from Kuri Bay, Western Austalia to Port Moresby in 1977.

INSECTS (See Wilson 1960; Herington 1977; Waterhouse and Norris 1987 for data on biological control introductions). Only more recent introductions are listed here. Many additional introductions have probably not been recorded in the formal literature.

- Parasitic fly *(Sturmiopsis inferens),* introduced from India in 1981 to control sugarcane borer *(Sesamia grisescens);* probably not established; Ismay and Dori 1985.
- Parasitic flies *(Trichopoda pennipes* and *Trichopoda pilipes),* introduced from Hawaii in 1977 and 1980-1981 to control green stink bug *(Nezara viridula);* probably not established; Ismay and Dori 1985.
- Parasitic wasp *(Apanteles flavipes),* introduced from India in 1981 to control sugarcane borer (*Chilo terrenellus);* Ismay and Dori 1985.
- Parasitic wasp *(Paraceraptrocerus nyascius),* introduced from Queensland in 1981 to control white wax scale (*Ceroplastes destructor);* Ismay and Dori 1985.
- Parasitic wasps *(Opius importatus* and *O. phaseoli),* introduced from Hawaii in 1980-1981 to control beanfly *(Ophiomyia phaseoli);* Ismay and Dori 1985.
- Parasitic wasp *(Trissolcus basalis),* introduced from Western Australia in 1978 to control green vegetable bug *(Nezara viridula);* Ismay and Dori 1985.
- Psyllid *(Heteropsylla spinulosa),* introduced in 1992 to control the weed *Mimosa invisa;* Kuniata 1993.

FISH (Allen 1991)

Freshwater fishes—26 species introduced (15 established); most notably – two species of tilapia, common carp, mosquito fish.

- Blenny *(Petroscirtes breviceps)* found in continuous flow bilge water at Port Moresby; from Northwestern Australia.

AMPHIBIANS (Allison 1993)

- Marine toad *(Bufo marinus)* to Papua New Guinea in 1937 from Hawaii and Australia (Zug et al. 1975).

BIRDS [also imported, ducks, geese, turkeys, pigeons, and cage birds] (Lever 1987; Coates 1990)

- Red jungle fowl (*Gallus gallus).*
- House sparrow *(Passer domesticus,* unsuccessful, 1976).
- Common starling *(Sturnus vulgaris,* considered vagrants from Australia).
- Common myna (*Acridotheres tristis*, Bougainville).

MAMMALS (Lever 1985; Flannery 1990)

- Domestic dog *(Canus familiaris).*
- Domestic pig *(Sus scrofa).*
- Domestic cat *(Felis catus).*
- Timor deer *(Cervus timoriensis).*
- Axis deer *(Axis axis*, restricted*).*
- Fallow deer *(Dama dama*, may be extinct).
- Water buffalo *(Bubalus bubalis).*
- Domestic cattle *(Bos taurus).*
- Domestic Horse *(Equus caballus).*
- Domestic goat *(Capra hircus).*
- Polynesian rat *(Rattus exulans).*
- Black rat *(Rattus rattus,* confined to lowlands).
- Brown rat *(Rattus norvegicus*, from major seaports).
- Ricefield rat *(Rattus argentiventer*, rare, few records).
- Himalayan rat (*Rattus nitidus*, from Vogelkop).
- House mouse (*Mus musculus*, serious pest).

Table 6.1: ***Biological Diversity — Major Taxonomic Groups of Organisms***

If data are not available for Papua New Guinea, they are provided for New Guinea or a small region (for example, Madang Lagoon). Some taxonomic categories overlap and some are artificial.

KINGDOM	MAJOR GROUP	SUBGROUP	COMMON NAME	NUMBER OF SPECIES: NG KNOWN	NG EST.	PNG KNOWN	PNG EST.	REGIONAL	ENDEMIC SPECIES: NO.	%	NG / PNG	REFERENCE
Virus			Virus			?	?					Phytopathogens in Shaw 1984; Muthappa 1987
Monera			Bacteria, etc.			?	?					Phytopathogens in Shaw 1984; Muthappa 1987
Protoctista	Rhodo-phycota	Freshwater	Red Algae			1	?					Johnstone et al. 1980
	Rhodo-phycota	Marine	Red Algae			?	?					Johnstone et al. 1980
	Chromo-phycota		Algae			?	?					
	Chromo-phycota	Bacillario-phyceae	Diatoms			430	?		Few			Vyverman 1991
	Eugleno-phycota		Euglenoids			?	?					
	Chloro-phycota		Algae			?	?					
	Mixed		Freshwater Planktonic Algae			164	?					Yamagishi 1975
	Chloro-phycota	Desmidineae	Desmids			428	?		Few			Vyverman 1991
	Myxomy-cota		Slime Moulds			?	?					
	Protozoa		Protists			?	?					
	Protozoa	Foraminifera				?	?	182				Langer 1992 Madang
Fungi	Fungi		Fungi			2 400	90 000					Shaw 1984; Hawksworth pers. comm.
	Lichens		Lichens	495		?	?					Lambley 1991; Streimann 1986
Plantae	Bryophyta		Mosses	850	1 000	?	?					Bartram 1965

Table 6.1: **Biological Diversity – Major Taxonomic Groups of Organisms**
If data are not available for Papua New Guinea, they are provided for New Guinea or a small region (for example, Madang Lagoon).
Some taxonomic categories overlap and some are artificial.

KINGDOM	MAJOR GROUP	SUBGROUP	COMMON NAME	NUMBER OF SPECIES NG KNOWN	NG EST.	PNG KNOWN	PNG EST.	REGIONAL	ENDEMIC SPECIES NO.	%	NG / PNG	REFERENCE
	Bryophyta		Liverworts	700		?	?			38	NG	Piippo 1994; Grolle & Piippo 1984
	Psiloto-phyta					?	?					
	Lycopod-iophyta		Club Mosses			?	?					
	Filicophyta		Ferns			?	2 000					Johns 1993
	Pinophyta		Pines, etc.			?	16 000			60	NG	Hoeft 1992;
	Magnolio-phyta		Flowering Plants									Johns 1993
			Orchids		3 200	?	?					Van Royen 1979
Animalia	Porifera		Sponges			90	2 000	67				Kelly-Borges pers. comm.
	Cnidaria		Coelent-erates			?	?					
		Hydroidea	Hydro-medusae			?	?	91				Bouillon et al., 1986, Bismarck Sea
		Siphonophora	Siphono-phores			?	?	31				Pages et al., 1989 Hansa Bay
		Scleractinia	Corals			?	700		low			D.C. Potts pers. comm.
		Actiniaria, etc.	Sea Anemones			?	?	18				Fautin 1988, Madang
		Alcyonaria, etc.	Octo-Corals			?	?	118				G.C. Williams ms Madang
	Cteno-phora		Comb Jellies			?	?					
	Platyhel-minthes	Freshwater	Flatworms	3		?	?					Sluys & Ball 1990

Table 6.1: Biological Diversity — Major Taxonomic Groups of Organisms

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KINGDOM	MAJOR GROUP	SUBGROUP	COMMON NAME	NUMBER OF SPECIES: NG KNOWN	NG EST.	PNG KNOWN	PNG EST.	REGIONAL	ENDEMIC SPECIES: NO.	%	NG / PNG	REFERENCE
	Platyhelminthes	Marine	Flatworms			?	?					
	Nemertea		Ribbon Worms			?	?					
	Gnatho-stomulida		Jaw Worms			?	?					
	Mesozoa					?	?					
	Gastro-tricha					?	?					
	Rotifera		Freshwater Rotifers			135	?		0	0	PNG	Segers and De Meester 1994
	Kino-rhyncha					?	?					
	Nematoda		Round Worms			?	?					
	Acantho-cephala		Spiny-Headed Worms			?	?					
	Priapulida					?	?					
	Mollusca	Land	Molluscs	> 481	1 000	?	?					Cowie 1993
	Mollusca	Freshwater	Molluscs	> 165		?	?					Cowie 1993
	Mollusca	Marine	Shelled Molluscs			> 950	?					Hinton 1979
	Mollusca	Marine Prosobranch Gastropods	Marine Snails (part)	809		?	?					Wells 1990
	Mollusca	Marine Nudibranchs	Sea Slugs			?	?	700				T. Gosliner 1994, and pers. comm., Madang

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KINGDOM	MAJOR GROUP	SUBGROUP	COMMON NAME	NUMBER OF SPECIES: NG KNOWN	NG EST.	PNG KNOWN	PNG EST.	REGIONAL	ENDEMIC SPECIES: NO.	%	NG / PNG	REFERENCE
	Annelida	Polychaeta				?	?					
		Hirudinoidea	Leeches, etc.	5		?	?					Van der Lande 1993, Haemadipsids only
		Oligochaeta	Earthworms, etc.			42	?		17	40	PNG	Nakamura 1992
	Echiura					?	?					
	Sipuncula		Peanut Worms			?	?					
	Arthropoda	Chelicerata	Mites, Spiders, etc.			?	?					
		Crustacea	Freshwater Crustacea			87	?		31	36	PNG	Eldredge 1993
			Marine/Freshwater Crustacea			?	?	198				Morgan 1988, Madang
		Uniramia	Insects, etc.			?	300 000					Miller 1993
	Onychophora			7		?	?		2	29	NG	Van der Lande 1993
	Tardigrada		Waterbears			?	?					
	Phoronida					?	?					
	Bryozoa		Moss Animals			?	?					
	Entoprocta					?	?					
	Brachiopoda		Lamp Shells			?	?					
	Chaetognatha		Arrow Worms			?	?					

Table 6.1: **Biological Diversity – Major Taxonomic Groups of Organisms**

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				NUMBER OF SPECIES					ENDEMIC SPECIES			
				NG		PNG						
KINGDOM	MAJOR GROUP	SUBGROUP	COMMON NAME	KNOWN	EST.	KNOWN	EST.	REGIONAL	NO.	%	NG / PNG	REFERENCE
	Echino-dermata					?	?	177				Clark 1921 Torres Strait
	Hemi-chordata					?	?					
	Tunicata					?	?					
Animalia/ Chordata	Agnatha					?	?					
	Chondri-chthyes		Sharks, etc.			91						Kailola 1987-91
	Osteich-thyes	All	Bony Fishes			2 055	3 000					Kailola 1987-91, Allen 1991, Allen & Swainston 1993
		Strictly Freshwater	Bony Fishes	214					149	70	NG	Allen 1991
	Amphibia	Anura	Frogs			193	?		115	60	PNG	Allison 1993
	Reptilia	Crocodylia	Crocodiles			3	?		1 ?		NG	Allison 1993
		Testudines	Turtles			13	?		3	23	PNG	Allison 1993
		Sauria	Lizards			184	?		59	32	PNG	Allison 1993
		Serpentes	Snakes			98	?		32	33	PNG	Allison 1993
	Aves		Birds			644	?		76	12	PNG	Beehler 1993
	Mammalia		Marine Mammals			?	25		0	0	PNG	Jefferson et al. 1993
			Mammals: Marsupials	71					60	84	NG	J. Menzies pers. comm. Beehler 1993
			Mammals: Monotremes	2					1	50	NG	J. Menzies pers. comm. Beehler 1993

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KINGDOM	MAJOR GROUP	SUBGROUP	COMMON NAME	NUMBER OF SPECIES: NG KNOWN	NG EST.	PNG KNOWN	PNG EST.	REGIONAL	ENDEMIC SPECIES: NO.	%	NG / PNG	REFERENCE
			Mammals: Bats	75					57	76	NG	J. Menzies pers. comm. Beehler 1993
			Mammals: Rodents	58					49	84	NG	J. Menzies pers. comm. Beehler 1993

Table 6.2: Protected Species and Species at Risk

Key to Table

Category Abbreviation	Definition
Papua New Guinea Fauna Act	
P	Protected. Taxa declared protected under the Fauna (Protection and Control) Act
R	Restricted. Taxa not declared protected but restricted for trade under the Fauna (Protection and Control) Act because of international market demand and traditional utilisation within Papua New Guinea
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
I	Appendix I listing (species in which international commercial trade is prohibited).
II	Appendix II listing (species in which international commercial trade is only authorised under permit).
IUCN	See text for explanation.

Order	Common Name	Scientific Name	Status	Fauna Act	CITES	IUCN
Mammals						
Monotremata	Short-beaked Echidna	*Tachyglossus aculeatus*	R			
	Long-beaked Echidna	*Zaglossus bruijni*	P	1975	II	E
Marsupialia	Great-tailed Triok	*Dactylopsila megalura*				V
	Fergusson Island Striped Possum	*Dactylopsila tatei*				E
	Lowland Tree-Kangaroo	*Dendrolagus spadix*	P	1990		V
	Doria's Tree-Kangaroo	*Dendrolagus dorianus*	P	1990		V
	Goodfellow's Tree-Kangaroo	*Dendrolagus goodfellowi*	P	1990		V
	Grizzled Tree-Kangaroo	*Dendrolagus inustus*	P	1966-73	II	V
	Huon Tree-Kangaroo	*Dendrolagus matschiei*	P	1990		V
	Scott's Tree-Kangaroo	*Dendrolagus scottae*	P	1990		E
	Feather-tailed Possum	*Distoechurus pennatus*	R			
	Black Dorcopsis	*Dorcopsis atrata*	R			V
	Macleay's Dorcopsis	*Dorcopsulus macleayi*	R			V
	Dimorphic Echymipera	*Echymipera clara*	R			R
	Kiriwina Bandicoot	*Echymipera davidi*	R			
	Giant Bandicoot	*Peroryctes broadbenti*	R			E
	Northern Glider	*Petaurus abidi*				V
	Woodlark Island Cuscus	*Phalanger lullulae*				V
	Stein's Cuscus	*Phalanger vestitus*				R
	Telefomin Cuscus	*Phalanger matanim*				V
	Papuan Planigale	*Planigale novaeguinea*	R			
	Manus Island Spotted Cuscus	*Spilocuscus kraemeri*				R
	Black-spotted Cuscus	*Spilocuscus rufoniger*	P	1990		V
	Dusky Pademelon	*Thylogale brunii*				V
	Calaby's Thylogale	*Thylogale calabyi*				E
Chiroptera	Bulmer's Fruit Bat	*Aproteles bulmerae*	P	1990		E
	Lesser Bare-backed Fruit Bat	*Dobsonia minor*				R
	Greater Tube-nosed Bat	*Nyctimene aello*				R
	Lesser Tube-nosed Bat	*Nyctimene draconilla*				R

Table 6.2: Protected Species and Species at Risk

Order	Common Name	Scientific Name	Status	Fauna Act	CITES	IUCN
	Unstriped Tube-nosed Bat	*Paranyctimene raptor*				R
	Fruit Bat	*Pteralopex anceps*				E
	Lesser Flying Fox	*Pteropus mahaganus*				V
	Moss-forest Blossom Bat	*Syconycteris hobbit*				R
Sirenia	Dugong	*Dugong dugon*	P	1966-73	I	V
Cetacea	Sei Whale	*Balaenoptera borealis*	R		I	V
	Blue Whale	*Balaenoptera musculus*	R		I	E
	Fin Whale	*Balaenoptera physalus*	R		I	V
	Humpback Whale	*Megaptera noveangliae*	R		I	V
Rodentia	Giluwe Rat	*Rattus giluwensis*				R
	Rock-dwelling Rat	*Xenuromys barbatus*				R
Birds						
Struthioniformes	Southern Cassowary	*Casuarius casuarius*	R			V
	Northern Cassowary	*Casuarius unappendiculatus*	R			V
Procellariiformes	Beck's Petrel	*Pterodroma becki*				C
	Heinroth's Shearwater	*Puffinus heinrothi*				E
Ciconiiformes	Great Egret	*Egretta alba*	P	1966-73		
	Little Egret	*Egretta garzetta*	P	1966-73		
	Intermediate Egret	*Egretta intermedia*	P	1966-73		
	Black-necked Stork	*Ephippiorhynchus asiaticus*	R			
Falconiformes	New Britain Sparrowhawk	*Accipiter brachyurus*			II	V
	Imitator Sparrowhawk	*Accipiter imitator*			II	E
	Slaty-backed Goshawk	*Accipiter luteoschiataceus*			II	N
	Gurney's Eagle	*Aquila gurneyi*	R		II	N
	Wedge-tailed Eagle	*Aquila audex*	R		II	
	Swamp Harrier	*Circus aeruginosus (approximans)*	R		II	
	Pied Harrier (not in PNG)	*Circus melanoleucus*	R		II	
	Spotted Marsh-Harrier	*Circus spilonotus*	R		II	
	Chestnut-shouldered Goshawk	*Accipiter buergersi*			II	D
	Brown Falcon	*Falco berigora*	R		II	
	Australian Kestrel	*Falco cenchroides*	R		II	
	Australian Hobby	*Falco longipennis*	R		II	
	Peregrine Falcon	*Falco peregrinus*	R		I	
	Oriental Hobby	*Falco severus*	R		II	
	White-bellied Sea-Eagle	*Haliaeetus leucogaster*	R		II	
	Sanford's Eagle	*Haliaeetus sanfordi*	R		II	V
	New Guinea Harpy Eagle	*Harpyopsis novaeguineae*	P	1966-73	II	V
	New Britain Buzzard	*Henicopernis infuscata*			II	
	Little Curlew	*Numenius minutus*	R		II	
	Osprey	*Pandion haliaetus*	P	1966-73	II	
Anseriformes	Salvadori's Teal	*Anas waigiuensis*	P	1966-73		V
Gruiformes	Brolga	*Grus rubicunda*	R			
	Woodford's Rail	*Nesoclopeus woodfordi*				E
Columbiformes	Yellow-legged Pigeon	*Columba pallidiceps*				C
	Western Crowned Pigeon (not in PNG)	*Goura cristata*	P	1966-73	II	
	Southern Crowned Pigeon	*Goura scheepmakeri*	P	1966-73	II	V
	Victoria Crowned Pigeon	*Goura victoria*	P	1966-73	II	V
	Pheasant Pigeon	*Otidiphaps nobilis*	R			
Psittaciformes	Papuan King-Parrot	*Alisterus chloropterus*			II	
	Red-winged Parrot	*Aprosmictus erythropterus*			II	

Table 6.2: Protected Species and Species at Risk

Order	Common Name	Scientific Name	Status	Fauna Act	CITES	IUCN
	Solomons Cockatoo	*Cacatua ducorpsi*			II	
	Sulphur-crested Cockatoo	*Cacatua galerita*	R		II	
	Blue-eyed Cockatoo	*Cacatua ophthalmica*			II	
	Little Corella	*Cacatua pastinator*			II	
	Cardinal Lory	*Chalcopsitta cardinalis*			II	
	Brown Lory	*Chalcopsitta duivenbodei*			II	
	Greater Streaked Lory	*Chalcopsitta scintillata*			II	
	Josephine's Lorikeet	*Charmosyna josefinae*			II	
	Duchess Lorikeet	*Charmosyna margarethae*			II	N
	Meek's Lorikeet	*Charmosyna meeki*			II	
	Streaked Lorikeet	*Charmosyna multistriata*			II	N
	Papuan Lorikeet	*Charmosyna papou*	R		II	
	Red-flanked Lorikeet	*Charmosyna placentis*			II	
	Little Red Lorikeet	*Charmosyna pulchella*			II	
	Red-chinned Lorikeet	*Charmosyna rubrigularis*			II	
	Red-fronted Lorikeet	*Charmosyna rubronotata*			II	
	Pygmy Lorikeet	*Charmosyna wilhelminae*			II	
	Eclectus Parrot	*Eclectus roratus*			II	
	Red-cheeked Parrot	*Geoffroyus geoffroyi*			II	
	Song Parrot	*Geoffroyus heteroclitus*			II	
	Blue-collared Parrot	*Geoffroyus simplex*			II	
	Papuan Hanging Parrot	*Loriculus aurantiifrons*			II	
	Bismarcks Hanging Parrot	*Loriculus tener*			II	N
	White-naped Lory	*Lorius albidinuchus*			II	N
	Stresemann's Lory	*Lorius amabilis*			II	
	Eastern Black-capped Lory	*Lorius hypoinochrous*			II	
	Western Black-capped Lory	*Lorius lory*			II	
	Red-breasted Pygmy-Parrot	*Micropsitta bruijnii*			II	
	Green Pygmy-Parrot	*Micropsitta finschii*			II	
	Yellow-capped Pygmy-Parrot	*Micropsitta keiensis*			II	
	Meek's Pygmy-Parrot	*Micropsitta meeki*			II	
	Buff-faced Pygmy-Parrot	*Micropsitta pusio*			II	
	Yellow-billed Lorikeet	*Neopsittacus musschenbroekii*			II	
	Orange-billed Lorikeet	*Neopsittacus pullicauda*			II	
	Double-eyed Fig-Parrot	*Cyclopsitta diophthalma*			II	
	Orange-breasted Fig-Parrot	*Cyclopsitta gulielmiterti*			II	
	Plum-faced Lorikeet	*Oreopsittacus arfaki*			II	
	Palm Cockatoo	*Probosciger aterrimus*	P	1990	I	N
	Dusky Lory	*Pseudeos fuscata*			II	
	Brehm's Tiger-Parrot	*Psittacella brehmii*			II	
	Madarasz's Tiger-Parrot	*Psittacella madaraszi*			II	
	Modest Tiger-Parrot	*Psittacella modesta*			II	
	Painted Tiger-Parrot	*Psittacella picta*			II	
	Large Fig-Parrot	*Psittaculirostris desmarestii*			II	
	Edwards' Fig-Parrot	*Psittaculirostris edwardsii*	R		II	
	Goldie's Lorikeet	*Psitteuteles goldiei*			II	
	Vulturine Parrot	*Psittrichas fulgidus*	R		II	V
	Rainbow Lorikeet	*Trichoglossus haematodus*			II	
Strigiformes	Fearful Owl	*Nesasio solomonensis*			II	V

Table 6.2: Protected Species and Species at Risk

Order	Common Name	Scientific Name	Status	Fauna Act	CITES	IUCN
	Barking Owl	*Ninox connivens*			II	
	Solomons Boobook	*Ninox jacquinoti*			II	
	Manus Boobook	*Ninox meeki*			II	
	Southern Boobook	*Ninox novaeseelandiae*			II	
	New Britain Boobook	*Ninox odiosa*			II	
	Rufous Owl	*Ninox rufa*			II	
	Bismarck Boobook	*Ninox solomonis*			II	
	Papuan Boobook	*Ninox theomacha*			II	
	Barn Owl	*Tyto alba*			II	
	Golden Owl	*Tyto aurantia*			II	V
	Grass Owl	*Tyto capensis*			II	
	Manus Masked-Owl	*Tyto manusi*			II	V
	Masked Owl	*Tyto novaehollandiae*			II	
	Sooty Owl	*Tyto tenebricosa*			II	
	Papuan Hawk-Owl	*Uroglaux dimorpha*			II	D
Coraciformes	Moustached Kingfisher	*Actenodes bougainvillei*				V
	Blyth's Hornbill	*Rhytceros plicatus*	P	1990		
Passeriformes (Sturnidae)	White-eyed Starling	*Apolonis brunneicapilla*				E
(Paradisaeidae)	Tomba Bowerbird	*Archboldia sanfordi*	R			
	Ribbon-tailed Astrapia	*Astrapia mayeri*	P	1966-73	II	V
	Splendid Astrapia	*Astrapia splendidissima*	P	1966-73	II	
	Stephanie's Astrapia	*Astrapia stephaniae*	P	1966-73	II	
	Arfak Astrapia (not in PNG)	*Astrapia nigra*	P	1966-73	II	
	Rothschild's Astrapia	*Astrapia rothschildi*	P	1966-73	II	
	King Bird-of-Paradise	*Cicinnurus regius*	P	1966-73	II	
	Crested Bird-of-Paradise	*Cnemophilus macgregorii*	P	1966-73	II	
	Magnificent Bird-of-Paradise	*Cicinnurus magnificus*	P	1966-73	II	
	Buff-tailed Sicklebill	*Epimachus albertisi*	P	1966-73	II	
	Pale-billed Sicklebill	*Epimachus bruijnii*			II	N
	Black Sicklebill	*Epimachus fastuosus*	P	1966-73	II	V
	Brown Sicklebill	*Epimachus meyeri*	P	1966-73	II	
	Yellow-breasted Bird-of-Paradise	*Loboparadisea sericea*	P	1966-73	II	D
	Superb Bird-of-Paradise	*Lophorhina superba*	P	1966-73	II	
	Loria's Bird-of-Paradise	*Cnemophilus loriae*	P	1966-73	II	
	MacGregor's Bird-of-Paradise	*Macgregoria pulchra*	P	1966-73	II	V
	Glossy-mantled Manucode	*Manucodia atra*	P	1966-73	II	
	Crinkle-collared Manucode	*Manucodia chalybata*	P	1966-73	II	
	Curl-crested Manucode	*Manucodia comrii*	P	1966-73	II	
	Jobi Manucode	*Manucodia jobiensis*	P	1966-73	II	
	Trumpet Manucode	*Manucodia keraudrenii*	P	1966-73	II	
	Short-tailed Paradigalla	*Paradigalla brevicauda*	P	1966-73	II	
	Greater Bird-of-Paradise	*Paradisaea apoda*	P	1966-73	II	
	Goldie's Bird-of-Paradise	*Paradisaea decora*	P	1966-73	II	V
	Lesser Bird-of-Paradise	*Paradisaea minor*	P	1966-73	II	
	Emperor Bird-of-Paradise	*Paradisaea guilielmi*	P	1966-73	II	N
	Raggiana Bird-of-Paradise	*Paradisaea raggiana*	P	1966-73	II	
	Blue Bird-of-Paradise	*Paradisaea rudolphi*	P	1966-73	II	V
	Carola's Parotia	*Parotia carolae*	P	1966-73	II	
	Helena Parotia	*Parotia helenae*	P	1966-73	II	
	Lawes' Parotia	*Parotia lawesii*	P	1966-73	II	

Table 6.2: Protected Species and Species at Risk

Order	Common Name	Scientific Name	Status	Fauna Act	CITES	IUCN
	Wahnes' Parotia	*Parotia wahnesi*	P	1966-73	II	V
	King of Saxony Bird-of-Paradise	*Pteridophora alberti*	P	1966-73	II	
	Magnificant Riflebird	*Ptiloris magificus*	P	1966-73	II	
	Twelve-wired Bird-of-Paradise	*Seleucidis melanoleuca*	P	1966-73	II	
(Sylviidae)	Fly River Grassbird	*Megalurus albolimbatus*				V
(Meliphagidae)	Long-bearded Melidectes	*Melidectes princeps*				V
(Pittidae)	Superb Pitta	*Pitta superba*				V
	Black-faced Pitta	*Pitta anerythra*				V
(Rhipiduridae)	Manus Fantail	*Rhipidura semirubra*				V
(Ptilonorhynchidae)	Fire-maned Bowerbird	*Sericulus bakeri*	R			
	Flame Bowerbird	*Sericulus aureus*	R			V
Reptiles						
Crocodylia	New Guinea Freshwater Crocodile	*Crocodylus novaguineae*	R		II	V
	Saltwater Crocodile	*Crocodylus porosus*	R		II	V
Sauria	Prehensile-tailed Skink	*Corucia zebrata*	R		II	
	Gould's Monitor	*Varanus gouldii*	R		II	
	Mangrove Monitor	*Varanus indicus*	R		II	
	Sepik Monitor	*Varanus karlmidti*	R		II	
	Emerald Monitor	*Varanus prasinus*	R		II	
	Salvadori's Monitor	*Varanus salvadorii*	R		II	
	Spotted Tree Monitor	*Varanus timorensis*	R		II	
Serpentes	Ground Boa	*Candioa aspera*	R		II	
	Pacific Boa	*Candioa carinata*	R		II	
	Green Tree Python	*Chondropython viridis*	R		II	
	D'Albertis'Python	*Liasis albertisii*	R		II	
	Barred Python	*Liasis boa*	R		II	
	Water Python	*Liasis mackloti*	R		II	
	Papuan Python	*Liasis papuanus*	R		II	
	Amethystine Python	*Python amethistinus*	R		II	
	Boelen's Python	*Python boeleni*	P	1975	II	
	Carpet Python	*Python spilotus*	R		II	
Testudinata	Loggerhead Turtle	*Caretta caretta*	R		I	V
	Pitted-shell Turtle	*Carettochelys insculpta*	R			K
	Green Turtle	*Chelonia mydas*	R		I	E
	Leathery Turtle	*Dermochelys coriacea*	R		I	E
	Hawksbill Turtle	*Eretmochelys imbricata*	R		I	E
	Pacific Ridley	*Lepidochelys olivacea*	R		I	E
	Flatback Turtle	*Natator depressus*	R		I	V
	Soft-shelled Turtle	*Pelochelys bibroni*	R			
Fishes						
Clupeiformes	Toothed River Herring	*Clupeoides papuensis*				R
Siluriformes	Taylor's Catfish	*Arius taylori*				V
	Kutubu Tandan	*Oloplotosus torobo*				V
Beloniformes	Robert's River Garfish	*Zenacrohopterus robertsi*				R
Atheriniformes	Axelrod's Rainbowfish	*Chilatherina axelrodi*				R
	Bulolo Rainbowfish	*Chilatherina bulolo*				R
	Kailola's Hardyhead	*Craterocephalus kailolae*				R
	Kutubu Hardyhead	*Craterocephalus lacustris*				V
	Pima Hardyhead	*Craterocephalus pimatuae*				R
	Spotted Rainbowfish	*Glossolepis maculosus*				R

Table 6.2: Protected Species and Species at Risk

Order	Common Name	Scientific Name	Status	Fauna Act	CITES	IUCN
	Tami River Rainbowfish	*Glossolepis pseudoincisus*				R
	Ramu Rainbowfish	*Glossolepis ramuensis*				R
	Lake Wanam Rainbowfish	*Glossolepis wanamensis*				R
	Glass Blue-Eye	*Kiunga ballochi*				V
	Lake Tebera Rainbowfish	*Melanotaenia herbertaxelrodi*				R
	Strickland Rainbowfish	*Melanotaenia iris*				R
	Lake Kutubu Rainbowfish	*Melanotaenia lacustris*				V
	Mountain Rainbowfish	*Melanotaenia monticola*				R
	Oktedi Rainbowfish	*Melanotaenia oktediensis*				V
	Papuan Rainbowfish	*Melanotaenia papuae*				R
	Pima River Rainbowfish	*Melanotaenia pimanensis*				R
	Fly River Rainbowfish	*Melanotaenia sexlineata*				V
	Popondetta Blue-Eye	*Pseudomugil connieae*				R
	Forktail Blue-Eye	*Pseudomugil furcatus*				R
	Paska's Blue-Eye	*Pseudomugil paskai*				V
Perciformes	Mountain Goby	*Glossogobius sp. 3*				R
	Robert's Goby	*Glossogobius sp. 7*				V
	Bluntsirout Goby	*Glossogobius sp. 8*				V
	Fly River Goby	*Glossogobius sp. 11*				R
	Kutubu Goby	*Glossogobius sp. 12*				V
	Bighead Goby	*Glossogobius sp. 13*				R
	Ramu Goby	*Glossogobius sp. 14*				R
	Adamson's Grunter	*Hephaestus adamsoni*				V
	Threespot Grunter	*Hephaestus trimaculatus*				R
	Black Mogurnda	*Mogurnda furva*				V
	Kokoda Mogurnda	*Mogurnda lineata*				R
	Eastern Mogurnda	*Mogurnda orientalis*				R
	Blotched Mogurnda	*Mogurnda spilota*				V
	Variegated Mogurnda	*Mogurnda variegata*				V
	Striped Mogurnda	*Mogurnda vitta*				V
	Karamui Gudgeon	*Mogurnda sp. 1*				R
	Wau Gudgeon	*Mogurnda sp. 2*				R
	Highlands Gudgeon	*Mogurnda sp. 3*				R
	Malas Gudgeon	*Mogurnda sp. 5*				R
	Kokoda Grass Perchlet	*Tetracentrum caudovittatus*				R
Insects						
Lepidoptera	Milkweed Butterfly	*Euploea doretta*				R
	Milkweed Butterfly	*Euploea eboraci*				R
	Milkweed Butterfly	*Euploea lacon*				R
	Swallowtail Butterfly	*Graphium meeki*				R
	Swallowtail Butterfly	*Graphium mendana*				R
	Swallowtail Butterfly	*Papilio moerneri*				V
	Swallowtail Butterfly	*Papilio toboroi*				R
	Swallowtail Butterfly	*Papilio weymeri*				R
	Milkweed Butterfly	*Parantica clinias*				R
	Milkweed Butterfly	*Parantica garamantis*				R
	Milkweed Butterfly	*Parantica rotundata*				R
	Milkweed Butterfly	*Parantica weiskei*				R
	Milkweed Butterfly	*Protoploea apatela*				R
	Birdwing Butterfly	*Troides (Ornithoptera) alexandrae*	P	1966-73	I	E

Table 6.2: Protected Species and Species at Risk

Order	Common Name	Scientific Name	Status	Fauna Act	CITES	IUCN
	Birdwing Butterfly	*Troides (Ornithoptera) alloteí*	P	1966-73	II	
	Birdwing Butterfly	*Troides (Ornithoptera) chimaera*	P	1966-73	II	I
	Birdwing Butterfly	*Troides (Ornithoptera) goliath*	P	1966-73	II	
	Birdwing Butterfly	*Troides (Ornithoptera) meridionalis*	P	1966-73	II	V
	Birdwing Butterfly	*Troides (Ornithoptera) paradisea*	P	1966-73	II	I
	Birdwing Butterfly	*Troides (Ornithoptera) priamus*			II	
	Birdwing Butterfly	*Troides (Ornithoptera) victoriae*	P	1966-73	II	
	Birdwing Butterfly	*Troides oblongomaculatus*			II	
Coleoptera	Lichen Weevil	*Gymnopholus lichenifer*				V
Molluscs						
Stylommatophora	Manus Green Tree Snail	*Papustyla pulcherrima*			II	R
Veneroida	Southern Giant Clam	*Tridacna derasa*			II	V
	Giant Clam	*Tridacna gigas*			II	V
Corals						
Antipartharia	Black Corals	*Antipartharia (entire order)*			II	
Scleractina	Stony Corals	*Scleractina (entire order)*			II	
Athecata	Fire Corals	*Millepora spp.*			II	
	Corals	*Stylasteridae (entire family)*			II	
Coenothecalia	Blue Corals	*Heliopora spp.*			II	
Stolonifera	Organ-Pipe Corals	*Tubipora spp.*			II	
Plants						
Cycadaceae	Cycads	*Cycas sp.*			II	
Euphorbiaceae	Spurges	*Euphorbia spp.*			II	
Nepenthaceae	Pitcher Plants	*Nepenthes spp.*			II	
Orchidaceae	Orchids	*Paphiopedilum spp.*			I	
	Orchids	*Orchids - all others*			II	

CHAPTER 7

ENVIRONMENTS IN PAPUA NEW GUINEA

This chapter reviews the major environments in Papua New Guinea, to provide a context for the Biodiversity Country Study. Details may be found in the Conservation Needs Assessment (Beehler 1993). The environments of Papua New Guinea are remarkably diverse as well as species rich, but have been inadequately studied ecologically. We know that some forests in Papua New Guinea are amongst the richest in the world and coral reefs along the north coast may be the richest in the world for invertebrate species. However, we have only a superficial knowledge of the taxonomic and ecological nature of this species richness, and we do not fully understand the processes that produce such high richness (Stone 1993). Virtually nothing has been published on local variation in species richness, so it is impossible to gauge the significance of differing findings within Papua New Guinea. This chapter reviews terrestrial environments (primarily on the basis of vegetation), freshwater environments, and marine and estuarine environments.

Papua New Guinea has an extraordinary range of ecosystems because of its geographic and geological complexity. This is reflected in the wide variety of its flora and fauna, many of which are endemic to either Papua New Guinea or the island of New Guinea. Papua New Guinea's variety of ecosystems range from mountain glaciers to humid tropical forests, and from swampy wetlands to pristine coral reefs. Papua New Guinean ecosystems are relatively unspoilt, and many natural habitats can still be conserved. Some areas, particularly the larger areas of wetlands, still have very low human population density (two to four persons per square kilometre). However, the environment, in general, is coming under increasing pressure. Terrestrial ecosystems, especially forests, are subject to increasing resource extraction, especially through forestry, but are also being cleared to make way for mining and agriculture. Freshwater ecosystems in some parts of the country are being degraded through the disposal of mining, agricultural, and urban wastes. The problems of freshwater systems flow downstream to the marine systems, and, along with additional pressures from fisheries and pollution, affect these systems. Some 97 percent of the land is held under customary tenure, and most rural people rely to some degree on natural resources for their livelihood (Powell 1976).

Independent management of terrestrial and aquatic resources and ecosystems will always fail because, in the absence of consultation between these sectors, incompatible developments will always occur (Huber 1993). For example, land degradation will certainly impact on the adjacent aquatic habitats, but will probably also affect downstream communities and eventually impact on the nearshore coral reefs. Prawns may spend the bulk of their life-cycle in shallow waters and be harvested from the continental shelf, but the removal of mangroves threatens the viability of the fishery as successful recruitment is dependent upon this habitat. Typically, marine systems operate on broad spatial and temporal scales. In general, these processes are poorly understood, but need to be considered in any coastal management if conservation of biodiversity is to be achieved. Freshwater systems are easier to delineate but have unique difficulties related to the fact that they can be more directly impacted by local terrestrial disturbances, and they represent a more closed system than the marine environment.

Terrestrial Environments

The present diversity of Papua New Guinea's vegetation is presumably a result of variation in four factors (Saulei and Beehler 1993) — rainfall, altitude, soil, and history of disturbance. Annual rainfall in Papua New Guinea ranges from as low as 950 millimetres to as high as 10 000 millimetres (McAlpine et al. 1983). The relief of New Guinea is generally rugged and mountainous except in the south-west and along the banks of the lower reaches of the larger rivers (Löffler 1977). Elevation ranges from sea level to over 4 400 metres. Soils range from old alluvium to those produced by recent volcanism or the weathering of ultrabasic rocks that comprise relict segments of uplifted sea floor. Disturbance of the vegetation in Papua New Guinea is varied, commonplace, and can be both natural and human induced. This disturbance includes periodic large fires, droughts, landslips, volcanism, frosts, and local annual burning, among other things (Johns 1986). The remarkable variation among this series of physical parameters creates the broad diversity of terrestrial habitats exhibited in Papua New Guinea.

Most of Papua New Guinea has a relatively high annual rainfall of 2 500-3 500 millimetres. Some lowland areas are drier, especially in the Port Moresby area. Large areas of the highlands receive in excess of 4 000 millimetres annually and up to 10 000 millimetres has been recorded. There is generally little seasonality in rainfall except in the drier areas. Air temperatures are high throughout the year with little seasonal variation. With increasing altitude the absolute and average temperatures decrease and seasonal variation tends to equal or exceed the daily temperature range. Above 2 200 metres elevation frosts occur, but only rarely. Frosts are common over 3 000 metres and snow occasionally falls on the higher mountains. The combination of high rainfall and temperature results in high humidity, cloudiness and only moderate rates of evaporation.

There is less climatic overlap between low and high-elevation sites in the tropics than in the temperate zone, suggesting that a given elevational separation provides greater opportunity for diversity of habitats in the tropics (Smith 1988). Thus, the range of elevation in Papua New Guinea creates a remarkable array of environments within a relatively small area.

The island of New Guinea has evolved into a major land area only over the past 20 million years through fusion and compression along the boundary of the northward moving Australian continent on the Indian Ocean tectonic plate and the westward moving margin of the Pacific tectonic plate. Only in the Pliocene and Pleistocene has its mountain ranges been uplifted to the snow line, to be glaciated extensively during the Pleistocene ice ages. While the current landscape of New Guinea is young in geological terms, it contains numerous accreted terranes in its northern half, some dating back to the cretaceous age, and many others to the Miocene age (summarised by Polhemus 1993). These older terranes may have provided refugia for relatively ancient organisms to persist in the area that later became New Guinea. This refuge hypothesis is borne out by the distributions of some apparently relictual organisms (Polhemus, in press). This hypothesised development of New Guinea through island arc accretions is reflected in present local areas of endemism (see various papers and maps in the Conservation Needs Assessment).

Despite an appearance of geological youth, the biota of New Guinea has attained a diversity that appears equivalent to that of the much older tropical lands of South-East Asia (Gressitt 1982). The majority of the biota has its closest relationships with that of Asia. Although the number of genera in any given group is often less than would be found in Asia, the genera are often more species rich. At least for insects, the majority of genera that are endemic to Melanesia are restricted to, or have their species richness strongly centered in, New Guinea (Miller and Holloway 1991). In some groups there is also an important Australian element, facilitated by dispersal from Australia across the Torres Strait during lowered sea levels in the Pleistocene (Kikkawa et al. 1981).

Several systems of vegetation classification are available (Johns 1993: 33). Here we follow the system of Johns (1977, 1982, 1993), as used by the Conservation Needs Assessment (for example, Saulei and Beehler 1993), but other important references include Paijmans (1976), McAlpine et al. (1983), Bellamy (1986), Bleeker (1975, 1983, 1988), and Löffler (1974, 1977). All such schemes represent compromises, subject to intergradation between vegetation types and also to variation because of local environmental conditions. Two sets of maps of vegetation are available: four sheets at 1:1 000 000 scale (Paijmans 1975) and 18 sheets at 1:500 000 scale (Papua New Guinea National Mapping Bureau). Some of these data are also available through the PNGRIS database system produced by CSIRO. However, these maps are all based on data more than 20 years old. A recent review of the various soils maps that are available showed major discrepancies amongst them (Humphreys 1991; Bourke 1993). Another problem is that most biogeographic data are not available in consistant formats for the entire island of New Guinea (an exception is the vegetation map by Whitmore 1984).

An authoritative, synthetic biogeographic regionalisation of Papua New Guinea is much needed. As noted already, many data sets are available to support it, but they need to be correlated in a modern context (such as recently done for Australia by the Environmental Resources Information Network – Thackway and Cresswell 1992) and enhanced with more recent information when possible. If sufficient coverage of weather data is available, BIOCLIM programs (Busby 1991) could be powerful analytical and predictive tools for Papua New Guinea. It might also be useful to test the application of the Holdridge Life Zone concept to New Guinea. The Life Zone system is a predictive scheme for identifying potential vegetation based on the effects of temperature, rainfall, and evapotranspiration (Holdridge 1978). The system has been widely applied in Central and South America, as well as in Thailand (Holdridge et al. 1971), although it did not work well in a limited test at high altitudes in New Guinea (Smith 1975).

Coastal Vegetation: Occurs on the succession of ridges aligned parallel to beaches; it is usually well-drained, but includes linear swampy depressions (swales). Vegetation ranges from pioneering herbacious beach communities, through beach scrub, and inland to mixed forest.

Mangrove Forest: Coastal and riverine/tidal forests that are typically inundated daily by salt or brackish water. These forests are most extensive in the deltas of the larger rivers primarily on the southern watershed, especially in the Purari, Kikori, and Fly River deltas. The dominant canopy tree genera are *Rhizophora, Avicennia, Brugiera, Xylocarpus,* and *Sonneratia* (Johnstone and Frodin 1982; Percival and Womersley 1975; Woodroffe and Grindrod 1991; Duke 1992).

Anthropogenic Grassland: Covers much of the dry hilly country along the northeast coast and is the main vegetation in many populated intermontane valleys. In many or most areas, these grasslands represent a disclimax vegetation maintained by human induced fires. Grasslands above 2 500 metres are floristically and structurally very different from those at lower elevations.

Swamp Vegetation: Inundated for part or much of each year, swamp vegetation is highly variable in composition and structure, in part because of varying regimes and patterns of inundation. Common canopy tree genera include *Campnosperma, Terminalia, Nauclea, Syzgium, Octomeles, Pometia, Intsia, Alstonia, Bischofia*, and *Palaquim*. The canopy is often broken and open, with gaps filled by understorey broadleaf species, or palms and pandans (Taylor 1959).

Savannah: Mixed savannah, found in the monsoonal southwest of Papua New Guinea varies in structure and floristics with local relief, drainage, and the frequency of burning. Dominant trees include *Eucalyptus, Albizzia,* and *Melaleuca*. Melaleuca savannah is found in the southwest, but also elsewhere in the country on waterlogged plains and on dry hill slopes, up to 500 metres. The savannahs of monsoonal southwest Papua New Guinea have strong structural and floristic affinities with those of northern Australia (Gillison 1983).

Monsoon Forest: Occurs mostly near sea level in areas with less than 2.5 metres of rain per year and a prolonged dry season, and is limited to areas northwest of Port Moresby, Western Province, and the Safia-Pongani region in the southeast. These grade into open savannah woodland. Dominant trees include *Bombax, Erythrina, Tetrameles, Albizzia, Acacia*, and *Mangifera*.

Lowland Tropical Rainforest: Generally below 1 000 metres and receiving more than 2.5 metres of rainfall annually, this forest is both taxonomically and structurally rich, but more poorly studied than most other forest types in Papua New Guinea. These can be split into forests below 500 metres that receive more than 3.5 metres of rainfall (Lowland Wet Forest) and those below 1 000 metres that receive between 2.5 and 3.5 metres of rainfall (Lowland Humid Forest). However, taxonomic and structural differences between the two forest types remain unclear (Paijmans 1970; Hyndman and Menzies 1990; Saulei and Beehler 1993; Hope and Tulip 1994).

Lower Montane Forest: Lying between ca. 1 000 and 2 000 metres elevation, this common forest type is quite variable in structure and composition. *Araucaria* species and *Castanopsis acuminatissima* are commonly dominant components (Gressitt and Nadkarni 1978; Hyndman and Menzies 1990). This is the zone of maximum environmental impact from subsistence agriculture. Forests at this elevation that receive over 3.5 metres of rainfall annually were separated as Lower Montane Wet Forest by Saulei and Beehler (1993).

Mid-Montane Forest: Occurs between ca. 2 000 and 2 500 metres elevation and is typically everwet (perhumid). Fog, mist, cloud, and nearly daily rainfall produce luxuriant growing conditions. These forests are typically rich in epiphytes, with broken, open, and uneven canopies. In some localities, the forest type is dominated by *Nothofagus, Phyllocladus*, other podocarps, and a series of typical montane broadleaf species (Gressitt and Nadkarni 1978; Hyndman and Menzies 1990; Kiapranis and Balun 1993; Valkenburg and Ketner 1994).

Upper Montane Forest: Found between ca. 2 500 and 3 200 metres, this is a complex community of primarily gymnospermous canopy tree species. Such forest is low canopied and structurally simple, usually heavily encrusted with moss or moss-like epiphytes (Grubb and Stevens 1985).

Subalpine Forest and Grassland: Occurs on mountain tops above 3 200 metres. Subalpine forests are usually very species poor and are structurally simple, with a canopy height of eight to twelve metres. Usually the forest exhibits a closed canopy that is often dominated by a single species (often *Dacrycarpus*) (Smith 1975; Grubb and Stevens 1985; van Royen 1980)

Alpine: The limit of tree growth is generally about 3 900 metres but varies locally. Above the tree line, shrubs gradually decrease in height and frequency to about 4 400 metres. Rosette and cushion herbs, mosses, lichens, and low ferns become progressively more abundant with altitude and largely replace grasses above 4 300 metres (van Royen 1980).

Papua New Guinea's lowland forests tend to have moderate to high biodiversity and low rates of endemism (for example, most of the species are widespread, extending beyond the island of New Guinea). Endemism increases with altitude. Biodiversity may increase with altitude to some point of maximum diversity, but it is not clear at what elevation peak diversity occurs, or how it varies between major taxonomic groups. Saulei and Beehler (1993) suggest that Lowland Tropical Rainforest is the richest vegetation type for plants in Papua New Guinea. In a transect in the Hunstein Mountains, Balun et al. (1993) found that diversity of plants increased from 50 to 400 metres, then decreased to 700 metres. For birds, Beehler (1982) found that bird species richness declines monotonically with altitude, with a slight plateau between 1 000 and 1 500 metres. Flannery (1990: 15) found the highest mammal diversity in Lower Montane Forest. Diversity of tropical insects is generally thought to increase with altitude into mid-montane elevations (ca. 500 to 1 000 metres) and then slowly decline, although some data sets show a simple decrease in diversity with altitude (Allison et al. 1993; Olson 1994). In Papua New Guinea, it has been suggested (Gressitt and Nadkarni 1978; Gressitt 1982) that the highest insect diversity occurs between 500 to 1 500 metres. In a study of beetles collected from rainforest canopy trees, Allison et al. (1993) found the unexpected result of diversity being higher at 2 100 metres than at 1 200 and 500 metres, but this may have been because of phenological differences between the trees. Research must continue in the relationship between altitude and diversity in Papua New Guinea.

Freshwater Wetlands

Over 80 percent of the 5 000 lakes in Papua New Guinea lie below 40 metres and most of these lakes are associated with large rivers and surrounded by extensive wetlands. Mangroves, brackish swamps, freshwater swamps and alluvial plains account for 7.5 percent of the total land area of the country but these regions are sparsely populated (two to four persons per square kilometre). The relief of Papua New Guinea is dominated by a central cordillera, north of which is a depression occupied by the Sepik River in the west and the Ramu River in the east. To the south, in the western part of Papua New Guinea, lies a huge tract of low-lying land drained by the Fly and Strickland Rivers. Lowland freshwater wetlands are a mosaic of open water, herbaceous swamp, swamp savannah, and woodland. Most of the wetlands in Papua New Guinea are in pristine condition, but one has been markedly altered from sewage disposal and others are under threat from mine tailings disposal. While there is no specific legislation for wetland conservation, protection is afforded under a number of general Acts of Parliament. The following discussion is based on an extensive bibliography (Osborne 1988) and inventory of sites (Osborne 1987, 1993).

Major Rivers

As a result of the high rainfall and rugged topography, most rivers in Papua New Guinea have large flow volumes and high sediment loads, and are generally fast-flowing and turbulent. The Fly Platform (see Figure 7.1) is the largest tract of low-lying land in Papua New Guinea and is drained by the Fly and Strickland Rivers. The Fly River, although only 1 200 kilometres long, is so large in terms of discharge (6 000 to 7 500 m/sec) that it ranks with the world's great rivers (Holeman 1968; Welcomme 1985). The gradient in its lower course is extremely gentle as the river port of Kiunga, 800 kilometres from the sea, is only 20 metres above sea level. The river is tidal for 250 kilometres upstream. Rainfall in the upper catchment regularly exceeds ten metres per annum, and in floods the river level may rise rapidly by up to ten metres. In the south, the area is gently undulating, with flat areas poorly drained and swampy. The middle Fly floodplain, 15 to 20 kilometres wide, is a mosaic of lakes, alluvial forest, swamp grassland, and swamp savannah. The river meanders extensively in this region, and in addition to tributary lakes, there are numerous backswamps and oxbows of variable depth depending on age.

The Purari River (see Figure 7.1) drains the central highlands and discharges into the Gulf of Papua through an extensive delta (Petr 1983). The rainfall in the catchment is high, particularly on the foothills where it reaches eight metres per year. This high precipitation, coupled with the high run-off, give this river system an enormous potential for hydroelectric power generation, and a dam planned for Wabo in the foothills was projected to have an installed capacity of 2 160 megawatts. Possible environmental impacts of this proposed dam were assessed in some detail (Petr 1983), but the scheme has not been developed further. Other rivers draining to the south and east of the Purari include the Vailala, Lakekamu, Angabanga, Vanapa, Laloki, and Kemp-Welch.

The Markham and Ramu Rivers (see Figure 7.1) flow through the eastern part of an intermontane trough which is a narrow graben zone occupied by a series of alluvial fans. These fans are formed of coarse debris derived from the tectonically active Finisterre and Saruwaged Ranges which rise steeply along the north-eastern margin of the trough. The Markham River, 170 kilometres long, flows through a wide, braided channel and has no estuary. The river channel is three kilometres wide at the Ramu divide and reaches its maximum width at its confluence with the Leron River. The Ramu River, which is approximately 720 kilometres long, has a relatively small catchment area. In its lower reaches, the floodplain terrain is very flat and swampy.

The Sepik River (see Figure 7.1) with a catchment of 77 700 square kilometres is the largest river system in Papua New Guinea. Its discharge is reported to range between 4 500 and 11 000 cubic metres per second (Mitchell et al. 1980), although the river is poorly gauged. Flow was recorded in June 1988 by the Royal Australian Navy Hydrographic Service to be 6 500 cubic metres per second (Fox 1990). The Sepik River is navigable for about 500 kilometres, and the main river channel is deep (over 35 metres at Angoram) as are the more recently-formed oxbow lakes in the lower floodplain. The river discharges directly into the sea through a single outlet, and this contrasts markedly with rivers in the south which invariably have extensive deltas and large estuaries. There are numerous (around 1 500) oxbow and other lakes associated with the Sepik floodplain. The largest of these is Chambri Lake (see Figure 7.2) which is shallow (maximum four metres) and has a highly variable area of up to 250 square kilometres in the flood season. There are no large rivers on the islands off the north coast but the short, fast-flowing mountain streams often have high discharges.

Lakes

Chambers (1987) surveyed the topographic maps of Papua New Guinea and counted 5 383 freshwater lakes. The lakes are mostly small, with only 22 having a surface area greater than 1 000 hectares. Lake Murray is by far the largest (64 700 hectares), some three times greater in area than the next largest (Lake Chambri) (see Figure 7.2). However, these two lakes are both shallow: Lake Murray has a maximum depth of approximately nine metres and a mean depth of around five metres; and Chambri Lake has a maximum depth of approximately six metres and contrasts markedly with the deep caldera lakes, Wisdom (360 metres) and Dakataua (120 metres) (see Figure 7.2). Over 80 percent of the lakes lie below 40 metres altitude reflecting their association with the floodplains of large rivers.

Two large lakes, Lake Wisdom on Long Island and Lake Dakataua on West New Britain (see Figure 7.2) occupy calderas. Lake Wisdom is surrounded by steep crater walls rising to 300 metres above sea level and the lake is 360 metres deep, making it one of the deepest lakes in the South-East Asia/Australia region (Ball and Glucksman 1978). Lake Dakataua was also formed by the post-eruptive collapse of a volcanic crater and the maximum depth of the lake is 120 metres (Ball and Glucksman 1980). Lake Kutubu was formed behind a dam of volcanics which erupted from Mt. Afuma (Osborne and Totome 1992a).

Several lakes on the high mountains of New Guinea were formed by glacial activity, for example, Lakes Piunde and Aunde on Mt. Wilhelm. Numerous lakes of two basic types are associated with floodplain rivers such as the Fly and Sepik Rivers. Tributary lakes such as those of the Fly River basin form where the river flows on an alluvial ridge of material eroded from the upper catchment. Because main river deposition was more rapid than that of tributary streams, the tributaries became blocked, forming numerous lakes (Bosset Lagoon and Lake Daviumbu). Floodplain rivers also meander extensively, and oxbow lakes of variable depth, depending on age, occur within the floodplain.

Biological Environments

Freshwater Wetland Flora

The freshwater flora of Papua New Guinea comprises eight species of Characeae, 21 species of ferns and fern-allies, and 130 flowering plants (Leach and Osborne 1985). Freshwater algae in Papua New Guinea have been poorly studied and most work has been taxonomic (Thomasson 1967; Yamagishi 1975; Watanabe et al. 1979a, 1979b; Yamagishi and Watanabe 1979; Vyvermann 1989, 1990, 1991a, 1991b, in press). Vyverman (1991a) studied desmids in 145 freshwater habitats in Papua New Guinea. He identified five main assemblages: one from tropical lowlands, one extending from lowlands to mid-altitudes, one from mid-altitudes, and two from medium to high altitude waters. The dominant taxa in all assemblages were cosmopolitan, but some with restricted geographical distributions were recorded. The number of desmid taxa with Indo-Malaysian-North-Australian pantropical and paleaeotropical distribution decreased with increasing altitude while Arctic-Alpine taxa were only found in highland waters.

The Herbaceous Vegetation of Lowland Wetlands

The vegetation of the lowland freshwater swamps forms a continuous sequence from open water to tall mixed swamp forest, depending on the depth and quality of the water, and drainage and flooding conditions. The aquatic vegetation consists of free-floating, floating-leaved, and submerged plants. They occupy the shallow margins between open water and grass swamp, and in places cover entire lakes filling a shallow, uniform basin. Herbaceous communities consisting of sedges, herbs, and ferns are characteristic of stagnant, permanent, relatively deep swamps. Two aquatic weeds, *Salvinia molesta* and *Eichhornia crassipes* are now widespread in the low-lying wetlands of Papua New Guinea and are discussed in Chapter 6 as examples of invasive pest species.

Lowland Swamp Savannah and Woodland

Mixed swamp savannah is a transitional vegetation type between purely herbaceous swamps and swamp woodland, and it occurs in permanent, stagnant swamps. In addition to an herbaceous cover, there is an open layer of trees –*Nauclea, Campnosperma, Syzygium* and *Melaleuca*. Melaleuca swamp savannah is characteristic of the fluctuating backswamps of the Middle Fly and Strickland Rivers, and also occurs along parts of the monsoonal south and south-west coasts. Melaleuca trees form an even, open, almost pure canopy. The main species is *M. cajuputi*. In the wet season, Melaleuca swamp savannah is inundated and colonised by aquatic plants. In permanent swamps, the tree storey of mixed swamp woodland is generally open and ranges from low to tall. Sago palm *(Metroxylon sagu)* is widespread throughout more or less permanent swampy woodland.

All gradations occur from stands of pure sago to woodland with a dense layer of trees and an open lower tier of sago. The palm grows best where there is a regular influx of fresh water. Swamp pandans occupy a habitat similar to that of sago palm but have a wider range. They form open to quite dense, pure stands in shallow, fresh to brackish, stagnant to frequently flooded swamps. Mixed swamp forest is the most common type of swamp forest. It generally has an open, but occasionally dense canopy. Dense stands of *Campnosperma* (*C. brevipetiolta* and *C. coriace*) are found in permanently flooded backswamps. Sago may form a dense understorey. Terminalia swamp forest is mainly found in North Solomons Province where *Terminalia brassii* grows together with *Campnosperma* and locally dominates in the canopy of open swamp forest. Low-lying, frequently flooded, bouldery and sandy rivers, and peat swamps with flowing waters are the habitats.

Montane Wetlands

Communities dominated by sedges and grasses occur above about 1 800 metres in swamps occupying intermontane basins, local depressions in valley floors, and seepage slopes. Many different sedges are present and they commonly make up most of the ground cover. Characteristic grasses are *Arundinella furva*, *Isachne* spp. , and *Dimeria* spp. *Phragmites karka* commonly forms pure stands in seepage areas on slopes and on flat valley floors to over 2 500 metres. At higher elevations (upper montane zone), herbaceous communities consisting of a mixture of low herbs, sedges, grasses and mosses occupy depressions, fringe open water and in the higher parts of the zone, also occur on slopes.

Freshwater Wetland Fauna

Wetland invertebrates have been poorly studied and research on fish has been largely taxonomic. The native fish fauna is mostly derived from the marine fauna, and has been supplemented by the introduction of at least 21 exotic species. Two species of crocodile are found throughout the low-lying wetlands and crocodile farming is an important village-based activity. Amongst New Guinea's birds, 112 are waterbirds and three of these are endemic. Of the native mammals, only three water rats are regarded as wetland species, but introduced Rusa deer occur in large numbers in the Fly River area.

The freshwater invertebrate fauna of Papua New Guinea has been poorly studied. MacArthur (1965) noted that numbers of species of freshwater invertebrates do not increase in the tropics. Lakes in Papua New Guinea feature low zooplankton diversities, with a notable paucity of cladoceran and copepod species (McKenzie 1971; Löffler 1973; Bayly and Morton 1980; Chambers 1988). Dudgeon (1990) studied benthic macro-invertebrates in two upland streams of the Sepik-Ramu River system. He concluded that despite generalisations concerning the poverty of freshwater fauna in Papua New Guinea (Gressitt 1982), both Kojé and Maram Creeks yielded diverse collections of benthic macro-invertebrates, dominated by insects. In terms of morphospecies richness, they did not differ greatly from stream communities in the oriental tropics. However, the composition of the fauna was rather different from that of oriental streams. This difference could not be attributed to the inclusion of Australian elements but reflected a lack of certain oriental groups and a radiation of others. For example, Heptageniidae, Ephemerellidae and Ephemeridae among the mayflies, Psephenidae among the aquatic beetles, and all Plecoptera were absent from the

Papua New Guinean collections, although these animals are abundant in similar streams on the Asian mainland. Naucorid bugs, by contrast, were well-represented and may have occupied the vacant stonefly-predator niche.

The status of knowledge of freshwater insects in Papua New Guinea was reviewed by Miller (1993: 256-257) and Polhemus (1993). Much work remains to be done, but reliable data are available for some groups of aquatic insects, including dragonflies and damselflies (Order Odonata), whirligig beetles (Order Coleoptera, Family Gyrinidae), and water bugs (Order Hemiptera). The status of knowledge of other freshwater groups has been reviewed recently for molluscs (Cowie 1993), crustaceans (Eldredge 1993), rotifers (Segers and De Mees 1994), flatworms (Sluys and Ball 1990), and leeches (Van der Lande 1993).

Wetland Degradation and Pollution

Most of the wetlands in Papua New Guinea are still in pristine condition. The human population density in wetland areas, is for the most part low, and their utilisation has been largely at a subsistence level. There are a number of instances where wetlands have been abused or threatened, and two case histories are presented in Boxes 7.1 and 7.2.

Box 7.1: Waigani Swamp: The History of Wetland Degradation

Waigani Swamp comprises a number of small, shallow lakes near Port Moresby (see Figure 7.2). It is a small part of the extensive swamp/river system dominated by the Brown and Laloki Rivers. The main Waigani Lake is shallow (1-2 metres deep) with an open water area of 120 hectares, situated in a valley dominated by urban development. The lake is surrounded by a *Phragmites karka* and *Typha domingensis* swamp and is heavily fished for two introduced species – *Oreochromis mossambica* and *Cyprinus carpio*. In 1965, sewage settling ponds were established nearby, and were expanded, and now about 80 percent of the sewage from the capital city of Port Moresby (population approximately 200 000) enters the swamp/lake system. Major changes in the aquatic flora of this system have occurred over the last 30 years (described from a series of aerial photographs by Osborne and Leach 1983).

From 1942 to 1956, Waigani Lake was dominated by emergent vegetation and there was very little open water. Between 1956 and 1966, this emergent vegetation was replaced by dense stands of floating-leaved plants *Nymphaea* spp. and *Nymphoides indica*. Following this period, the increase in sewage effluent disposal correlates with a decline in floating-leaved plants, and by 1974 only a few small stands remained. By 1978, no floating-leaved plants could be found in the main lake and their decline in Waigani Lake was accompanied by a regression of the surrounding reed swamp. This latter decline has continued (Osborne and Leach 1983; Osborne and Totome 1992b).

Osborne and Leach (1983) suggested that nutrient enrichment of the lake was the most likely cause of these vegetation changes and concluded that much more research is required before tropical wetlands are used for the purification of waste waters.

Timing of sewage effluent disposal into Waigani Lake correlates with elevated levels in the sediments of lead, sulphur, manganese, barium, calcium, sodium, and strontium (Polunin et al. 1988; Osborne and Polunin 1988). The accelerated loadings of these elements may help to explain the disappearance of the swamp vegetation, and it also appears that the different vegetation stages may have influenced patterns of sediment geochemistry.

Box 7.2: The Wetlands Of Western Province: Threats from Mining

The central feature of this area is the Fly River (see Figure 7.1), which is the second largest in Papua New Guinea, and has a discharge of some 6 000 cubic metres per second. The river is over 1 200 kilometres long and is navigable as far as Kiunga, 800 kilometres from its mouth. The gradient in its lower reaches is extremely gentle as Kiunga is only 20 metres above sea level, and the river is tidal 250 kilometres from the sea. The Middle Fly is characterised by an extensive floodplain 15 to 20 kilometres wide, with a mosaic of lakes, alluvial forest, swamp grassland and swamp savannah. The river flows on an alluvial ridge formed by deposition of material eroded from the upper catchment, and as this deposition was more rapid than that of tributary streams, the tributaries became blocked, forming numerous tributary lakes. The river meanders extensively in this region, and in addition to tributary lakes, there are numerous back swamps and oxbows of variable depth depending on age. Lake Murray (see Figure 7.2) is the largest of these habitats and lies in a shallow depression (maximum depth of seven metres) in the Y formed by the Strickland and Fly Rivers.

This enormous wetland system is of high conservation value, providing a refuge during drought years for waterfowl from Australia. More importantly, over 40 000 people are sustained by the natural resources of the Ok Tedi and Fly Rivers. Consequently, the environmental impacts on these wetlands resulting from the construction and operation of the Ok Tedi and Porgera mines in the upper catchment of the Fly and Strickland Rivers, respectively, has been a cause for some concern (Pernetta 1988; Townsend 1988; Rosenbaum and Krockenberger 1993). The Ok Tedi mine, located at Mt. Fubilan in the far west of Papua New Guinea, is now one of the largest in the world. Waste rock and tailings are currently dumped into the Ok Tedi, a tributary of the Fly River.

Gold production commenced in May 1984 and copper production in March 1987. The gold circuit was closed in August 1988, and the mine now only produces copper. The impact of mine waste discharges has been characterised by increasing suspended solid levels and concomitant increases in dissolved and particulate trace metal levels, particularly copper (Salomons and Eagle 1990). Biologists working for the mining company monitored fish populations at two sites in the Ok Tedi River and one site in the Fly River (Smith and Hortle 1991; Smith and Morris 1992). They found that at the upstream site, catches were reduced to low levels shortly after mine operations commenced. In the lower Ok Tedi, there were distinct changes in the fish assemblage during the different phases of mine operation. At Kuambit, below the Ok Tedi-Fly River junction, mine contaminants were considerably diluted by the waters of the Fly River. The fish stocks at this site were also greater and more diverse than those of the lower Ok Tedi. Consequently, changes in the fish assemblages have been more gradual with the exception of a dramatic reduction in herring (*Nematalosa* spp.) abundance. Smith and Morris (1992) attributed the reduction in herrings to very high levels of cyanide recorded on 13-14 October 1986, and a subsequent inability of the population to recover. Smith and Hortle (1991) predicted that the greatest impact of the mine will be felt between 1989 and 1993 following which catches should be close to 1988 levels for the remainder of the mine's life. Recovery of the fishery following the cessation of mining will depend on the rate of erosion of accumulated mine wastes in the bed of the Ok Tedi and at the mine site, and on the availability of recruits from fish stocks in water bodies less seriously affected by mine discharges. Recovery may take 20 years, which together with the 30-year life of the mine, represents at least a 50-year disruption to the traditional lifestyles of the local inhabitants and to the ecology of the Fly River system (Rosenbaum and Krockenberger 1993).

Other aquatic ecosystems have also been affected through waste disposal, and the impact of sewage effluents on the Waigani wetland have already been described. The principal environmental threat from the Porgera copper and silver mine is through tailings disposal into the Laiagap-Strickland River system (Natural Systems Research 1988). Tailings disposal at this mine is complicated by their high mercury content. High levels of mercury in fish of the Fly-Strickland River systems have been known for some time (Lamb 1977; Kyle and Ghani 1982, 1984). The Herbert River, which drains Lake Murray into the Strickland, has been shown to reverse flow on occasions, a result of the flatness of the topography and marked seasonal fluctuations in the water level of Lake Murray and the Strickland River (Natural Systems Research 1988; Osborne et al. 1987). This discovery indicated a pathway for mine wastes to accumulate in Lake Murray. No significant studies assessing the impacts on aquatic ecosystems of forest harvesting by either clear felling or selective logging have been carried out in Papua New Guinea.

Papua New Guinea faces the dilemma of choosing between potential environmental degradation from such projects and the large monetary rewards that they bring. This dilemma indicates the urgent need for research into the general ecological functioning of wetlands in the tropics, and, more specifically, into the effects of increased heavy metal and sediment loadings on the Middle Fly wetlands.

Marine and Coastal Environments

Papua New Guinea has a total sea area of 3 120 000 square kilometres (Pernetta 1990), and a total coastline of 17 110 kilometres (Bualia and Sullivan 1990) which encompasses the coastal peripheries of the mainland and islands of 15 of its 20 provinces. The marine environments of Papua New Guinea and the organisms they support are surprisingly poorly studied. In general, the areas where the marine biota is understood are near the major ports and research centres of Port Moresby, Lae, Christensen Research Institute (CRI) in Madang, and Motupore Island Research Station in Port Moresby (McGregor and Huber 1993; Agardy and Pernetta 1993). Data also exist for the Gulf of Papua, because of its rich commercial fisheries resources and the environmental impact studies related to the Purari hydroelectric scheme done in the late 1970s and early 1980s. Oceanographic data for Papua New Guinea are scattered, largely because most of the work has been done by foreign research laboratories, mainly from New Zealand and Australia, while observing large-scale oceanographic phenomena in this region (Wyrtki 1960; Kailola and Wilson 1978; Scully-Power 1973a, 1973b; Wolansky 1985).

Several processes are responsible for the present distributional patterns of the different environments and their constituent biota. These can be classified into three broad categories:

- geological processes, including tectonic activity, quaternary sea-level changes, and weathering, erosion and terrestrial run-off;

- oceanographic and climatic processes, including currents and wind-induced circulations; and

- biogeographical processes, being the dispersal, colonisation and development of characteristic biota in response to suitable environmental and ecological conditions.

Papua New Guinea is surrounded by three major water masses whose coherence and separation is largely influenced by the sea-bed bathymetry — the Bismarck Sea, the Solomon Sea, and the Coral Sea (Krause 1967; Mutter 1972).

Papua New Guinea is situated in a geologically very active area. Tectonic movements of the land up and down, together with fluctuations of sea level associated with climatic change during the Quaternary Period have given rise to a number of features in the coastal and marine environment of Papua New Guinea. These include the fjords (drowned river valleys) near Tufi in Oro Province (Ranck and Jackson 1973), the high islands of the D'Entrecasteaux Islands and the Louisiade Archipelago which are remnants of the drowned extension of the Papuan Peninsula (Krause 1967), the raised coral reef terraces along the northeast coast of the Huon Peninsula (Zhu et al. 1988), and the exposure of reefal limestones of Miocene Age at Delena near Yule Island, Central Province (Perembo 1983).

Figure 7.1: Major Wetland Areas in Papua New Guinea.

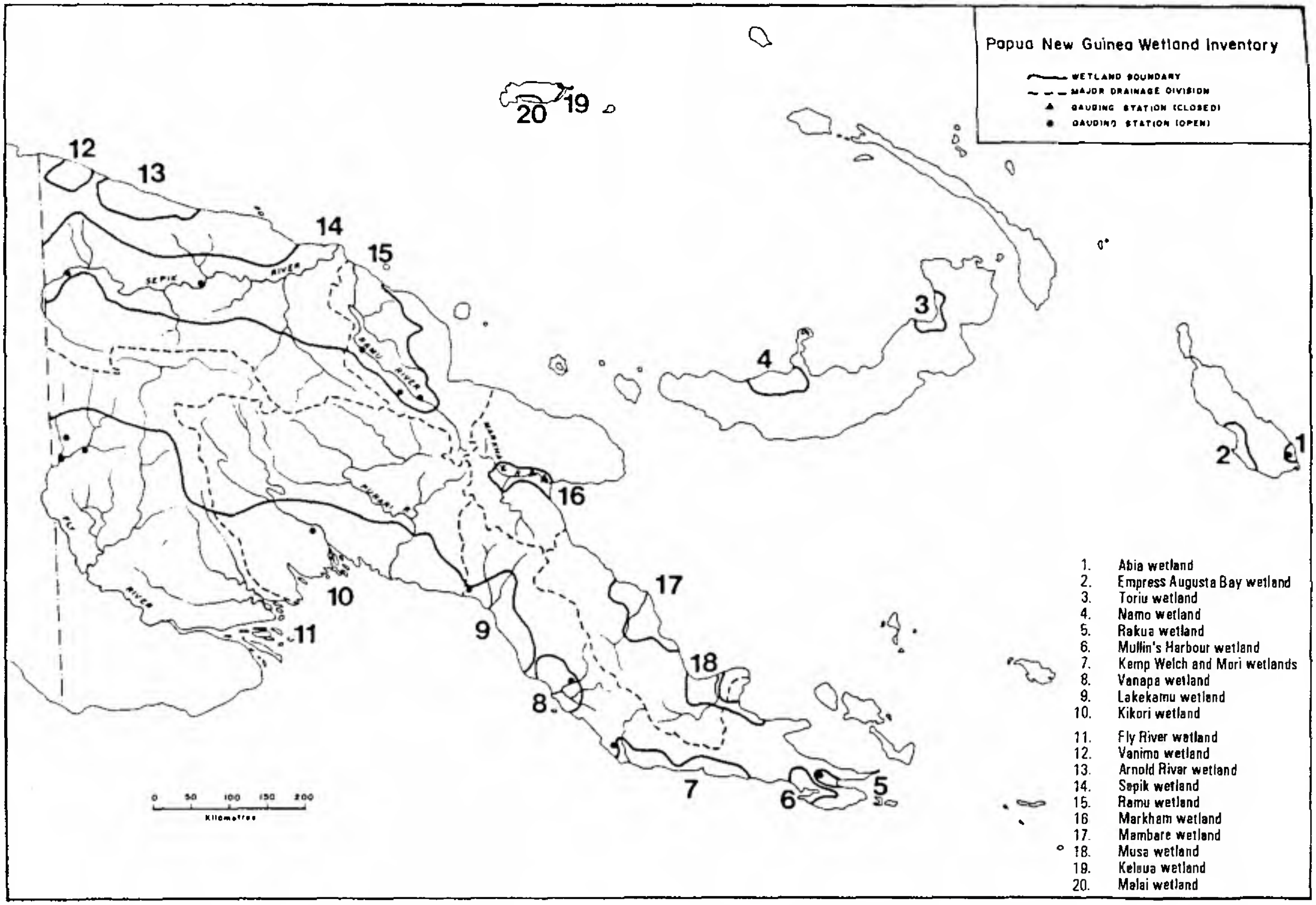
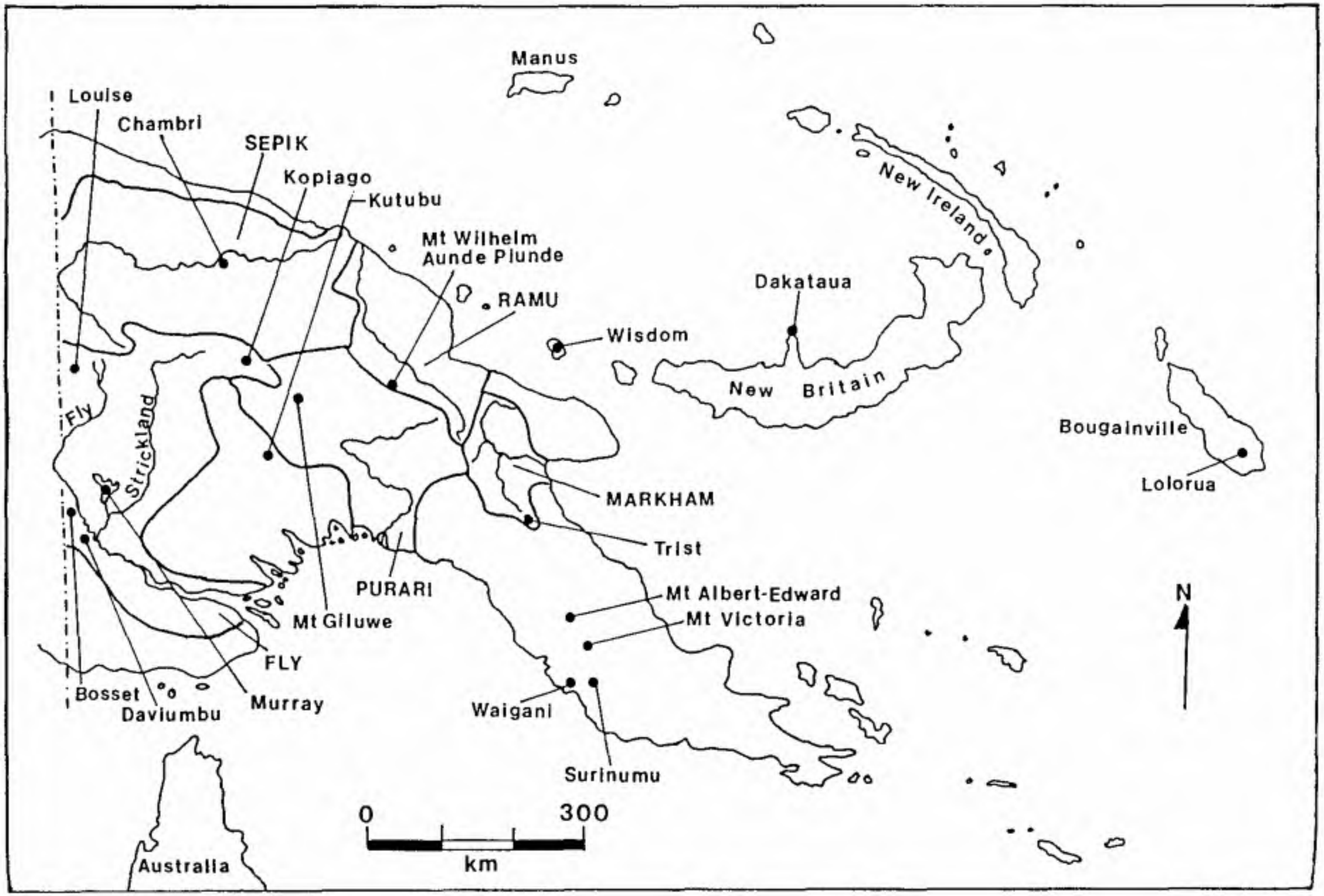


Figure 7.2: The Major River Catchments of Papua New Guinea and Geographical Position of Mountains and Lakes.



Weathering, erosion, and terrestrial run-off contribute sediments and freshwater input into coastal and marine environments. These products either help build a habitat, or destroy or limit its development. Examples of depositional environments are Papua New Guinea's numerous non-calcareous sandy beaches and the deltas of the major river systems of the Fly, Purari and Sepik Rivers. A good example of sandy beaches of this origin is along the northwest coast from Wewak to Vanimo; this area has been considered to have potential for beach-sand mining for minerals such as chromite (Wangu, personal communication). Sedimentation processes are also important to the maintenence of mangrove ecosystems (Woodroffe 1992). Deposition of fine muds and silts in sufficiently lighted estuaries or the adjacent coastal habitats of suitable salinities is conducive to the establishment and development of seagrass beds. The input of sediments and freshwater into the nearshore marine environment is detrimental to the development or maintenance of coral reefs. Waters with salinities much less than 35 percent suppress coral growth. Turbid waters cut off light needed by the photosynthetic symbionts (Zooxanthellae) as well as clogging and suffocating the coral polyps. This influence on the establishment and development of coral reefs shows in the absence of coral reefs near the mouths of major rivers.

Key Environments

The key marine environments of Papua New Guinea were briefly described in the Conservation Needs Assessment (Agardy and Pernetta 1993). These descriptions are incomplete, but serve as points of reference and as bases to plan and execute more detailed studies. Agardy and Pernetta (1993) listed the following principal environments: (1) reefs (fringing, barrier, and patch reefs); (2) mangroves; (3) seagrass beds; (4) sand and mud-accreting shorelines and intertidal flats; (5) barrier dunes and associated lagoons; (6) deltaic floodplains and estuarine areas; (7) sea mounts; (8) rocky shorelines; and (9) reef walls and drop-off areas of the continental slope. There is a vital need for a comprehensive survey of the coastal ecosystems of Papua New Guinea to provide the basis for resource management (see further suggestions by Maragos 1991; Agardy and Pernetta 1993).

With the exception of sea mounts and continental slope environments (types 7 and 9), all the other environments occur on the continental shelf and the coastal environments associated with its landward margin. Continental slope habitats occur at the seaward margin of the continental shelf, and sea mounts are usually features of the bathyal and abyssal environments projecting up to 1 000 metres vertically into the overlying deep waters, providing feeding and refuge habitats for large deepwater predatory fishes and their prey. Deepwater species such as yellowfin tuna (*Thunnus albacares*), deepwater sharks, and billfishes are examples of these large predatory pelagic species.

Coral Reefs and Seagrasses

Coral reefs (fringing, barrier and patch reefs) and seagrass beds are subtidal habitats that are often sympatric in their distribution but require environments with different oceanographic conditions. Coral reefs occur in warm and well-lighted oligotrophic waters with less destructive moderate water currents which circulate and disperse any suspended sediments contained therein (Cahill et al. 1973; Manser 1973; Weber 1973; Moore 1982; Veron 1985). These currents and waves sweep the suspended material over the reef crest into the lagoon (energetically quieter environments) at the back reef; this basic pattern of reefal sediment sorting occurs on both barrier and fringing reefs (Cahill et al. 1973; Manser 1973b; Weber 1973; Haig 1988).

Most of the reefs in Papua New Guinea are of the fringing and patch reef type (Whitehouse 1973). Extensive barrier reefs only occur along the south coast, around the Louisiade Archipelago, and end at East Cape on the eastern coast, indicating a sinking continental margin in this area (Whitehouse 1973). The northern coast and the islands, although not as rich in coral growth as the southern and eastern coasts (Whitehouse 1973), are dominated by fringing and patch reefs. There is a relative disparity in coral reef habitats in the four regions — northern, islands, southern and eastern (Papua New Guinea Geological Map 1976, Scale 1: 2 500 000).

The sediments deposited in the lagoons of barrier and fringing reef systems are conducive to the establishment of seagrasses. Being marine angiosperms (monocots) (Larkum and Den Hartog 1989),they require the sediments for root establishment, anchoring and nutrient uptake (Brouns 1986). The distribution of seagrasses in Papua New Guinea has been studied (Johnstone 1979, 1982), but detailed ecological studies of seagrasses and their habitats have been undertaken only on Motupore and Lion Islands (Brouns and Heijs 1986).

Coral Biodiversity

As discussed in Chapter 6, Papua New Guinea's coral reefs, especially those along the northern coast, may be the most diverse in the world. The reasons for this spectacular diversity are not clear but a possible explanation is as follows. The northern coast of New Guinea forms the southern margin of the Indonesian-Malaysian-Philippine region of global maximum marine biodiversity. The complex geological history of accretion of many small tectonic plates into northern New Guinea provides a mechanism for recruitment of entire biotas from other parts of the Indo-Pacific. As the Australian continental plate moved north towards Asia, its leading edge (now New Guinea) may have accumulated elements from faunas at higher latitudes. The history of prolonged geological uplift in the area ensures that comparable reef habitats always persisted under similar environmental conditions, even during the major sea-level fluctuations of the Pleistocene glaciations. Elsewhere, most reefs were on broad continental shelves that became dry land as sea levels fell, and local extinctions of reef faunas were widespread. As cyclones rarely reach this coast, forms vulnerable to physical disturbance are much more likely to persist, even on exposed outer reefs. Until very recently, human population densities have been very low and technology limited, so that human impacts have been minor.

Papua New Guinea coral reefs are highly vulnerable to disturbance for the following reasons. Coastal human populations, largely retaining traditional uses of reefs, are increasing rapidly, and putting much greater demands on the systems. Many reefs in Papua New Guinea are very close to shore (fringing and barrier reefs) so that access to all parts of the reef is easy. Rapid increases in technology (boats, motors, masks, SCUBA, explosives, etc.) greatly increase the impact of each person on reefs. Commercial and export trades increase demands on reefs far beyond those of just the people living there. Physical damage from anchors, fishing gear, divers, explosives, and so on, simplifies the reef structure, destroys micro-habitats for many other species, and creates rubble that further destroys more reef habitat and reduces biodiversity further. Close proximity to land, plus limited tidal flushing of inshore lagoons, makes Papua New Guinea's reefs especially vulnerable to siltation and other adverse effects of increased run-off and erosion of land.

Box 7.3: Coral Reef Management: Lessons from the Caribbean

In many ways, marine environments in Papua New Guinea are still relatively close to pristine. In this respect, they resemble the Caribbean when Europeans arrived 500 years ago. Since then, the Caribbean has seen prolonged population increases, massive habitat modification on land (for plantations, etc.), and a sequence of fisheries for both subsistence and export. To provide a background for planning the future management of Papua New Guinea's reefs, it is instructive to review the history of decline of Caribbean reefs.

Beginning in the 16th century with the largest organisms, specialised fisheries have sequentially depleted stocks to levels from which they have never recovered. In turn, the Caribbean has been depleted of most large carnivores (for example, sharks, barracuda, and coral trout) and most large herbivores (manatees, turtles, parrot and other grazing fishes, conches, etc.) to the point where today, most higher levels of the food webs are largely missing in many regions. For example, in Jamaica, so few large fish now remain that subsistence fishing now consists almost entirely of netting very small fish for stews and fishmeal. While overfishing of particular species began in the 16th century with primitive technologies, it has accelerated exponentially ever since as technologies, populations and economic pressures surged.

Virtually all Caribbean reefs are now accessible to large numbers of people on a daily basis. The problems became severe almost simultaneously in many parts of the Caribbean since about 1980. First, a disease killed most of the only remaining large herbivore species (the sea urchin *Diadema*) throughout the Caribbean in only eight months. Second, the frequency of severe hurricanes increased after several quiet decades leading to widespread physical damage. Third, rapidly increasing terrestrial activity (industrialisation, agriculture, forestry, tourism, population explosion, etc.) greatly increased adverse effects on adjacent reefs (siltation, freshwater run-off, pollution, sewage, nutrient input, marine construction, etc.). Hughes (1994) details the situation in Jamaica.

In many places since 1980 (for example, Jamaica, Florida, Costa Rica, Colombia, etc.), coral-dominated communities have been replaced by algal-dominated communities. This has also involved loss of many species usually associated with corals (including many preferred food species), loss of physical habitats through bioerosion of coral limestones and their conversion to sediments, and major changes in turbidity, nutrient content and other undesirable seawater properties. The changes appear relatively stable and permanent, and the trend appears to be towards much simpler, lower diversity communities, probably with greatly reduced economic value and certainly much less aesthetic appeal for the tourist industries (SCOPE Coral Reef Biodiversity Workshop 1993).

There is anecdotal evidence that analogous changes towards algal-dominated communities are beginning close to Papua New Guinea in the Philippines in reponse to similar processes exacerbated by the widespread chronic damage to Philippine reefs caused by repeated destructive fishing techniques (explosives, cyanide, sound walls of rocks pounded on bottom). If this is true, the processes that took centuries to approach completion in the Caribbean, took only decades in the Philippines; similar deleterious changes in Papua New Guinea could also occur in decades if it permits similar terrestrial and marine exploitation practices, enhanced by the most modern, large-scale technologies.

Mudflats, Estuaries and Mangroves

Mudflats, estuaries and mangroves are associated with areas influenced by fluvial run-off and delta formation. These environments are largely found in southern and northern Papua New Guinea. The principal river systems on the south coast are the Fly, Kikori and Purari, with smaller ones such as the Brown River/Vanapa and Kemp Welch River to the south east of these major river systems. The principal river systems on the north coast are the Sepik River and the nearby Ramu River, and the Markham River to the southeast. Extensive and well-developed mangrove habitats are associated with these major river systems. The most extensive of these occur along the southwest coast in association with the Fly, Kikori and Purari River systems (Percival and Womersley 1975; Johnstone and Frodin 1982).

Sandy and Rocky Shores

Sandy and rocky shores are environments of coastlines where oceanographic, fluvial and geomorphological processes are suitable. Oceanographic conditions that change seasonally in response to local wind patterns and the amount of energy transfered to the coastal currents regulate where transported sediments are deposited or where material is eroded. On the mainland and high islands beaches form in embayments with gently sloping coastlines which are shaded from high-energy coastal currents. Exposed coastlines with steep slopes tend to contain rocky shores. On low-lying islands in the vicinity of extensive coral reefs, coastlines are predominantly covered by sandy beaches. The relative sizes of beaches are different on the leeward and windward sides of these islands. The north coast of Papua New Guinea from Wewak to Vanimo has a good stretch of sandy-shore habitats. Similar habitats have been documented for the coastline between Labu Tali and Busama, southeast of Lae, Morobe Province. The sandy beaches in this area are important nesting grounds for the leatherback turtle *(Dermochelys coriacea)* (Hirth et al. 1993).

Summary of Conservation Needs Assessment Maps

The following summarises the priority maps (major unknown areas, marine systems and critical watersheds, and the terrestrial synthesis) derived by the Conservation Needs Assessment, with appended accounts for each of the delineated areas of importance. The Conservation Needs Assessment process involved reviews of existing data on both organisms and habitats by national and international specialists. Team leaders then met in Madang and reached consensus, with the assistance of a geographic information system, on these maps. The following is taken verbatim from Beehler (1993), which should be seen for additional details.

The following three maps reflect the effort at the workshop to synthesise the available information and complete a series of biodiversity assessments. These, then, can be presented in map form for the future use of biologists and resource managers concerned with the conservation of Papua New Guinea's remarkable natural resources. For additional data on many of the sites, the reader can refer to individual topic chapters in Volume 2 of the Conservation Needs Assessment Report, but a summary listing of additional supporting data appears with each of the three maps. These supporting data include key information on a focal area's biological richness, its biogeographic and ecological importance, potential threats, and supporting documentation in the literature.

A number of points were made clear from the assessments and the workshop interactions. First and foremost was that there are large gaps in our knowledge of Papua New Guinea's biodiversity. Whereas birds, rhododendrons, mammals, and birdwing butterflies are fairly well documented, most invertebrates and most plant groups are little known, with many species still undescribed. Large segments of Papua New Guinea remain unstudied and thus are biological unknowns (highlighted in the map of unknowns featured). The marine resources, perhaps, stand as the least surveyed of all.

On a more positive note, the agreement between biologists on terrestrial sites of significant biological importance was surprisingly high. Although there was disagreement about the detail of area boundaries, there were very few disagreements about the general location of Papua New Guinea's most important storehouses of biodiversity. We believe this signals that we have sufficient information to make informed assessments in spite of our recognition that there is still a great deal yet to survey and study.

The Conservation Needs Assessment workshop also agreed that the following statement should be distributed with the final map:

> The *Constitution* of Papua New Guinea promotes equality and participation, the wise use of natural resources, and Papua New Guinean forms of development. Ninety-seven percent of Papua New Guinea is owned according to customary tenure. This map was prepared by biological scientists and, based on available knowledge, identifies areas richest in biodiversity. This map is not intended to, nor should it be used to, exclude any areas or any landowners from conservation programs and initiatives. When identifying appropriate conservation strategies and areas, local initiative is as important a criteria as biodiversity.

Synthesis Map A: Major Terrestrial Unknowns

Major areas unknown to science were delineated mainly from a combination of the mapping by the vertebrate and botany teams. These are the two groups for which there is a well-refined knowledge of the major geographic gaps in knowledge of Papua New Guinea's biodiversity. The 16 major terrestrial unknowns are shown in Figure 7.3, and are discussed.

Figure 7.3: Major Unknown Terrestrial Areas of Papua New Guinea

Scale 1: 9000000

columns 1 : 712
lines 1 : 534

Name of classes	Frequency (cells)	Area (Km^2)	(%)
unassigned	52604	328775.00	69.9
largely unstudied	22607	141293.80	30.1
TOTAL	75211	470068.80	100.0

1. *Bewani Mountains*: The low coastal range that reaches westward to the Irian border, and the humid lowlands south of this range, are little studied and apparently biologically rich. Recent discoveries of two new mammal species, and a lowland Bird of Paradise formerly known only from Irian Jaya, support the idea that further survey and research are needed here.

2. *Central Range*: The high range that rises south of the Sepik basin is little studied and largely forested. This area is ecologically and physiographically diverse and presumably very rich biologically.

3. *Southern Scarp Wet Zone:* This is Papua New Guinea's great wilderness area – lowlands, low hills, and old Pleistocene volcanoes, with a high annual rainfall. It is sparsely populated and little known. Notable are the Kikori karst hills and prominent volcanic outliers, including Mount Bosavi and Mount Murray. Eastward one finds rugged wet forests that form the southern foothills of the Kubor Range and Eastern Highlands. These are virtually uninhabited and very wet.

4. *Finisterre Range*: The highlands and hills of the western segment of the Huon Peninsula are virtually unstudied, but certainly comprise a significant biological resource. Alpine peaks exceeding 4 000 metres descend to the hilly coastal zone facing the Bismarck Sea.

5. *Lakekamu Basin/Chapman Range*: Like the Finisterre Range, this area is relatively close to population centres, and yet is both little developed and virtually unknown biologically. The area includes pristine humid lowland forest to subalpine highland zones (> 3 000 m) in the Chapman Range, and is very rich in wildlife.

6. *Bowutu Ultrabasics*: Rugged hills and mountains that descend to the rocky coast of Morobe Province. The area is botanically unusual and virtually unsurveyed.

7. *Ioma/Mambare Lowlands:* An isolated lowland area that merits study. It supports a large lowland basin that is largely forested – comprising the largest lowland forest tract on the Papuan peninsula.

8. *Musa Basin:* Important wetlands and lowland swamp forests that are unknown.

9. *Kemp-Welch River Lowlands:* A remnant wetland area representative of the dry lowlands of Central Province. Not yet surveyed.

10. *Cloudy Mountains:* An isolated range of mountains that is, as yet, unsurveyed. These form the southernmost mountains of mainland Papua New Guinea.

11. *Fergusson Highlands*: Zoologically unsurveyed highlands on one of the most complex high islands in Melanesia. Mt. Kilkerran comprises a large forested massif never surveyed zoologically. One of the top priority zoological unknowns.

12. *West New Britain:* Little known mountains and lowlands.

13. *Central and Eastern New Britain:* Unsurveyed high ranges and southern scarp lowlands. The Nakanai Mountains comprise a large uplifted plateau (mostly > 1 000 m) in eastern New Britain whose montane fauna has never been surveyed (Coultas failed to collect any of the significant montane birds). The area constitutes the largest continuous expanse of montane forest on New Britain.

    Southern New Ireland: Biologically unknown highlands that constitute New Ireland's most complex environments. The Verron Range is unsurveyed and unknown, with summits higher than 2 000 metres.

The Hans Meyer Range is the highest of any island in the Bismarcks, and still has not been surveyed adequately for vertebrates.

15. *Bougainville Bamboo Forests:* The only known bamboo forests in Melanesia. Unstudied biologically.

16. *Mt. Takuan/Lake Lorolu:* Little-surveyed wet highlands forests with a Solomon Islands biota.

Synthesis Map B: Marine Systems and Critical Watersheds

One of the major points of the Conservation Needs Assessment workshop discussions was that the health of coastal marine ecosystems depended, in part, on the integrity of the watersheds that empty into them (see Figure 7.4). We thus present a map that combines watersheds and coastal/marine ecosystems. We list marine priorities, followed by critical watersheds.

Marine Priorities

1. *Maza/Fly Delta:* Mangrove and associated nursery habitats, with seagrass beds, green sea turtle foraging habitats, and dugong habitat. The area is possibly threatened by overfishing and river-borne pollutants.

2. *Gulf:* Shallow intertidal and soft bottom habitats; mangrove communities that comprise important nursery areas for prawns, barramundi, and other commercially important species. Possible threats include overfishing, oil exploration, and pipeline construction.

3. *Galley Reach:* Highly productive mangrove forests, wetlands, and reef. The area is threatened by development and exploitation because of its proximity to Port Moresby.

4. *Papuan Barrier and Lagoon:* Barrier reef, coastal lagoon, and mangroves containing Hawksbill turtles, reef fishes, corals, and marine invertebrates. High diversity. Threatened by dynamite fishing, overfishing, and eutrophication from sewage effluents related to Port Moresby development.

5. *Dumoulin:* Reef in proximity to southern drop-off (potential upwelling). Largely unknown but contains populations of giant clams.

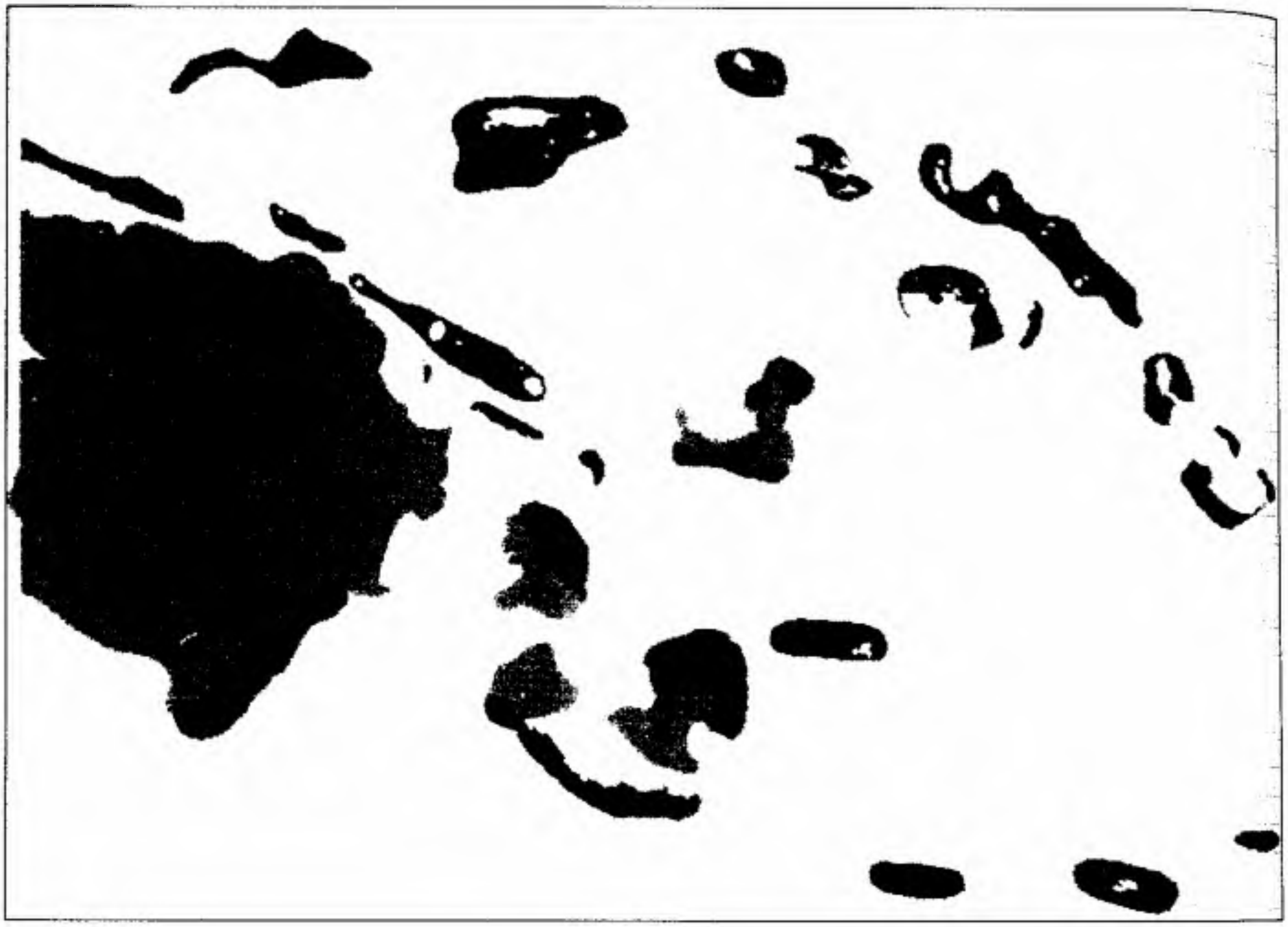
6. *Rossel Island:* Reef systems, lagoons, isolated island areas, upwelling area. Largely unknown biologically. Possible threats from foreign poaching.

7. *Pocklington Reef:* Extensive reef system, thought to be relatively pristine; isolated by deep water from all other reef systems in Milne Bay. May show affinities to New Georgia reef system.

8. *Morobe Coast:* Mangroves, sea walls, Leatherback turtle nesting beaches, and fringing reefs. Potential for community initiated conservation program. High beta diversity. Potential threats from nearby Lae town, especially from logging of coastal hill forests.

9. *Tufi Coastal Fjords:* Coral fjords, fringing reefs, mangrove, sea walls, and thermal vents. An environment unique in Papua New Guinea. High potential for nature tourism.

Figure 7.4: Critical Watersheds and Marine Ecosystems



Scale 1: 9000000

columns 1 : 712
lines 1 : 534

Name of classes	Frequency (cells)	Area (Km²)	(%)
unassigned marine	277358	1733488.00	72.9
highly significant	27639	172743.80	7.3
significant watershed area	46431	290193.80	12.2
unassigned terrestrial	28780	179875.00	7.6
TOTAL	380208	2376300.00	100.0

10. *Fullerborne*: Raised limestone islands, mangrove and associated nursery areas, and seagrass beds. Habitat and structural diversity high. Threats from large-scale timber operations.

11. *Talasea*: Reef and soft bottom marine habitats. Leatherback turtle nesting beaches.

12. *Rabaul/Duke of York:* Mangrove, seagrass, reef, offshore deepwater areas with vents. Threats because of proximity to nearby Rabaul town and timber operations in watersheds above coast.

13. *Tigak Islands:* Mangroves, seagrasses, reef, and deepwater mangrove lagoon. Highly productive fishery. Beta diversity very high. Threats from dynamite fishing.

14. *Mussau Island:* Reef systems and seagrasses. Sea turtles and dugongs. Some parts of this marine system are relatively pristine because of traditional practices of islanders. Threats from dynamite fishing.

15. *Tanga/Tabar/Feni Islands:* Subsea volcanic formations, mineral rich areas, isolated island systems; may be very important for endangered vertebrates (sea turtles). Diverse habitats and unusual geomorphology. Possible threat from nearshore and offshore overfishing.

16. *Southern New Ireland*: Fringing reefs.

17. *Buka: Reef-and-lagoon complex; soft bottom communities.* Coral reef fishes, but otherwise largely unknown. Buka Channel comprises a unique habitat in Papua New Guinea. Threats from overfishing and poor land-use practices.

18. *South Coast Bougainville*: Reefs and associated habitats; swamp forest differs from those on mainland. Largely unknown fauna. Selected because of presence of reef systems in proximity to deep open ocean waters.

19. *Borone Bay:* Largely unknown. Unusual hydrography coupled with steep sloped shore fall-off. Threats from logging and mining in upland areas.

20. *Hermit Islands:* Extensive, discrete, patch reefs. Sea turtles. Highly productive, fisheries rich. Reef areas far from population centres. Threats from overfishing and poaching. Uncontrolled tourism in western islands may be a potential threat.

21. *Manus Complex:* Reefs and lagoon complexes, seagrass beds, seabird rookery islands. Presence of green tree snail, reef fishes, pelagics, sea turtles. High beta diversity. Reefs diverse yet highly threatened. Threats from dynamite fishing and phosphate mining on seabird islands.

22. *Cape Cretin:* Ancient reef faces.

23. *Vitiaz Straits*: Reefs. Steep land in proximity to reef areas. Threat from land-use practices.

24. *Volcanic Chain*: Manam to Long Island. Volcanic islands, reef walls, sea mounts, sea turtle nesting beaches, upwelling areas. Pelagic fishes congregating at sea walls and sea mounts. Threats from overfishing and overharvest of sea turtle eggs.

25. *Madang Lagoon:* Coral reefs, lagoon islands, and mangrove patches. Coral and fish species. Extremely well studied; species rich; high habitat diversity. Threat from commercial development in association with Madang town; dynamiting, and logging.

26. *Laing Island:* Reef system and marine research station. Threats from dynamiting and copra plantation waste.

27. *Sepik Delta:* Mangrove, brackish lake systems; crocodiles; highly productive; unique hydrology. Threats from watershed mismanagement and introduction of exotic fishes.

28. *Vokeo and Islands:* Small island systems in association with deep water.

29. *Northwest Coast:* Sandy beaches; fauna largely unsurveyed. Interesting current regimes and bottom topography; productive waters. Threats from overfishing and coastal logging.

Critical Watersheds

- *Sepik/Fly Drainages:* These comprise the two largest watersheds in Papua New Guinea. The Fly River is of critical importance to the health of the Gulf of Papua. The Sepik River supports a large human population which is dependent on the river for much of its livelihood.

- *Morobe/Waria Watershed:* Important upland drainages that affect the coastal islands and reef of Morobe.

- *Vanapa/Brown:* A compact but important peninsular river system that drains into a significant mangrove system.

- *Musa/Topographers:* A small but important watershed that affects the marine systems around Tufi.

- *West New Britain:* Important to the priority marine systems of West New Britain.

Synthesis Map C: Terrestrial Biodiversity

Details on all of these priority areas appear in Volume 2 of the Conservation Needs Assessment report. Summaries for each follow. The map shows four categories: (1) unassigned, (2) biologically important, (3) very important biologically, and (4) important wetlands not included in (2) or (3) (see Figure 7.5).

1. *North Coastal Hills* : Lower montane and lowland alluvial forests that are relatively poorly surveyed but known to be rich in Irianese specialties. The area includes the endemic fern genus *Rheopteris* and also interesting coastal limestone communities. The highlands of the North Coastal Ranges support two endemic species of large mammals (the Giant Glider and Scott's Tree Kangaroo), and a number of isolated and taxonomically distinct bird populations.

2. *Star Highlands*: include pristine alpine and montane environments descending to mid-montane valleys, foothills, and fringing lowlands. They support a diverse montane and high altitude vegetation with many plant species in common with the mountains of Irian Jaya. The subalpine forests are home to a significant population of the globally threatened Macgregor's Bird of Paradise. The environmental transect from the summit heights northward to the Ai River lowlands has been documented as having the richest known mammal fauna in New Guinea.

3. *Central Range/Sepik Foothills:* Comprise a large wilderness area with low human population and remarkable habitat diversity, from lowland to subalpine forest. The area includes extensive stands of

Agathis labillardieri, which support a highly diverse epiphytic flora. The health of the Sepik hill forests are important to the river and its human cultures.

4. *Upper Fly Lowlands:* This area of lowland and hill forest is delimited by the Palmer River on the east and Irian border on the west, and the southern scarp of the central cordillera on the north. Except for the extensive settlements related to the Ok Tedi mine (in the west) this area comprises a large expanse of old growth wet rainforest that supports a small human population and is characteristic of the extraordinarily rich biota of the upper Fly platform.

5. *Tonda/Bulla Plain:* Savannah and riverine gallery forest unique in Papua New Guinea. The large areas of savannah and seasonally flooded grasslands and marshes constitute a globally significant wintering ground for migratory waders and waterfowl both from Australia and the Palearctic.

6. *Northern Trans-Fly:* Unsurveyed seasonal forest and woodland that is probably a habitat formation unique in Papua New Guinea. An undercollected flora closely related to that occurring in the Cape York Peninsula.

7. *Mount Bosavi/Aramia Watershed:* An outlying Pleistocene volcano and vast alluvial plain. Virtually uninhabited. Proposed for national park status more than a decade ago, the forests of the great extinct Mount Bosavi volcano have long been recognised to be of importance to conservation in Papua New Guinea. The tract comprises the volcanic cone plus lower slopes to the west and southwest. These forests are faunistically rich and virtually undisturbed.

8. *Doma Peaks/Leiwaro Highlands:.* Rich highlands environments with high scenic and biotic value. Doma Peaks (and Tari Gap) have been considered for national park status. These comprise a large mid-montane and upper montane tract of uninhabited forest that is exceedingly rich in birds of paradise. Road access to 3 000 metres on Tari Pass. The area includes volcanic peaks.

9. *Kikori Karst/Lake Kutubu:* Unknown and unsurveyed, with a remarkable karst topography and Papua New Guinea's largest highland lake. Lake Kutubu supports a diverse aquatic plant flora, and eleven of the fourteen known fish species in the lake are endemic to it. The area also includes an enormous tract of tower limestone, which is botanically unknown. Limestone floras in southeast Asia are often very rich, and, if the Great Papuan Plateau reflects this diversity, it is most important that detailed studies be made of its flora. The limestone flora is poorly known from New Guinea, but it will likely include many undescribed species and possibly new generic records.

10. *Giluwe:* The massive Giluwe shield volcano is capped by the largest contiguous expanse of alpine vegetation in Papua New Guinea. This is a globally-significant montane and alpine wilderness threatened by logging of the beech-podocarp forests of its middle and upper slopes. The area is very rich biologically, and contains extensive subalpine bogs.

11. *Adelbert Mountains:* Threatened lower montane forests that are home to the endemic Fire-Maned Bowerbird, the rarest bird species in Papua New Guinea and the bird species with the most circumscribed geographic range known for mainland Papua New Guinea. The forests are little known, but probably diverse.

12. *Bismarck Highlands/Ramu Basin*: From Papua New Guinea's highest summit to one of its richest lowland alluvial forests. The Ramu supports extensive areas of lowland rainforest (including swamp forest), some of which is developed on ultrabasic parent rock [with the only known locality of *Lauterbachia* (Monimiaceae)].

Figure 7.5: Important Areas for Terrestrial Animal Life, Vegetation and Wetlands

Scale 1: 9000000

columns	1	:	712
lines	1	:	534

Name of classes	Frequency (cells)	Area (Km²)	(%)
unassigned	36408	227550.00	48.4
highly significant	15202	95012.50	20.2
very highly significant	18090	113062.50	24.1
significant wetland	5511	34443.75	7.3
TOTAL	75211	470068.80	100.0

13. *Kubor Highlands*: High peaks and uninhabited montane forests, much on limestone capped with volcanic ash. A fragile ecosystem that probably contains local endemic plant species.

14. *Crater Mountain:* Comprises wet lower montane forest and Pleistocene volcanoes. The Crater Mountain ecosystem is a Wildlife Management Area, chosen because of its large expanse of original forest and large populations of a diverse array of birds of paradise, including the rare Black Sicklebill (*Epimachus fastuosus*) and Blue Bird of Paradise (*Paradisaea rudolphi*).

15. *Purari Basin*: Wet zone lowlands and hills that are virtually uninhabited and little studied. This includes a very diverse area of mangrove and swamp vegetation with lowland rainforest on small limestone hills out of the surrounding swamps. These evidently support many local plant endemics but are virtually uncollected. The area includes numerous species of *Pandanus* and also a rich palm flora, particularly of *Calamus*.

16. *Finisterre Range:* Papua New Guinea's youngest mountain range, with alpine highlands that remain little surveyed. This large montane forest tract, with a broad elevational range, from coastal hill forest to the treeline, supports species endemics of three birds of paradise, two honeyeaters, and a tree kangaroo.

17. *Saruwaged and Cromwell Ranges:* Alpine highlands and hill tracts threatened by development. This and the Finisterre area support numbers of locally endemic bird and mammal species, and the only extensive *Dacrydium* forests in the Southern Hemisphere that remains unlogged.

18. *Watut Hills and Watershed:* Little-studied hill country east of the central highlands area. The endemic plant genus *Piora* is recorded only from Mt. Piora and Mt. Amungwiwa. The lower reaches of the Watut River drainage support populations of the endemic root parasite *Langsdorfia papuana*, a genus otherwise known only from Madagascar, and Central and South America.

19. *Lakekamu Basin/Chapman Range:* Includes an entirely uninhabited tract of forest that ranges from pristine lowland alluvial forest to upper montane forest near treeline, all within a transect of no more than 20 km. The lowland forest supports large populations of the Southern Crowned Pigeon, Southern Cassowary, and Pesquet's Parrot.

20. *Central Province Dry Zone:* Savannah and monsoon forest complex with wetlands, threatened by development. Also includes the second largest mangrove area in Central Province.

21. *Bowutu Mountains/Kuper Range:* The Bowutu Mountains comprise an area of ultrabasic montane flora, plus coastal, mangrove, and seagrass communities. The Kuper Range is a high coastal mountain complex that is virtually uninhabited and the site of a number of detailed ecological studies on birds and plants.

22. *Owen Stanley Highlands:* Extensive alpine areas and vast tracts of pristine montane forests, ranging downward in the north to the forested Ioma lowlands. The Mount Albert Edward dome includes the largest alpine uplands in eastern Papua New Guinea, and thus is a critical montane resource. The lowland forests constitute a critically threatened resource in peninsular Papua, and those suggested for protection here may support populations of the globally threatened (and world's largest) butterfly, *Troides alexandrae*.

23. *Musa River:* Little known lowland forests and wetlands.

24. *Safia Dry Zone:* A low rainfall interior zone with unusual animal and plant communities.

25. *Topographers Range:* An isolated volcanic cone in association with the coastal fjordlands of Tufi.

26. *Mt. Suckling:* A large montane wilderness isolated from the main Owen Stanley highlands. Virtually uninhabited and little disturbed at this point. The Suckling massif is the only significant alpine uplands in the eastern peninsula, and, in conjunction with the adjacent Bonua basin, stands as a remarkably pristine aggregate of montane and lowland forest in easternmost mainland Papua New Guinea.

27. *Cloudy Mountains:* The most southerly mountain range in Papua New Guinea. No collections are known from the area which urgently needs study.

28. *Goodenough Highlands:* The massive central peaks of Goodenough Island are higher than any other mountains on New Guinea's fringing islands. The mountain forests that cloak these summits are home to an endemic species of forest wallaby and a bat endemic to these eastern islands. The area contains many botanical novelties.

29. *Fergusson/Normanby:* Unusual montane habitats and (on Normanby) ultrabasic dwarf forest. Fergusson Island is one of Papua New Guinea's great biological unknowns, with three distinct mountain ranges, geothermal areas, and other natural wonders. The triok possum *(Dactylopsila tatei)* is a species endemic to Fergusson. Goldie's Bird of Paradise is confined to the forests of these two islands.

30. *Woodlark Island:* Floristically unusual; the forests of the interior of Woodlark are home to the endemic Woodlark Cuscus.

31. *Louisiades:* The flora of this archipelago has been recognised as one of extreme botanical interest with high rates of local endemism, particularly at the species level. It includes important stands of *Diospyros* (including an undescribed ebony) and several locally endemic species of *Hopea*. The forests of Tagula Island are home to an endemic species of honeyeater and butcherbird.

32. *Umboi Island:* Umboi is the largest and richest of Papua New Guinea's north coastal islands. It is home to populations of large numbers of species endemic to Papua New Guinea, as well as a remarkable array of fruit bats (eight species). Lake Buan, in Umboi's highlands, supports one of the richest waterbird populations in the Bismarck Archipelago.

33. *West New Britain:* Mountain and lowland forests distinct from those of the mainland. Threatened by large-scale timber operations. The Whiteman Range and its foothills support an important tract of limestone flora, surrounded by forests developed on sedimentary materials. Little is known of the area, but large tracts of *Nothofagus* forest occur on the higher plateaus.

34. *Willaumez Peninsula:* A remarkable physiographic feature with Lake Dakataua, it includes a very diverse area of lowland rainforest on rich volcanic soils. Threatened by logging and proposed development for oil palm plantations.

35. *Eastern New Britain:* Primarily includes the uplifted and limestone-capped Nakanai Plateau. Little surveyed but apparently biotically rich. Lowland rainforest and montane forest, including areas of forest dominated by *Lithocarpus* and *Nothofagus* developed on the limestone substrate. The largest high altitude area in the Bismarck Archipelago.

36. *The Baining Mountains:* The high ranges of easternmost New Britain are threatened by logging activities. These mountains, isolated by rivers and lowlands from the Nakanai Mountains to the southwest, are certainly as fascinating as the latter. They have not been adequately surveyed, and are 500 metres higher. These mountains are surrounded by lowlands with a growing populace, and probably will be degraded unless action is taken soon.

37. *Southern New Ireland:* The Verron and Hans Meyer ranges are little known high ranges that merit study and conservation. An area with important montane and lowland vegetation. Brief initial surveys have shown this montane area to be very rich, with a number of bird species endemic to New Ireland.

38. *Southern Bougainville Island:* Highland wet forests threatened by logging and development. This area includes the central and southern segments of the Crown Prince Range, from Panguna south to Lake Lorolu, and includes Mt. Takuan and Mt.Taraka. Where appropriate, this area extends downward towards the coast where good original forest prevails. Bougainville is home to many species whose affinities lie with the other Solomon Islands to the south and southeast. Among the many interesting vertebrates is the little known Bougainville Honeyeater (*Stresemannia bougainvillei*), representing a genus endemic to this island.

39. *Eastern Bougainville* : Supports the largest stands of bamboos in Papuasia. A variety of vegetation types occur, including remnant stands of *Terminalia brassii* in swamp forests. Threatened by logging and possibly sulfur mining.

40. *Lelet Plateau*: Comprises important hill and lowland rainforests, with some lower montane elements as well. These probably contain many plant endemics with interesting biogeographical relationships with Manus, the Philippines, and the Solomon Islands. Threatened by selective logging in the lowlands.

41. *Mussau Island:* The interior of Mussau Island, the largest in the St. Matthias group, comprises a large block of rain forest. It supports seven species of birds endemic to Papua New Guinea, two of which are endemic to Mussau – the Mussau Rufous Fantail (*Rhipidura matthiae*) and the Mussau Pied Monarch (*Monarcha menckei*).

42. *Manus Island* : The largest of the Admiralty group, isolated both from the great Bismarck islands to the southeast, and from mainland New Guinea far to the south. Not surprisingly, Manus's isolated fauna is rich in Papua New Guinean endemics (eleven birds, two mammals). Of these, six are endemic to the Admiralties. Botanically, the area includes stands of an endemic *Calophyllum* and *Sararanga*, which are threatened by logging activity.

Wetland Sites Not Subsumed in the Main Terrestrial Selection

- *Sissano Lagoon and Wetlands* : Comprise the largest coastal lagoon on the north coast of mainland Papua New Guinea, associated with a large wetland.

- *The Middle Sepik:* A huge complex of river meanders, oxbows, tributary lakes, marshes, and woodland swamps, both of ecological and economic importance.

- *Sepik Delta/Middle Ramu:* A coastal wetland/deltaic complex (Sepik) in association with a low alluvial meander belt of the Ramu River, the latter rich in swamp forests.

- *Middle Fly:* The Fly River, although only 1 200 km long, is, in terms of the volume of water discharged, so large that it ranks with the world's great rivers. The middle Fly floodplain, 15-20 km wide, is a mosaic of lakes, alluvial forest, swamp grassland, and swamp savannah. This includes Papua New Guinea's largest lake (Lake Murray).

- *Lower Fly:* A mosaic of swamps, open water, savannah, and gallery forest. The area has abundant wildlife and is an important tourist destination. It constitutes a very important wetland both for migrating birds and resident waterfowl. In Australian drought years, it becomes an important refuge for Australian wetland birds.

- *Sirunki Wetlands:* The Sirunki Basin straddles the main montane watershed divide of Papua New Guinea, with one segment of the wetlands draining northward into the Sepik, and the other segment draining southward into the Fly system.

- *Lake Tebera:* One of Papua New Guinea's few lower montane lakes. Supports at least one endemic fish species, plus other rare fish species.

- *East Gulf Coastal Wetlands:* The greater Purari delta comprises a large complex of mangroves, deltaic swamps, and tidal environments.

- *Mambare Wetlands:* Woodland swamps and mangroves.

- *Central Province Wetlands:* A series of wetlands lie northwest of Port Moresby; because of proximity to the capital these wetlands are under varying levels of exploitation and disturbance. They support large and diverse populations of waterfowl and other wetland birds. The area is particularly important as a dry season refuge for migrant waterfowl from Australia, and as a staging area for Palearctic shorebirds on their way to and from wintering areas in Australia.

- *Aria Wetlands:* Northern coast of western New Britain.

- *Toriu Wetlands:* On the eastern coast of the Gazelle Peninsula, comprise a large area of estuarine marshes and flood plains along the lower courses of the Toriu, Nesai, and Pali Rivers. Mangrove forests occur in the north and there are extensive areas of herbaceous swamps.

- *Bougainville South Coastal Wetlands:* Important insular wetlands on the western coast of Bougainville island, dominated by *Campnosperma brevipetiolata*, *Terminalia brassii*, and *Metroxylon solomonensis*.

- *Lakes Onim and Bune:* Small lakes surrounded by herbaceous wetland (not shown on Figure 7.5).

- *Ramu River at Brahman Mission:* Lowland swamp forest dominated by *Campnosperma brevipetiolata* (not shown on Figure 7.5).

- *Biges River:* A short coastal stream with a tidal estuary. The stream supports a diverse fish fauna (28 species recorded) (not shown on figure 7.5).