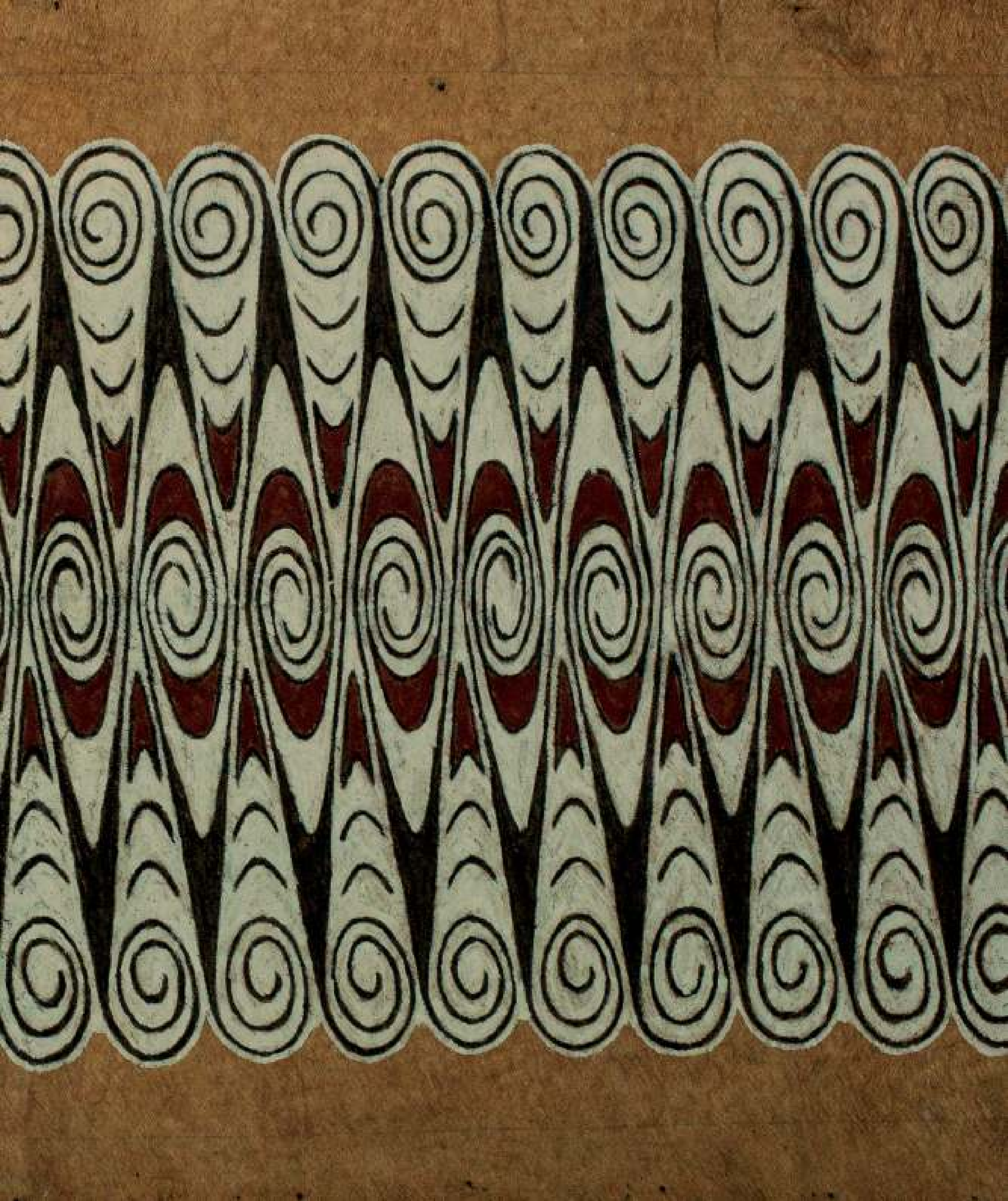
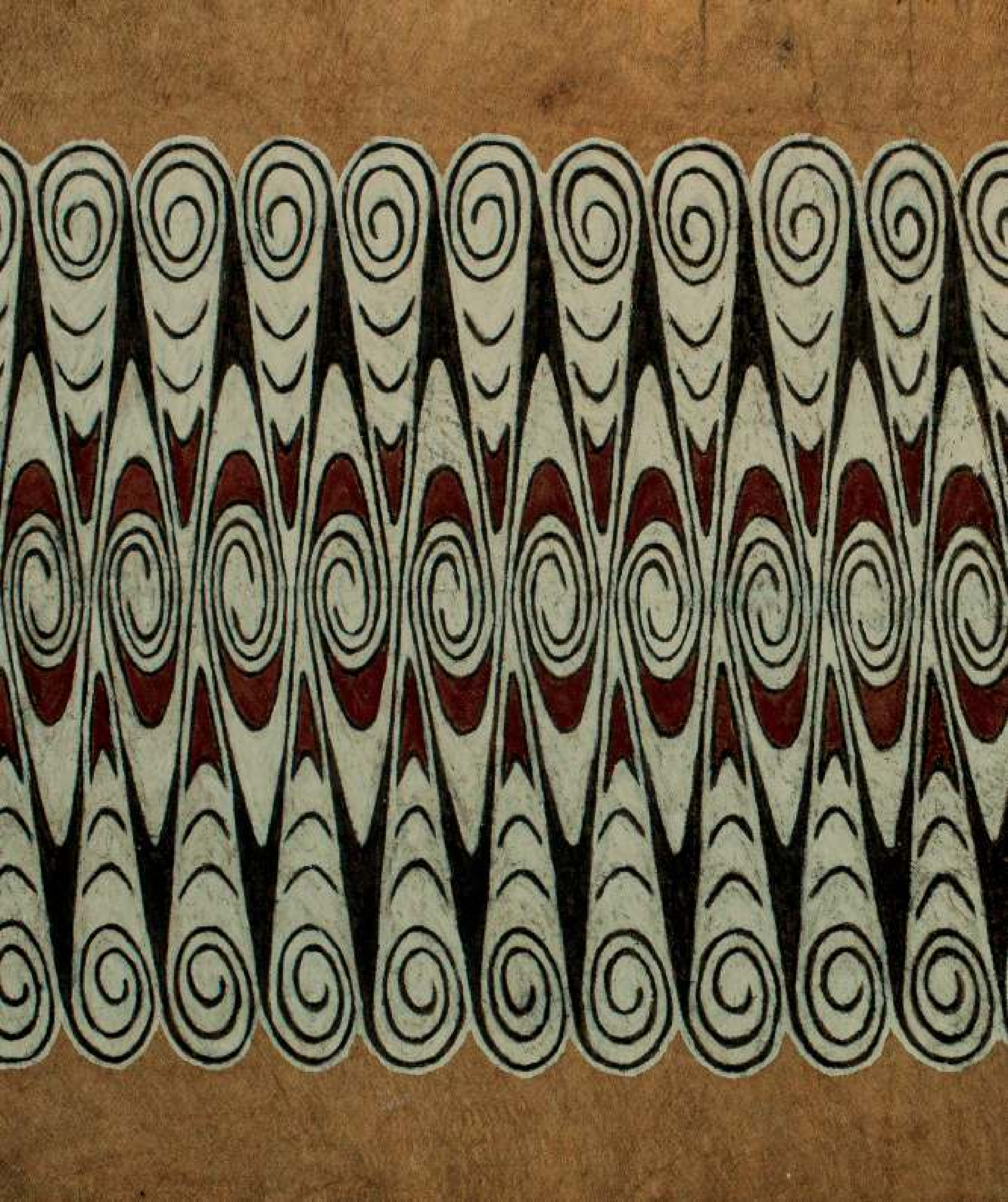
Bruce M. Beehler | Photography by Tim Laman

New Guinea

NATURE AND CULTURE OF EARTH'S GRANDEST ISLAND





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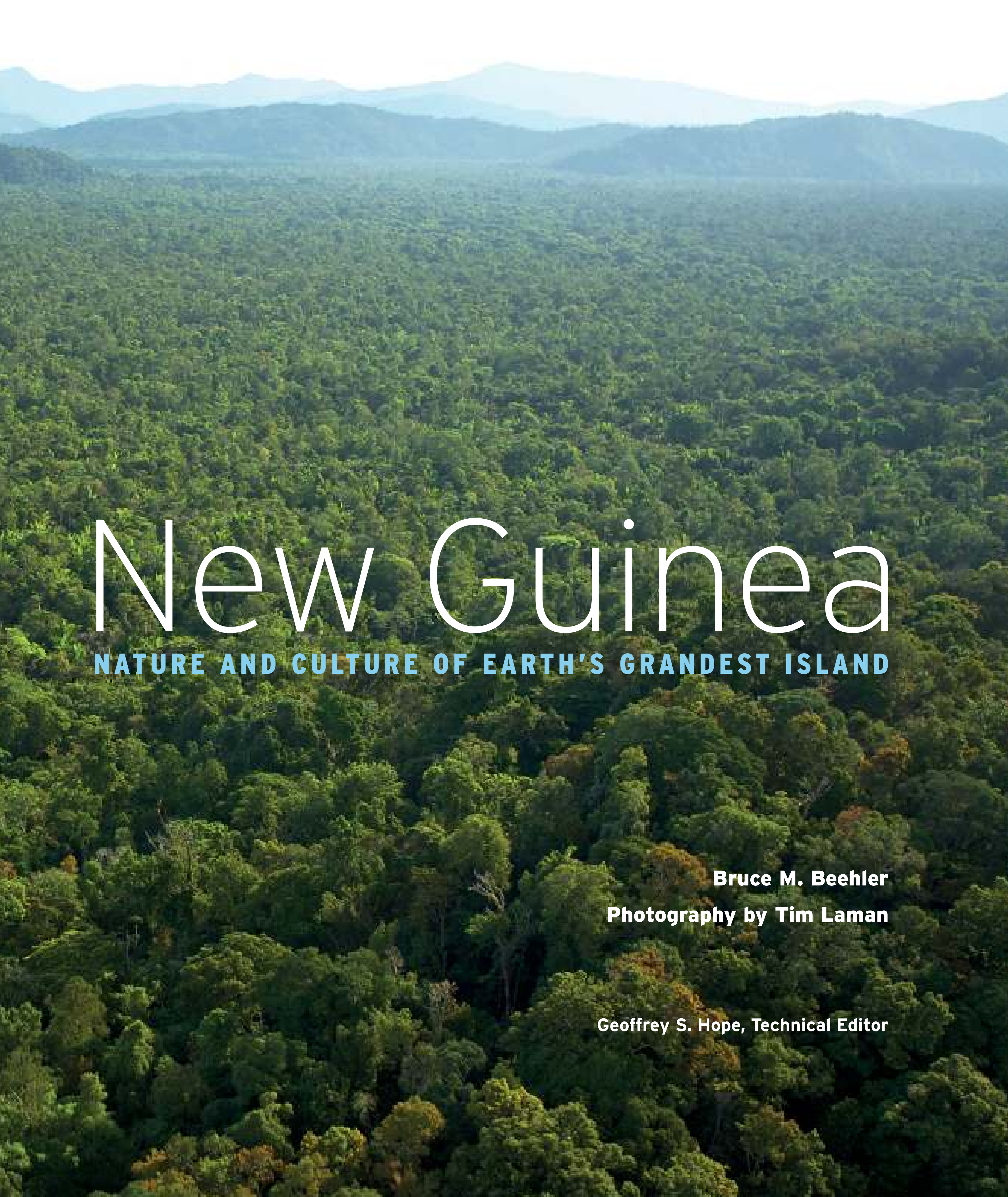

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Bruce M. Beehler

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Front cover: Adult male Blue Bird of Paradise (*Paradisornis rudolphi*)
Back cover: Western Highlands dancers at a traditional sing sing in Payakona village, ENG.
Endsheets: Tapa cloth from Lake Sentani, WNG.
Title page: Aerial view of an extensive expanse of alluvial lowland rainforest, backed by foothills.
Right: Neck-craning view up into the mossy forest canopy of the Foja Mountains, NW Lowlands, WNG.

All uncredited photos are by Tim Laman.

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We dedicate this book to our families, who have carried on and kept the home fires burning during our long absences doing fieldwork in New Guinea.

BB says, "thanks a million!" to Carol, Grace, Andrew, and Cary.

And TL thanks Cheryl, Russell, and Jessica for their love and support.

We couldn't have done it without you!





Contents

Abbreviations and Terms

ABBREVIATIONS

AMNH	American Museum of Natural History, New York
ca.	circa = approximately
CITES	Convention on International Trade in Endangered Species
ENG	eastern New Guinea (mainland PNG)
ENSO	El Niño-Southern Oscillation
IUCN	International Union for Conservation of Nature
LGM	Last Glacial Maximum
mya	million years ago
PNG	Papua New Guinea (which includes several island groups off New Guinea)
WNG	western New Guinea (Indonesian New Guinea)

TERMS

anadromous the life habit of a migratory fish (like a salmon) that is born in freshwater, then migrates to spend much of its life in the sea, and then returns to its freshwater birthplace to spawn.

angiosperm member of the flowering plants, a group of seed plants that develop seeds within an enclosed ovary.

anticline a fold in sedimentary rocks in which the bend of the apex of the fold lies at the top, and the underlying sediments are the oldest of the formation. The opposite formation is known as a *syncline*.

arc see *island arc*

biota flora and fauna of a region.

cf. compare; when used with a species name, indicates possibly the named species, but it needs to be compared to others to confirm the identification.

clade a term in systematics that refers to a group of species all derived from the same evolutionary lineage (adjective *cladistic*). For instance, the plumed birds of paradise of the genus *Paradisaea* form a well-defined clade within the family Paradisaeidae.

cline a term in biogeography referring to a gradual change in physical variation within a population across a geographic transect (adjective *clinal*).

craton an expanse of stable and ancient continental crust sitting atop a tectonic plate.

eastern New Guinea (ENG) the eastern half of mainland New Guinea, which encompasses the mainland portion of Papua New Guinea.

El Niño–Southern Oscillation (ENSO) an irregularly occurring variation in atmospheric pressure (the Southern Oscillation) and winds and sea surface temperatures over the tropical Pacific Ocean, affecting the climate of much of the tropics and subtropics (and secondarily the rest of the world). The warming phase of the sea temperature is known as El Niño and the cooling phase as La Niña (courtesy: Wikipedia). El Niño brings drought to the New Guinea region.

endemic native to a confined area of interest (noun *endemism*). Thus a mouse endemic to New Guinea occurs only on New Guinea.

epiphyte a plant that grows and lives upon the trunk, branches, or twigs of another plant (adjective *epiphytic*). In the montane forests of New Guinea, many epiphytic plants live upon mature canopy trees, especially on large branches high in the canopy of the forest.

extirpation the dying out (extinction) of a local or circumscribed population of a species.

gabbro a coarse-grained igneous rock formed from the slow cooling of magnesium-rich and iron-rich magma into a crystalline mass deep beneath Earth's surface. Much of Earth's oceanic crust is gabbro (courtesy: Wikipedia).

Gondwana (Gondwanaland) the ancient southern continent that split from the supercontinent Pangaea, at the same time creating a second successor continent, Laurasia.

gymnosperm member of the group of seed plants in which the seeds do not develop within a closed ovary; includes the conifers and cycads.

Indonesian New Guinea western New Guinea (WNG), which constitutes Papua Province and West Papua Province plus the Aru Islands.

island arc a chain of islands formed at convergent plate boundary zones when oceanic lithosphere is subducted beneath continental lithosphere; the structure includes a trench and a line of active volcanoes. Prime examples of this important feature of plate tectonics include the Aleutian Islands, the Ryukyu Islands, and the coastal volcanic islands off the northern coast of central Papua New Guinea trending northeast to the northern margin of New Britain.

karst a geological term referring to distinctive landforms resulting from the solution of water-soluble rocks such as limestone or dolomite, and commonly producing irregular landforms as well as underground caves and drainage systems. South-central New Guinea features various types of karst landforms.

La Niña see *El Niño–Southern Oscillation*

Last Glacial Maximum (LGM) the most recent period of maximum glacial coverage on Earth, ca. 24,500–19,000 years ago.

lek a polygamous mating system in which the males of a species cluster in groups and compete to mate with visiting females. Lek may also refer to the site of these courtship rituals. In lek systems, the males provide no assistance to the females in nesting and raising of the offspring.

Preceding page, top to bottom: *Graphium thule* swallowtail, *Nyctimystes* tree frog, Highlands woman in all her sing-sing finery, *Dendrobium* cf. *lasianthera* orchid, Painted Grasshawk dragonfly

lithosphere in geology, the outermost rocky shell of Earth, which is moved about in a series of tectonic plates by the processes of magmatic upwelling and seafloor spreading.

lycophytes spore-bearing vascular plants including the clubmosses, firmosses, spikemosses, and quillworts, dating back to the Silurian period (425 mya); there are currently 1,250 described extant species.

Malesia a term used primarily by botanists to indicate a region that ranges from Sumatra, Peninsular Malaysia, and the Philippines east to the island of New Guinea.

marsupials a lineage of mammals (such as opossoms, kangaroos, and koalas) in which the young are born at a very undeveloped state and are transferred into the female's marsupium (pouch) to feed and develop. Distinct from the placental mammals (exemplified by cats, dogs, bats, and humans).

monotremes a small lineage of primitive egg-laying mammals (including the echidnas and platypus) that today are found only in Australia and New Guinea.

New Guinea The great tropical island (the second-largest island on Earth) that includes the mainland portions of both Indonesian New Guinea and Papua New Guinea.

New Guinean Region the entire island of New Guinea plus all of its fringing and land-bridge islands.

New Guinean subregions See map on page 20, and text on pages 20–23.

nonpasserines a large and diverse lineage of birds that encompasses all the bird families not encompassed by the *passerine* (perching bird) lineage. Nonpasserines include ducks, hawks, falcons, owls, hummingbirds, and many other bird families; all of the waterbirds are nonpasserines.

obduction a little-used term in plate tectonics that describes the overthrusting of oceanic crust onto continental crust at a convergent plate boundary. Distinct from classic subduction, in which oceanic crust dips below continental crust, obduction usually occurs when a piece of continental crust or island arc becomes jammed in the plate boundary, an uncommon phenomenon.

ophiolite an assemblage of rocks derived from Earth's oceanic crust and upper mantle that have been exhumed by the processes of plate contact and obduction and emplaced in contact with continental rocks. Ophiolites include serpentine, black shales, cherts, gabbro, diabase, peridotite, sheeted dikes, and pillow lavas (courtesy: Wikipedia).

Papua New Guinea (PNG) an independent Pacific nation that comprises eastern New Guinea (ENG) plus the islands in Milne Bay, the Bismarck Archipelago, the Admiralty Islands, and the northern Solomon Islands.

passerines/oscine passerines the large lineage of perching birds (or songbirds), which apparently originated in the Australian region and dispersed all across Earth. This lineage includes the crows, swallows, warblers, and many other familiar land-bird families. The oscines (higher songbirds) are a subset of the passerines that possess a specialized syrinx (vocal organ).

Pleistocene the geological period when fluctuating ice ages occur every 100,000 years or so over the past 1.83 million years. Increasing ice leads to lower sea levels; up to 125m lower at glacial peaks and averaging 42m lower over the past 110,000 years. The Pleistocene ends with the present intergalcial about 11,000 years ago when present-day climates and sea levels become established

rain shadow refers to a region that receives less rainfall than surrounding environs. Typically, nearby blocking mountains harvest the rain from moist air masses, by lifting and cooling them over their heights, before they arrive at the area in the rain shadow, depleted of moisture.

Sahul greater Australia, comprising Australia, New Guinea, Tasmania, plus other land sitting atop the Australian tectonic plate. During glacial maxima, Sahul was a single landmass.

saprophytic refers to organisms, such as fungi and some plants, that obtain their nutrients not from photosynthesis but from dead organic material.

skin/study skin a bird specimen that has been collected and prepared by skinning and removing all meat and organs from the body and then drying it, either for use in a headdress (something done by New Guinean tribes) or for preservation as a museum specimen (something done by museum fieldworkers). *Trade skins* are typically dried plumed birds of paradise that are traded among tribes and worn in ceremonies. *Study skins* are scientific specimens preserved in museum collections for study.

subduction in plate tectonics, the action of one tectonic plate slipping below another during plate contact. Typically, oceanic crust subducts below the lighter continental crust.

Sundaland the great islands of Borneo, Java, Sumatra and other lesser islands sitting atop the Asian continental shelf; these islands were one with mainland Asia during glacial phases of the Pleistocene.

tectonic plate one of a number of distinct expanses of Earth's lithosphere upon which rest pieces of continental and oceanic crust. These plates are moved about by the forces produced by centers of seafloor spreading that produce new oceanic crust and spread outward from mid-ocean ridges, powered by rising magma from Earth's mantle.

tectonostratigraphic refers to the layering of rocks produced by the contact between tectonic plates. Ophiolite sequences would be one subset of this assemblage of layered rocks.

terrane a distinct piece of crustal rock that has been sutured to another piece of crust lying on a distinct tectonic plate. Such a sutured piece is typically termed an exotic terrane, which is distinct in geology and history from the adjacent crustal rock to which it is now associated. New Guinea features more than 25 exotic terranes sutured to the northern margin of its main body, evidence of the complex plate dynamics that have been produced by the northward collision of the Australia Plate against the obliquely moving Pacific Plate.

Wallacea an Indonesian island region just west of the New Guinean Region and east of Borneo, and including Sulawesi, Halmahera, the Moluccas, and the Lesser Sundas.

Wallace's Line biogeographic barrier of deep water that separates mainland Asia from Wallacea, the region to its east. The line travels between Bali and Lombok, Borneo and Sulawesi, and Mindanao and Halmahera.

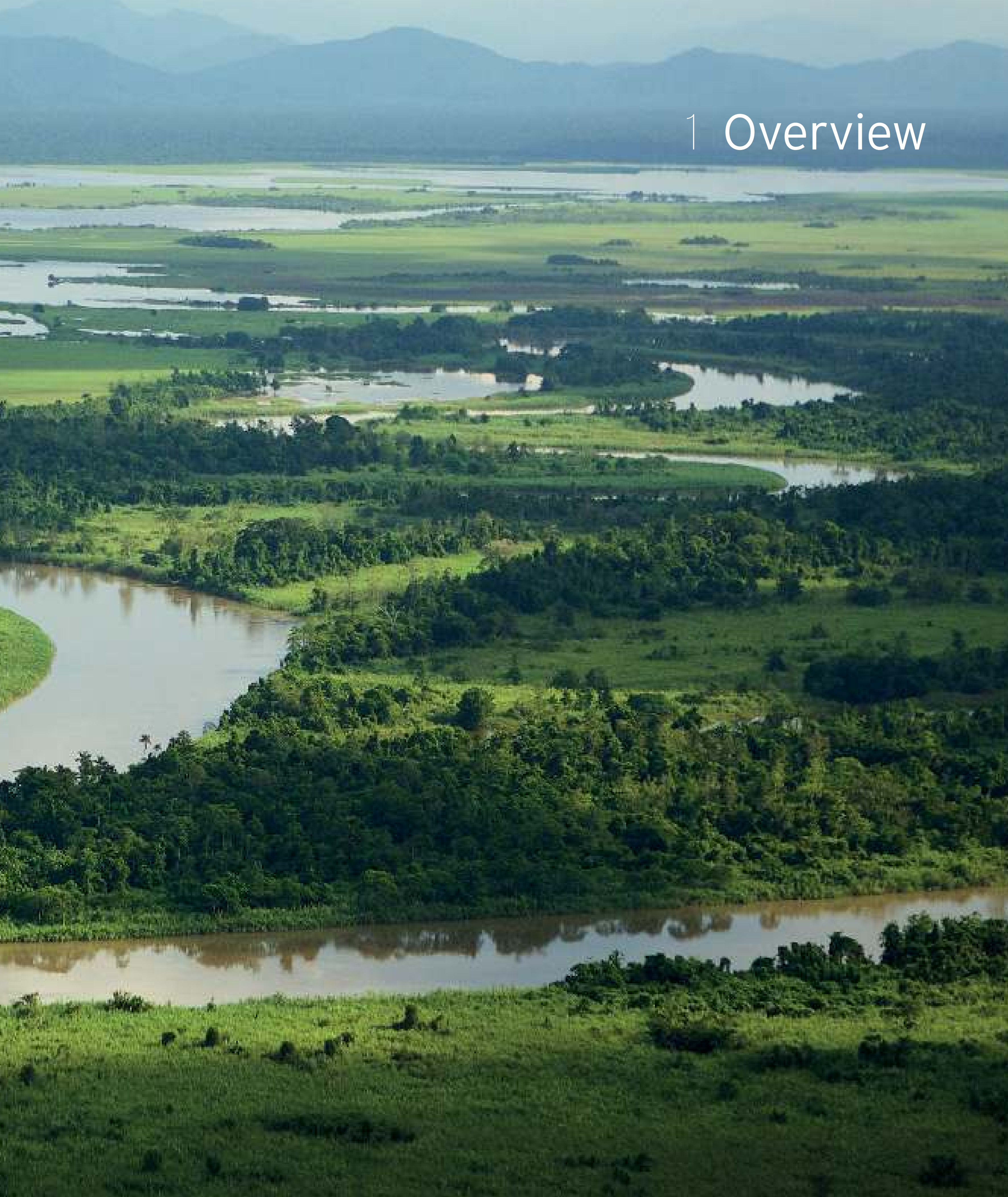
Weber's Line biogeographic barrier of deep water that forms the line of "faunal balance" between Asia and Australia. It travels between Timor and the Australian continental shelf, between Sulawesi and Buru, and just west of Halmahera.

western New Guinea (WNG) the western half of New Guinea, which includes Indonesian New Guinea and (here) the Aru Islands.

NW Islands
(Raja Ampat Is)
Gebe
Waigeo
Gam
Batanta
Salawati
Kofiau
Misool
Sorong
Tamrau Mts.
Kebar
Manokwari
Bird's Head
Arfak Mts.
Numfor
Biak
Bay Islands
Yapen
Serui
Geelvink or
Cenderawasih
Bay
Bintuni Bay
Berau Bay
Bird's Neck
Wandammen Mts.
Fakfak
Seram
Kumawa
Mts.
Triton
Bay
Etna
Bay
Nabire
Paniai
Lake
Western Ranges
Weyland
Mts.
Puncak Jaya
(4884 m)
Ilaga
Tembagapura
Timika
Doormantop
(3350 m)
Swart
Valley
Puncak Trikora
(4730 m)
Wamena
Sarmi
Mamberamo
Van Rees Mts.
Foja Mts.
NW Lowlands
Mamberamo Basin
Tariku
Bernhard Cp.
Taritatu
Cyclops Mts.
Jayapura
Humboldt Bay
Vanimo
North
Imonda
Sobger
Border Ranges
Star Mtns.
Puncak Mandala
(4760 m)
Mt. Capella
(3960 m)
Lorentz
Baliem
Eilanden
Agats
Asmat
Southern
Kiunga
Lake
Murray
Digul
Trans-Fly
Fly
INDONESIA
PAPUA NEW GUINEA
Dolak
Island
Merauke
Bensbach
Kai Islands
Aru
Islands
Aru Islands
Wokam
Kobroor
Trangan
Arafura Sea
Tanimbar
Islands
Timor Sea
Australia

The New Guinean Region

1 Overview



The Grandest Island

NEW GUINEA IS THE largest and highest tropical island. Perhaps most famous for its 39 species of birds of paradise and its substantial role in the Pacific theater of World War II, New Guinea is the island of tree kangaroos, equatorial glaciers, myriad endemic languages, and a fantastic array of traditional cultures. It is home to the richest coral reef ecosystems on Earth and a hyper-abundance of orchids, rhododendrons, forest tree species, and arthropods. Our geographic coverage follows the German-born American biologist Ernst Mayr's definition of this natural region, comprising the great tropical island of New Guinea as well as an array of islands lying on its continental shelf or immediately offshore. This region extends from the equator to 12° south latitude and from 129° to 155° east longitude—2,800 kilometers long by 760 kilometers wide, and supports the largest remaining contiguous tract of old-growth humid tropical forest in the Asia-Pacific region.*

Welcome to the richest island on Earth as measured by plant and animal species and human languages, as well as by harvestable natural resources such as gold, copper, petroleum, and natural gas. In spite of all this wealth and the superlatives that can be used to describe it, the tropical island of New Guinea remains poorly known by the world at large, is rarely visited by outsiders, and is overlooked in most conversations about the developing world. Here, in this narrative, New Guinea is placed in the spotlight and on the world stage, where it properly belongs.

In this book, a portrait of New Guinea's incredible natural history and culture is painted for the reader through narrative descriptions and photographs. Encompassing

Preceding pages: Aerial view of Sepik floodplain with abundant water, grassy swales, and regenerating woodland. Similar habitats can be found in the upper Trans-Fly.

Opposite: A Golden-mantled Tree Kangaroo (*Dendrolagus pulcherrimus*) photographed by a camera trap set in the Foja Mountains, an isolated north coastal range situated in the NW Lowlands of WNG.

* This chapter draws on information in the following: Gressitt (1982a), Mittermeier et al. (2002), Beehler (2007a), and Pratt and Beehler (2015), as well as other publications cited in the references section.

786,000 square kilometers, New Guinea is about twice the size of the state of California. This, the world's second-largest island, is exceeded in size only by ice-covered Greenland. It is substantially larger than better-known Madagascar, Borneo, and Sumatra. New Guinea is topographically diverse and geologically complex. With its equatorial location and oceanic influence, New Guinea has a humid and warm climate, but its highest mountains feature tropic-alpine tundra as well as remnant tropical glaciers. Even though the region is equatorial, it indeed snows regularly at the highest elevations. Torrid-zone lowland jungles prosper within 30 kilometers of glacial ice. This is indeed an island of extremes and contrasts.

NOMENCLATURE

New Guinea is a nonpolitical geographic term referring to the whole of the great equatorial island lying just north of Australia. New Guinea is not to be confused with Guyana (in northern South America) or Ghana (in West Africa). In fact, it was named after Guinea in West Africa by Spanish explorer Yñigo Ortiz de Retez in 1545 because of the superficial similarity of the indigenous populations of New Guinea with those of "Old" Guinea.

Once politics are included, geographic place names in the New Guinean Region get considerably more complex and confusing. The island of New Guinea is divided right down the middle at 141° east longitude. To the west is Asia and Indonesian New Guinea, what we call here western New Guinea ("WNG" for short in this book). To the east lies the Pacific region and the mainland portion of Papua New Guinea; for short, we call the eastern mainland portion of New Guinea "ENG," to distinguish this eastern half of the island from the nation Papua New Guinea (PNG), which also encompasses many island groups to the north and east of its own section of New Guinea. Papua New Guinea is a full-fledged nation that achieved independence from Australia in 1975, whereas western New Guinea (WNG) constitutes two eastern provinces of the giant nation of Indonesia. These two provinces are today known as Papua and West Papua (or Papua Barat).

Older names for western New Guinea were Netherlands New Guinea (prior to World War II), Irian Barat, Irian Jaya, and Papua (before the area was split into two provinces in 2004). Just to confuse things further, the informal name used for western New Guinea in the blogosphere is "West Papua," a term in wide global usage, even though officially and politically West Papua is the Indonesian province that encompasses only the western sector of WNG. Historically, "West Papua" was the name chosen by the local assembly for the planned independent nation that was to arise in 1962 through a United Nations mandate (circumvented by military action by Indonesia). Historically, the term "Papua" was also applied to the British-held colonial territory of southeastern New Guinea, which became a protectorate of Britain in 1883 and remained known as Papua until 1975, when Papua New Guinea gained independence. This is yet another reason the following narrative avoids using the terms Papua or West Papua in this text. Reader, once again, take note: "WNG" is western New Guinea and "ENG" is eastern New Guinea. These abbreviations are used throughout the narrative.

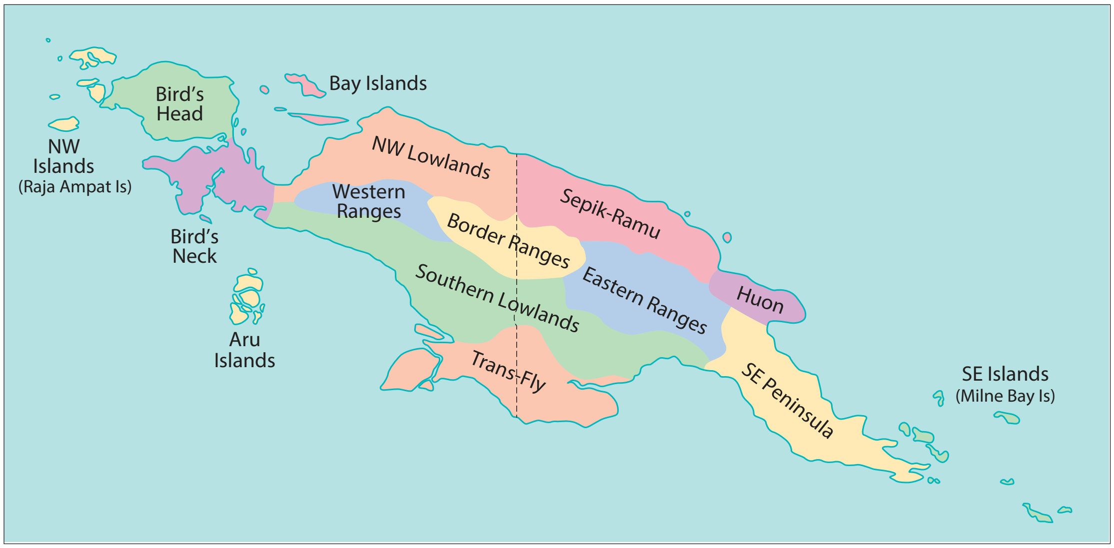
GEOGRAPHY AND PHYSIOGRAPHY

On a map of the Pacific, New Guinea is sandwiched between the equator just to the north and Australia just to the south. In this location, New Guinea sits at the hub of a suite of islands in the tropical Southwest Pacific. Many of the most famous island groups of the Pacific surround New Guinea (outside of our region): To the west lie the Moluccas (Maluku) and Lesser Sundas (Nusa Tenggara) of Indonesia. To the north and northeast lie the Philippines, Palau, and the Mariana Islands. The Bismarck, Admiralty, Caroline, Marshall, and Gilbert Islands (Kiribati) lie to the northeast and east, and the Solomons, Vanuatu, Fiji, and New Caledonia lie to the southeast. This fantastic collection of islands is home to more coastal marine and terrestrial island biodiversity than any other portion of the globe, and New Guinea is the king among this regal assemblage—the richest among the very rich.

New Guinea sits above Australia like some ungainly creature with the shape of a strange pheasant, its head in the far west (the "Bird's Head"), the eastern point of the Huon Peninsula serving as the tip of its protruding wing in the northeast, and its tail in the far southeast.

A wet lowland rainforest interior scene with buttressed trees and massive lianas.

New Guinea's subregions. These geographic shorthand terms are used throughout the text to aid the reader unfamiliar with New Guinea. Image courtesy of T. K. Pratt & B. M. Beehler, 2015, *Birds of New Guinea*, 2nd ed., Princeton University Press, Princeton, NJ



NEW GUINEA'S SUBREGIONS

New Guinea is geographically complex and poses challenges to the newcomer seeking to gain a grasp of its internal geography. Here, we introduce a set of 15 standardized names for New Guinea's subregions, which we use throughout the book to aid the reader. These subregions articulate geographic, geologic, and biogeogeographic zones, the last defined by areas of species or subspecies endemism and bounded by physiographic barriers that separate abutting ranges of sister forms. These are adapted from the bird areas highlighted in *Birds of New Guinea* (second edition) and influenced by Birdlife International's endemic bird areas as well as the World Wildlife Fund's Pacific ecoregions. The subregions appear in the map on this page, and are briefly described below, from northwest to southeast.

The **NW Islands** (Northwest Islands, also known as the Raja Ampat or Western Papuan Islands) include Waigeo, Batanta, Salawati, Misool, Kofiau, Gam, Gag, and Gebe (plus other smaller islands). This group is home to an array of intriguing Moluccan species found nowhere else in the New Guinean Region, plus five endemic avian species. It is also a center of coral reef diversity and richness in the region and is today a popular destination for luxury dive boats as well as international visitors to several high-end island-based eco-resorts. The islands are accessed by boat from Sorong town, on the western verge of the Bird's Head.

The **Bird's Head** (Vogelkop, Berau, or Doberai Peninsula) features the Arfak and Tamrau Mountains, home to a number of montane endemic bird and mammal species (some shared with the Bird's Neck). The southern sector of the subregion also includes substantial lowlands. On the northern coast at Yamursba Medi is a famous nesting beach for Leatherback Turtles. Two major towns provide services for the subregion: Manokwari in the east (home to the University of Papua, or UNIPA) and Sorong in the far west. Both of these ancient port towns have long histories. Manokwari was formerly known as Doré or Dorey, and many of the first natural history collections made from New Guinea in the early 19th century came from here.

The **Bird's Neck** features rugged and isolated low mountains and remarkable fjordlands on the southern coast. This little-studied and physiographically spectacular subregion includes some of the Bird's Head's endemic bird species, such as the Vogelkop Bowerbird. Note that the Bird's Neck includes the Onin Peninsula and the Fakfak Mountains; the Bomberai Peninsula and the Kumawa Mountains; and the Wandammen Peninsula and the Wandammen Mountains (which include Mount Wondiwoi), all of which are important areas of biological endemism.

The **Bay Islands** (islands of Teluk Cenderawasih, or Geelvink Bay) feature Biak and Supiori Islands (a matched pair), Numfor, Mios Num, and Yapen Island. Biak-Supiori and Numfor are oceanic islands and support nine endemic species of birds. Some of these endemic species also range out to small nearby islands. Substantial and mountainous Yapen Island is a land-bridge island with some endemism at the subspecies level. Yapen's linear shape and position marks the Sorong Fault (also called the Yapen-Tamrau-Sagewin Fault), the major fault line that trends southeastward along the north coast and westward through the Bird's Head and just south of Batanta Island of the NW Islands.

The **NW Lowlands** (Northwest Lowlands; also known as Meervlakte, Lakeplain, or Lakes Plain) constitute the vast interior drainage of the Mamberamo basin, which includes the Mamberamo, Tariku, Taritatu, and Van Daalen Rivers. The region combines lowland forest, swamps, and small but important north coastal ranges (Foja, Van Rees, and Cyclops). This is one of the wildest and least-populous subregions of New Guinea. The capital of Papua Province, Jayapura, lies in the northeastern corner of this subregion.

The **Aru Islands**, lying just south of the western sector of the main body of New Guinea, are large islands of uplifted coral separated by extensive mangrove channels. The islands share many species with the adjacent Southern Lowlands. Politically, Indonesia treats them as part of the Moluccas (Maluku Province). During times of low sea level in the Pleistocene, the Aru Islands were connected to the land bridge that linked southern New Guinea with northern Australia. Therefore, the Aru Islands have close biogeographic affiliations with both New Guinea and Australia.

The **Western Ranges** constitute the highest sector of New Guinea's central cordillera, with a number of summits exceeding 4,500 meters and several small glaciers on Puncak Jayakesuma, shortened to Puncak Jaya (also called Mount Carstensz or the Carstensz Massif), which rises to 4,884 meters. It includes (historically) the Charles Louis Mountains, Weyland Mountains, Nassau Range, and Oranje Mountains, now called the Sudirman (western) and Jayawijaya (eastern) ranges. This subregion is home to a number of endemic animal and plant species. The eastern terminus of this region is the great Baliem River gorge that cuts through this range.

The **Border Ranges** are only marginally less impressive than the Western Ranges, and include great summits like Puncak (or Mount) Mandala (also called Mount Juliana; 4,699 meters) and Mount Capella (3,992 meters), and share some montane bird and mammal specialties with the Western Ranges. The mountains of the WNG component of this subregion are now called the Jayawijaya Mountains or the Wisnumurti Range. The Star Mountains span east and west of the border, and the ENG component also features the Victor Emanuel Mountains.

The **Southern Lowlands** comprise a vast expanse of lowland rainforest that transitions to swamp forest and mangrove in the west and east and to seasonally flooded savanna in the central-southern sector. In the far northwest, where the Southern Lowlands meet the Bird's Neck and the NW Lowlands, one finds a biogeographic mixing zone where the ranges of many sister species and subspecies meet. In the eastern part of the Southern Lowlands subregion, the Fly River and the Strickland River flow south toward the Trans-Fly subregion (see next). This area constitutes an expanse of uplifted sediments resting on the Australian craton that we call the Fly Platform.

A native gold nugget from Mount Kare in the Eastern Ranges. In a high and isolated upland valley, the Mount Kare strike attracted crowds of adventitious Papua New Guinean miners, who got rich quick with the stunning wealth of the deposit. Photo: Michael Bonafede

The **Trans-Fly** encompasses the southern portion of the Fly Platform, an important geological feature of the region—the central "belly" of New Guinea. The Trans-Fly lies mainly south of the lower Fly River, which flows east in that sector. This subregion features large expanses of monsoon woodland and marshy savanna that share many animal and plant species with Australia. It is an important stopover and wintering area for migratory waders as well as resident waterbirds and migratory waterbirds from Australia.

The **Sepik-Ramu** encompasses an interior basin of two rivers: the Sepik and the Ramu. It is the eastern counterpart to the NW Lowlands, from which it is separated by a series of low ranges (part of what geologists call the Tasman Line) near the ENG-WNG border. The subregion includes much lowland rainforest plus some fire-generated grassland patches and grassy marshlands of the Sepik. It also encompasses the ENG north coastal ranges and the Adelbert Mountains. Two important PNG urban centers are found on the north coast of this subregion—Wewak in the west and Madang in the east.

The **Eastern Ranges** constitute the east-central segment of New Guinea's central cordillera. It includes the central highlands of ENG (Kaijende Highlands, Mount Giluwe, Mount Hagen, Kubor Mountains, Schrader Range, Bismarck Range, and Kratke Mountains). This region extends westward to the Strickland River gorge and eastward to the Kratke Mountains, beyond which lies the Watut-Tauri Gap, marking the northwestern terminus of the mountains of the SE Peninsula. Major interior towns of this subregion include Mount Hagen, Kundiawa, Goroka, and Kainantu.

The **Huon Peninsula** includes a compact collection of high north coastal ranges (Finisterre Range, Saruwaged Range, Cromwell Mountains, and Rawlinson Range) isolated from the Eastern Ranges by the broad lowland Markham and Ramu valleys. The Huon is home to a number of endemic birds, mammals, and plants. Its highest summit is Mount Bangeta (4,121 meters). This subregion features PNG's second city, Lae.

The **SE Peninsula** (Southeastern Peninsula, Papuan Peninsula) is a rugged feature that boasts the Herzog Mountains and the Kuper, Owen Stanley, and Wharton Ranges. Highest summits include Mount Victoria (4,037 meters) and Mount Albert Edward (3,989 meters). This distinctive subregion includes endemic birds, mammals, and plants, as well as PNG's capital—Port Moresby, midway down the peninsula on the southern coast. Other towns include Popondetta and Alotau.

The **SE Islands** (Southeastern Islands, Milne Bay Islands) are the southeastern counterpart to the NW Islands at the opposite end of New Guinea. Major islands include Goodenough, Fergusson, and Normanby Islands (comprising the D'Entrecasteaux Archipelago); the Trobriand Islands; Misima, Rossel, and Tagula (Sudest) Islands (the Louisiade Archipelago); and Woodlark (Muyua) Island. The subregion is famous for its coral reefs and beautiful island beaches. It is home to a number of endemic plants, birds, and mammals.

OTHER GEOGRAPHIC FEATURES

Mountain Ranges New Guinea is peppered with mountain ranges small and large. Mountains define New Guinea. The landmass is dominated by the huge central cordillera, which stretches across most of the island's length—from the eastern base of the Bird's Neck southeastward for the length of the main body of the island, continuing all the way down the SE Peninsula. This continuous range exceeds 1,500 meters elevation throughout its length. The central cordillera reaches its highest elevations in the far west, topping out at 4,884 meters at Puncak Jaya (or Mount Carstensz, called Nemangkawi Ninggok in the Amungkal language, which translates to "Peak of the White Arrow"). Sister to Puncak Jaya is Ngga Pilimsit, or Idenburg Top (4,716 meters), home to a glacier until ca. 1980. Other high cordilleran peaks include Puncak Trikora, or Mount Wilhelmina (4,750 meters), and Puncak Mandala (4,699 meters) in central WNG; Mount Wilhelm (4,508 meters) and Mount Giluwe (4,376 meters) in central ENG; and Mount Albert Edward (3,947 meters) and Mount Victoria (4,037 meters) in the central SE Peninsula. The great central cordillera narrows at the Indonesia-PNG border, at the western end of the SE Peninsula between Menyamya and Wau, and toward the eastern terminus of the SE Peninsula.

To the west, northwest, north, and northeast of New Guinea's central cordillera rise a series of 21 coastal ranges. These outlying ranges arose from island arcs that have been swept up and sutured to the island of New Guinea by the northward tectonic movement of the Australian Plate and the westward movement of the Pacific Plate and associated microplates. Thus the main cordillera is higher and older—a product of the original compression caused by northward movement of the Australian Plate. The coastal ranges are younger and lower and continue to rise as they undergo ongoing compression from the impact of the Australian Plate against the Pacific and other smaller plates.

The highest subsidiary ranges are found on the Huon Peninsula of the northeast—the Finisterre Range in the west (4,094 meters) and the Saruwaged Range in the east (4,120 meters). Also found here are the Rawlinson Range (1,900 meters) and the Cromwell Mountains (2,904 meters). The mountainous Huon Peninsula is separated from the central cordillera by the prominent grasslands-dominated lowland gap produced by the Ramu and Markham drainages, which flow northwest to Madang and southeast to Lae, respectively.

The mountains of the Bird's Head follow those of the Huon Peninsula in height and extent. They include the Arfak Mountains (2,954 meters), trending north–south in the eastern

Puncak Jaya (or Mount Carstensz), the highest summit in the Pacific, at 4,884 meters, exhibits several patches of glacial ice as well as a fresh dusting of snow. Photo: George Steinmetz

part of the Bird's Head, and the Tamrau Mountains (2,472 meters) trending east–west in the north-central sector of the Bird's Head.

The Bird's Neck includes three distinct outlying ranges: the Fakfak Mountains (1,410 meters), the Kumawa Mountains (1,615 meters), and the mountains of the Wandammen Peninsula (2,075 meters), which include Mount Wondiwoi.

A series of north coastal ranges rise along the main body of New Guinea from west to east: the Van Rees Mountains (ca. 1,300 meters), the Foja Mountains (2,218 meters), the Cyclops Mountains (2,160 meters), the Bewani Mountains (1,886 meters), the Torricelli Mountains (1,650 meters), the Prince Alexander Mountains (ca. 1,000 meters), and the Adelbert Mountains (1,600 meters).

Finally, the SE Peninsula includes several northern fringing ranges: the Kuper Range (2,849 meters), the Bowutu Mountains (2,533 meters), the Ajule Kajale Range (1,706 meters), and the recently active volcanoes in the far southeast, Mount Lamington (1,804 meters) and Mount Victory (1,829 meters).

Rivers The aforementioned assemblage of equatorial mountain ranges, many adjacent to warmest tropical seas on earth, generates abundant relief-associated rainfall, which feeds hundreds of rivers that flow down the various flanks of these ranges. Four great rivers—the Fly, Digul, Sepik, and Mamberamo (including the Tariku, Taritatu, and Van Daalen), two southern and two northern—arise near the high center of the island, born up on the heights of the central cordillera. The Taritatu (Idenburg) River flows northwestward across the vast Mamberamo basin. The Digul (Digoel) River flows southwestward into the triangular alluvial platform of southwestern New Guinea. The Sepik River flows northeastward into the Sepik basin. And the mighty Fly River rushes southeastward out onto the Fly Platform of south-central New Guinea. To these big four, we could add the names of dozens of powerful rivers that contribute to the equatorial flow of free water across the island—including the Derewo, Tariku, Van Daalen, Mappi, and Lorentz in the west and the Kikori, Ramu, Markham, and Purari in the east.

Literally thousands of rivers and streams break up the geography of New Guinea. They initially rush through deep, rocky mountain gorges and then wind sinuously through planar swamplands. During the height of local rainy seasons, the gorges become thundering torrents and the plains become expansive floodscapes. These many watercourses break up the landscape in ways that certainly promoted the evolution of the flora and fauna as well as the development of a rich diversity of traditional human cultures. There is little doubt that the abundance and activity of the many watercourses have seriously hindered economic and political development on the island. A prodigious spate of bridge building would be needed to properly link the various regions by road—something not readily foreseen at this time because of its great expense.

Lakes New Guinea has a scattering of prominent lakes. Lake Sentani, near Jayapura, in the northeastern corner of WNG, was apparently created by tectonic movement related to the uplift of the coastal Cyclops Mountains just to the north. It is (or was) home to a freshwater population of sawfish (last seen in the 1970s). The lower Mamberamo River features Lake Rombebai, the largest lake in WNG, as well as smaller Danau (Lake) Bira. These are swampy backwater lakes. At the western end of the central cordillera we find the Paniai Lakes (also called the Wissel Lakes) in an interior highland basin. Lake Yamur, on the Bird's Neck, is home to a freshwater population of Bull Shark. Picturesque highland lakes (Anggi Gigi and Anggi Gita) are found in the Arfak Mountains of the Bird's Head. Finally, there are several lakes in the upper Bian drainage, in the southeast of WNG.

The largest upland lake in ENG is Lake Kutubu, in the southern sector of the Eastern Ranges. The Chambri Lakes are in the middle Sepik River. Lakes Murray, Kaim, and Daviumbu are in the Fly-Strickland watershed. Lake Murray, at 64,736 hectares, is the largest freshwater lake in New Guinea; it lies in the middle Fly River. Lake Wanum is just west of Lae in a side valley of the lower Markham, and upland Lake Trist is hidden southeast of Wau in the Bowutu Mountains. Some highland interior lakes and watersheds support endemic species of rainbowfishes. The introduction of exotic fishes into these systems threatens the existence of the endemic species.

Interior Valleys Where the central cordillera broadens out into a series of parallel ranges, mainly in central WNG and west-central ENG, one finds picturesque upland interior valleys populated by traditional highland peoples. These populous highland valleys were encountered by Western explorers first in the 1930s and again during World War II, to worldwide amazement. Prior to those events, the interior of New Guinea had long been thought to be unpopulated, when, in fact, the largest concentrations of people on this island were and are in these interior valleys, where the mid-montane climate and old volcanic soils are ideal for subsistence agriculture, especially of the recently introduced Sweet Potato. The most famous of these interior upland valleys are the Ilaga and Baliem in WNG and the Tari, Wahgi, and Asaro in central ENG. Today these populous valleys have bustling towns, good road networks, and many rural villages. In ENG these valleys are now famous for their Arabica coffee, grown for export. Many smaller upland valleys support traditional populations: for instance, the Enarotali, Beoga, Ilaga, and East Baliem valleys in WNG and the Telefomin, Porgera, and Wau-Bulolo valleys in ENG. There are literally hundreds of populated highland valleys tucked away in nooks and crannies of upland New Guinea. A visit to one of the more isolated among these can be a wonderful anthropological experience and a journey to what seems to be an earlier time.

Lowland Basins and Platforms On the north side of New Guinea, two large interior basins are sandwiched between the central cordillera and the long string of north coastal ranges. In WNG, the vast Mamberamo basin drains the north-flowing Taritatu, Tariku, and Van Daalen Rivers into the Pacific. Very lightly populated and mainly cloaked in swamp forest and lowland rainforest, this interior basin remains entirely undeveloped and mainly without roads. In ENG, the Sepik-Ramu basin, even larger than the Mamberamo, lies south of the Bewani, Torricelli, Prince Alexander, and Adelbert Mountains, and drains the many tributaries of the mighty Sepik River and the only slightly less grand Ramu River northward into the Pacific. This basin is lightly developed and has several access roads, but no bridges yet span the Sepik. A single bridge spans the Ramu near its headwaters above Dumpu.

Two large lowland platforms dominate south-central New Guinea. In the west, the platform of the Digul drains to the southwest, into the Arafura Sea. In the east, the Fly Platform drains to the southeast into the Gulf of Papua. Whereas the basins are very low and surrounded by hills, the platforms are slightly uplifted and have no circumscribing coastal hills. During the periods of maximum glacial advance in the Pleistocene (2.6 million–11,700 years ago), these platforms were linked to Australia by a low and broad land bridge.

Coastlines WNG's abundant coastline is not uniform. In the northeast, one finds hilly country reaching the coast, which features a mix of white-sand beaches and rocky shorelines. Long stretches of beach backed by coastal hills dominate in the north. The eastern shore of Cenderawasih Bay features swamps and mangroves, whereas the western shore is more rugged and hilly. The north side of the Bird's Head is rugged, while the south side is low and swampy. Much of the southern and southeastern coastline is low and silty, with dark-sand beaches backed by stands of casuarinas and then swamplands farther inland. The most spectacular coastlines are found on the south side of the Bird's Neck, between Arguni Bay and Etna Bay. Here one finds tropical karstic fjordlands that feature coastal mountains rising to more than 1,000 meters, steep cliffs, deep embayments, and scenery galore.

In ENG, the north coast is hilly and descends to white- or dark-sand beaches. In the south, the central bulge features mangroves and silty beaches, whereas in the SE Peninsula there are mainly white-sand beaches, with mangroves choking the low-relief mouths of some of the larger rivers.

The common montane honeyeater, Belford's Melidectes, forages for pollen and nectar from the canopy to the understory of forest and edge. Here feeding on a plant of the Myrtaceae.

Island Groups When we speak of the New Guinean Region we traditionally include a collection of associated island groups that are scattered about the fringes of the great island. Nearly all of these are islands that sit on New Guinea's continental shelf. The NW Islands (Raja Ampat Islands) range off the western coast of the Bird's Head peninsula and include Waigeo (3,155 square kilometers), Salawati (1,624 square kilometers), Misool (2,041 square kilometers), Batanta (453 square kilometers), Kofiau (150 square kilometers), and many smaller islands. This remarkable archipelago supports the world's richest coral reefs and considerable endemic avian biodiversity (e.g., Wilson's Bird of Paradise, Red Bird of Paradise, Waigeo Brushturkey). The islands of Cenderawasih Bay include two isolated oceanic islands with distinct island faunas (Biak-Supiori, 2,497 square kilometers, and Numfor, 311 square kilometers), as well as the mountainous land-bridge island of Yapen (2,227 square kilometers). In addition, there are the Padaido Islands, southeast of Biak Island; Num Island, west of Yapen; and a number of small coastal islands in the southern and western portions of the Bay. Small islands also dot the north coast of the Bird's Neck and fringe the Fakfak and Triton Bay region. WNG's largest island is Dolak (11,191 square kilometers), which is a vast mudbank outwash from the silt-laden rivers of the south-central coast (it is also known variously as Dolok, Kimaam, Kolepom, Yos Sudarso, or Frederick Hendrik). It is often forgotten because of its unprepossessing nature, its isolation, and its minimal distance from the mainland.

A series of active volcanoes form islands north of the west-central section of ENG's north coast, including Karkar (474 square kilometers), Manan (83 square kilometers), Long (329 square kilometers), and Umboi (816 square kilometers), leading east to New Britain.

Note also Daru (16 square kilometers) and Kiwai (360 square kilometers) Islands of western south-central ENG. In the southeast, the D'Entrecasteaux Archipelago, just north of the tail of the SE Peninsula, includes Goodenough (696 square kilometers), Fergusson (1,438 square kilometers), and Normanby (1,036 square kilometers). The Trobriand Islands (Kiriwina, Kaileuna, Vakuta) and the Woodlark Islands, including Woodlark (793 square kilometers) and various small island clusters, stand just north and northwest of the D'Entrecasteaux. The

Karst islands surrounding Gam Island, in the Raja Ampat Islands. The Raja Ampat Islands are popular diving and snorkeling destinations, featuring the biologically richest reef systems on Earth.

Louisiade Archipelago, which includes Misima (557 square kilometers), Tagula (or Sudest; 2,147 square kilometers), Rossel (759 square kilometers), and others, lies to the east-southeast of the tip of the tail of New Guinea.

Off New Guinea's south coast, the Torres Strait Islands of Australia lie just south of the central southern bulge, and the Aru Islands lie due south of the Bird's Neck. The islands of the Banda Sea (outside of the New Guinean Region) lie to the southwest of the Bird's Neck and Bird's Head.

Seas and Bays Much of the western coast of northern New Guinea faces onto the Pacific—from the Bird's Head east to the mouth of the Sepik and Ramu Rivers. The remainder of New Guinea is hemmed in by little-known lesser seas. East of the Ramu River mouth, northern ENG faces the Bismarck Sea. The SE Peninsula faces the Solomon Sea on the north and the Coral Sea on the south. The west-central part of the south coast faces the Arafura Sea and the southern Bird's Neck and Bird's Head face the Seram Sea.

GEOLOGY

The shallow and geologically ephemeral Arafura Sea and the Torres Strait separate New Guinea from Australia. In fact, New Guinea and Australia rest atop a single tectonic plate that is slowly plowing northward into the westward-moving Pacific Plate. At the front of this moving plate, New Guinea is suffering compression, subduction, obduction, and mountain uplift all along the contact zone. New Guinea's northern margin today is a mélange of more than 25 tectonostratigraphic terranes—former oceanic, arc, or continental fragments that have accreted to the main body of the island as it has been pushed northward at the prow of the Australian plate. By contrast, Australia, to the south, is a stable expanse of earth's crust (a craton) typified by little relief or tectonic activity. Also by way of contrast, New Guinea is tropical and humid, whereas Australia is mainly temperate and arid.

The youthful topography of New Guinea is evident from its ungraded rivers, numerous waterfalls, narrow V-shaped valleys, frequent land slippage, and harsh physiography. This rugged topography is in places interrupted by extensive intermontane valleys (e.g., Wahgi, Baliem, Tari), most of which drain southward through the central cordillera. This central cordillera steeply declines to the south and more gradually grades to the north into a series of lowland river basins. Pleistocene volcanoes (e.g., Mount Giluwe, Mount Ialibu, Mount Hagen, and Mount Michael) mark the landscape in the Eastern Ranges, and more recent volcanism is found in a series of small islands along the north coast of ENG and on the north slopes of the SE Peninsula (Mount Lamington, Mount Victory, Mount Trafalgar).

New Guinea has economically significant deposits of gold, copper, nickel, oil, and natural gas—all products of the island's tectonic history. These mineral and petroleum resources are driving much of the economic development on the island.

CLIMATE

New Guinea is situated between the equator and 12° south latitude and thus supports a wholly tropical climate. The moisture-laden winds that come off the surrounding warm tropical seas produce abundant precipitation when striking the island's high relief. New Guinea is one of the rainiest and cloudiest places on Earth. The region is seasonally dominated by a northwest monsoon and the southeast trade winds. In most parts of New Guinea, the effects of the northwest monsoon dominate in the period from November to March, bringing rain and unsettled weather. The southeast trades predominate from April until September and tend to bring cooler and relatively dry weather. That said, New Guinea has many microclimates. Rainfall regimes range from low in the southern bulge and eastern rain shadows (less than 2,000 millimeters/year) to extremely high on the southern scarp of the central cordillera (more than 5,000 millimeters/year). In the wetter areas, rainfall seasonality appears reversed, and the most rain falls in the April–October period. In fact, the wettest sites, which tend to be found in the mountains along the southern front of the central cordillera, receive substantial rainfall during both the monsoon and the trades. Moreover, annual accumulation in the very wettest areas shows great interannual variability.

Seasonally, local temperatures vary little. Elevation is the key to temperature in equatorial zones. The correlation, called the "lapse rate," is equivalent to 0.65°C per 100 meters elevation. Thus, at sea level, in forests of the interior lowlands, one encounters an unpleasant combination of high humidity and warm temperature day and night on all but the coolest days of the austral winter. By contrast, at 4,000 meters in the central cordillera one can expect regular night frosts during the dry season, when the skies are clear. Above 4,500 meters elevation, periodic snowfalls are recorded. Glaciers cap the two highest peaks of the far west. These glaciers expanded outward and downward during the Pleistocene cooling (when the snowline was at 3,500 meters elevation), melted altogether by 6,000 years ago, and returned during the recent cooling of the Little Ice Age (early 14th through mid-19th centuries), only to begin retreating again in the past century.

The elevation-versus-temperature relationship is a defining environmental phenomenon in mountainous New Guinea. Thermal stratification allows essentially distinct biotas to inhabit adjacent patches of land, separated only by elevation and minimal geography. It certainly explains much of the species richness of the great island (something known as beta diversity), where cold-dwelling species inhabit upslope habitats only a few kilometers from the hot-dwelling species downslope. No similar precise relationship exists in the temperate zone of North America because of the annual interference of the winter season, which moves populations because of the seasonal intrusion of cold and snow.

Rain shadows exist in some interior valleys (such as the Baliem, Wahgi, Markham, Wau-Bulolo, and Safia-Pongani), on the Bomberai Peninsula, in the Trans-Fly, near Port Moresby, and along the north coast of the far southeast. Rainfall is also slightly attenuated along the northern coast from the mouth of the Mamberamo east to Jayapura. The low-rainfall zones in the interior upland valleys are among the most pleasant places to live on the island. They are in the minority. Much of the interior receives well in excess of 3,000 millimeters per annum.

Super-wet zones can be found in several areas, from west to east: the southern slopes of the Western Ranges, the southern slopes of the Border Ranges, the Purari Basin of the southern slopes of the Eastern Ranges, and the head of the Huon Gulf. These regions are among the very wettest places on Earth and are, frankly, difficult places to subsist because of the nearly daily downpours. For indigenous residents, the heavy and persistent rains and associated dense clouds hinder productive agriculture, make accomplishing day-to-day activities a challenge, and probably have substantial long-term health impacts.

ENVIRONMENTS

New Guinea supports 11 equatorial environments, which we briefly describe here.

Lowland Rainforest dominates below 500 meters elevation across much of the island—in all but the driest zones of the Trans-Fly and in the rain-shadow lowlands of the far SE Peninsula (Safia-Pongani Gap and along the coast both east and west of Raba Raba), which exhibit fire-dependent **Tropical Savanna**, a mix of eucalypt and melaleuca and various coarse grass species. This savanna habitat also dominates in the coastal rain shadow that extends southeastward from Port Moresby.

Much of New Guinea is rugged and mountainous. In such zones, **Hill Forest** dominates between 500 and 1,500 meters elevation. This is much like the rainforest but with trees of smaller diameter, more species per hectare, and lots of forest disturbance because of land slippage and other impacts. **Montane Forest** predominates between 1,500 and 3,000 meters elevation. This forest is quite variable but in certain locales is dominated by oaks, southern beeches, and conifers of considerable diameter and height. These appear above 2,500 meters and are often heavily encrusted with colorful mosses, liverworts, and bryophytes and other epiphytic growth. **Subalpine Forest**, a stunted elfin forest like that of the high Andes, is dominant above 3,200 meters elevation and leading up to the tree line. It is typified by sapling-size trees encrusted with moss. These trees are often twisted and gnarled. Light gaps can be filled with thick tangles of nearly impenetrable scrambling bamboo. In openings, shrubby genera of heaths are prominent, especially species of brightly flowering rhododendrons. **Alpine Shrubland/Grassland** caps the highest mountaintops.

Modest Forest Dragon camouflaged in the verdant forest of the Muller Range, in the Border Ranges of ENG. Photo: Piotr Naskrecki

The patchy shrublands abound on protected slopes, and the grasslands predominate in basins and flats, where drainage is impaired and where killing frosts tend to settle during the austral winter months. These extend into the subalpine zone from burning by hunters.

Swamp Forest dominates in the lowlands where drainage is poor; it is commonplace in the NW Lowlands, the Sepik-Ramu, and the Southern Lowlands, and occurs patchily in many lowland sites at the base of hills. The vast Lakeplain of the Mamberamo basin is dominated by seasonally inundated swamplands of various types. There are great coastal swamplands along much of the southern coast of Indonesian New Guinea, from the Casuarina Coast in the southeast to the swamplands south of Timika, far to the west. **Mangrove Forest** dominates at the head of Bintuni Bay, where the Bird's Head contacts the Bird's Neck. There are also abundant mangroves along the coast of the western sector of the Southern Lowlands and at the head of the Gulf of Papua in the eastern sector of the Southern Lowlands.

Seasonal Monsoon Forest occurs near Port Moresby and in the northern Trans-Fly, where the rainy season is broken by a long and persistent dry season. This habitat is typified by species of seasonally deciduous trees. It is an uncommon forest type in New Guinea. **Wetlands and Marshes** support mainly grasses, rushes, and reeds and are home to many of the region's waterbirds and freshwater fish fauna. This habitat is most common in the middle Fly River, the NW Lowlands, and the Sepik-Ramu. Finally, **Anthropogenic Grasslands** prevail in places where human settlements have been long present and humans set fires annually during the dry season. The repeated fire leads to the loss of fertile soil and prevents recolonization by woody vegetation. The grasslands are composed of several robust grass species and are most common in the most densely populated parts of the island (coastal lowlands, interior upland valleys), where fire is annually deployed through the habitat for various purposes (habitat management for agriculture and hunting). Large expanses of grasslands in areas otherwise dominated by humid forest are a clear indication of long human occupation.

THE BIOTA

New Guinea is the most species-rich island on Earth, with substantially more biodiversity than is found on Borneo, Madagascar, Sumatra, or Sri Lanka. This applies to the plant life as well as the animal life. The breadth of richness is due to the size of the island, its geological association with the Australian craton, its extreme topography and high rainfall, its equatorial position, and the resulting diversity of natural environments present.

The humid forests are diverse in form and floristics. Recent counts of vascular plants in New Guinea estimate a total of ca. 15,000 species; estimates of endemism stand at ca. 9,000 species. In any case, much remains to be discovered, and virtually every biological expedition that explores New Guinea encounters species of plants new to science.

Lying east of Wallace's Line and perched on the Australian plate, New Guinea is in many ways faunally distinct from Asia, to the west-northwest, and instead displays its closest affinities to Australia, to the south. Wallace's Line defines the deepwater passages that have long isolated western Indonesia from eastern Indonesia and Australia. To the west of Wallace's Line one finds wildcats, monkeys, squirrels, pheasants, and bulbuls amid the array of typical Asian vertebrates. To the east one finds an impoverished vertebrate fauna dominated by marsupials, bats, rats, and Australian-endemic bird families (honeyeaters, bowerbirds, birds of paradise, cassowaries, butcherbirds, Australian robins, and more). By contrast, the arthropod fauna and the flora tend to be Malesian, which refers to a large tropical and subtropical region that extends in an arc from Sumatra and Peninsular Malaysia to New Guinea. The more ancient insect and plant biota have been able to successfully cross the barrier formed by Wallace's Line in a manner that the substantially younger vertebrate groups have not. Some vertebrates exhibit this Malesian distribution (e.g., hornbills, megapodes), but they are exceptional.

In spite of its physical isolation, the fauna of New Guinea is rich. Mammals are represented by 289 species. Bird diversity is high, with 621 resident species. This is more than double the number of bird species found in Madagascar. Reptile diversity is also high (though not as high as in Madagascar), with 373 species. Amphibian diversity, by contrast, is very high (exceeding that of Madagascar), with 442 species. All these numbers are likely to increase due to new discoveries and better taxonomic knowledge, but the amphibian numbers are certain to increase dramatically, perhaps eventually even doubling. There are also 380 species of freshwater fishes. That New Guinea has more than 920 butterflies and 108 tiger beetles known to science gives an indication of the richness of invertebrates.

The forest invertebrate fauna is diverse beyond imagination, defying our ability to enumerate it. There are probably in excess of 200,000 species of insects alone, only a small fraction of which have been named. Most prominent are the huge and beautiful birdwing butterflies, the giant phasmid stick insects, several lineages of giant beetles, and the world's second-largest moth. One can also find freshwater crabs, a range of edible freshwater shrimp and crayfish, and an abundance of species of bloodsucking leeches.

A prehistoric stone zoomorphic object, featuring what is perhaps an echidna, from the Lagaip watershed of the Eastern Ranges. Photo courtesy of John and Marcia Friede, the Jolika Collection of the de Young Museum, Fine Arts Museums of San Francisco

The marine reef environments found in the NW Islands, Bay Islands, and SE Islands are among the very richest on Earth in terms of species diversity. One finds extraordinary numbers of hard corals, mollusks, and reef fishes. These environments are also very productive and form an important sustainable resource for local communities. The New Guinean Region also supports a significant pelagic fishery, with key migratory species (such as various tuna species).

HUMAN CULTURES

Although the island of New Guinea is rather young in geological terms, its peoples are of apparently ancient stocks, and there is evidence that humans have been present on the island for at least 47,000 years. Not surprisingly, the details of the earliest habitation on the island are scanty, and it is possible that humans have occupied Australia–New Guinea for as long as 65,000 years, given the oldest northern Australian dates (though these are contested). New Guinea supports as many as 1,100 language groups. No other comparable landmass supports as many languages. This could be taken as an indication of the longevity of human occupation of New Guinea. WNG supports about 250 languages; this is dwarfed by ENG's 830 languages.

Many of New Guinea's language groups are small and insular, with fewer than 2,000 speakers. A few languages (e.g., Melpa, Huli, Anga, Dani, Asmat) are spoken by many. These dominant languages seem to indicate cultural dominance as well. The local languages are an obvious marker of diversity in local culture, and thus New Guinea is culturally very diverse and heterogeneous. This is one reason there has been only limited local development on the island. Small, diverse, egalitarian societies do not have the human capacity and structure needed for complex social and economic structures to develop, as has been explained eloquently by Jared Diamond in his book *Guns, Germs, and Steel*. The near absence of stratified societies and the lack of key domesticated livestock and storable grain crops have probably contributed to the generally minor development of local economies in New Guinea. In one point of contrast, important Sweet Potato-growing cultures replaced the labor-intensive banana-taro agriculture in the fertile interior valleys of the Western and Eastern Ranges since the arrival of the Sweet Potato on the island—perhaps as recently as 400 years ago.

The major traditional population centers are found in the interior uplands (Baliem and Ilaga valleys, Paniai Lakes, and Tari, Wahgi, and Asaro valleys). Most societies are either forest or coastal dwelling, with primary dependence upon Sweet Potatoes and pigs (interior) or fish and yams (coastal). It seems all New Guineans are accomplished gardeners as well as accomplished warriors. In most instances, the warlike traditions have been suppressed over the last century, mainly through government pacification and the teachings of Christian missionaries.

As discussed above, New Guinea has had a complex human prehistory, and in today's world its human cultural diversity is unmatched. On top of this, not only do these languages and cultures still exist, most of them are still intact, vibrant, functioning entities, not mere remnants of what once existed—as are found, unfortunately, in many other culturally rich parts of the world, where tribal cultures are in serious decline. Furthermore, 97 percent of the land on the ENG side is still in the hands of the traditional landowners, again a situation that is unique in today's world. An apt comparison would be the United States at the beginning of the 17th century, when much of the land was occupied and still under the control of the Native American tribal peoples.

In all, the human population of the island of New Guinea is just over 12.5 million people (as of 2018), 8 million on the Papua New Guinea side and 4.7 million on the Indonesian side. A large number of people are concentrated in the larger cities and towns such as Port Moresby, Lae, Madang, Jayapura, Sorong, Biak, Manokwari, and a handful of others, and in the fertile valleys of the highlands of WNG and ENG.

DEVELOPMENT AND THE ENVIRONMENT

Threats to biodiversity and traditional peoples in New Guinea are similar to those in most other parts of the tropical world, but here more of the region's natural resources are still intact. Obvious near-term threats include industrial logging, expansion of Oil Palm monoculture, and poorly planned large-scale economic development that does not take account of the economic, cultural, and social needs of many rural traditional societies found across the island. Longer-term threats might include population growth and its various impacts, deforestation, climate change, and exotic species introductions.

At this time, timber, minerals, and petroleum and natural gas are the major land resources. New Guinea, unfortunately, has been one of the major targets of Asian predatory logging companies since the 1980s. In general, New Guinea's commercially logged forests have received little or no environmental management; the companies carry out their activities with no consideration whatsoever for their impacts on biodiversity, and they employ logging methods that cause considerable ecosystem degradation.

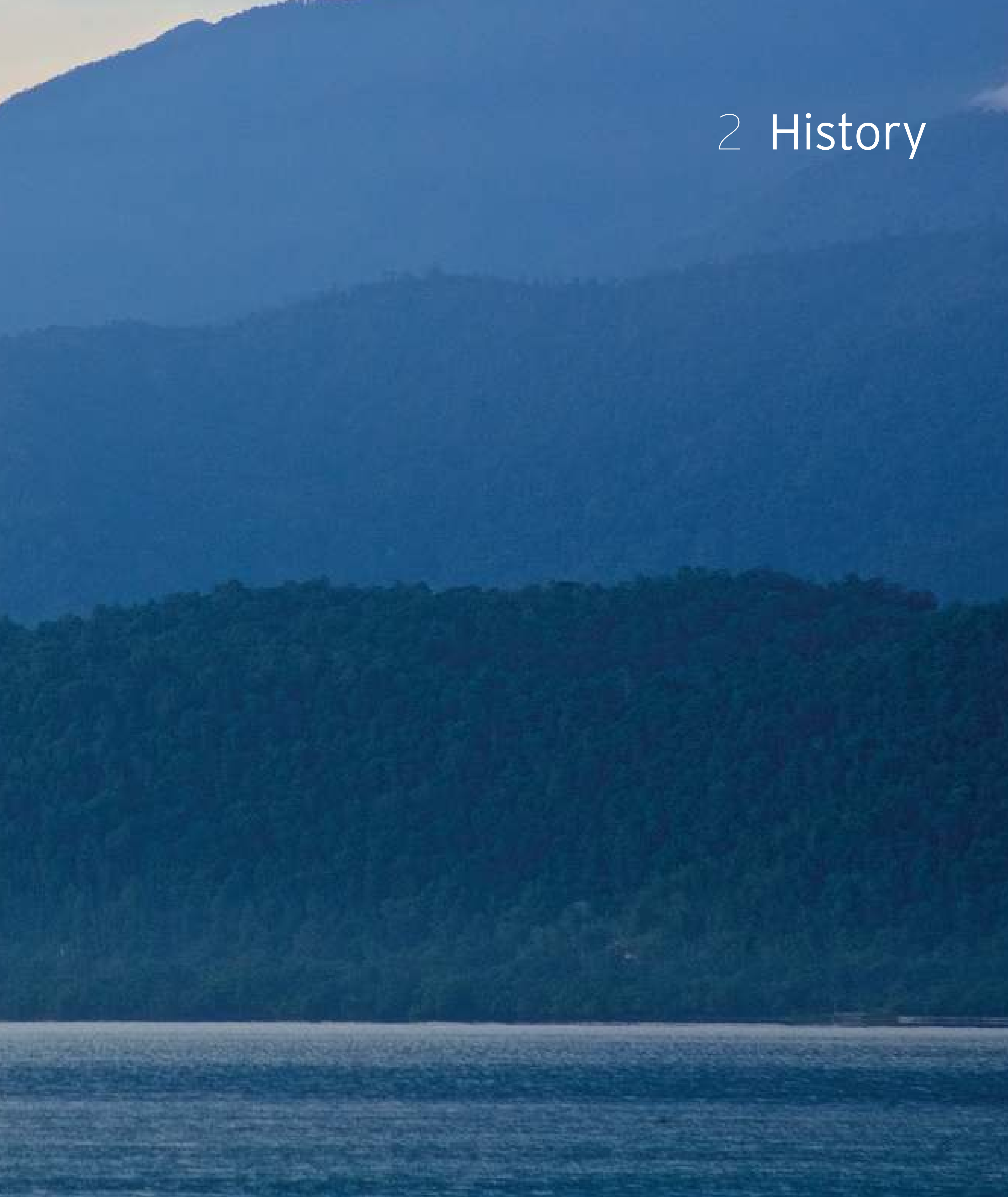
Large-scale commercial agriculture also exists, with the major export goods being coffee, palm oil, cocoa, copra (a dried coconut product), tea, and rubber. Operations of this kind are still relatively scarce compared to their presence in most other parts of the world, but they are on the increase.

Threats to the marine fisheries that surround New Guinea are growing. These tend to be in line with those that impact fisheries in other parts of the tropical world and include overfishing, illegal harvest, pollution, coral mining, dynamite fishing, and cyanide fishing.

As indicated above, Oil Palm may be the next great threat to the island of New Guinea. Production of palm oil already has proven to be a money winner in Papua New Guinea and Malaysia, and there is now a push to expand Oil Palm development in both ENG and WNG. Oil Palm monoculture has the potential to cause substantially more damage to New Guinea's rainforests than industrial logging, mainly because the logging is selective, whereas the Oil Palm operation mandates wholesale clearing of forest, with the result being total loss of local biodiversity (as has proven to be the case in Malaysia and other parts of the tropical world).

Climate change threatens low islands, local coastal zones, and sensitive habitats. The rapid melting of the highland glaciers makes clear that the local climate in New Guinea is warming. The nature of future changes is difficult to anticipate, but the impacts could be extensive.

Human population growth is a major underlying threat that looms on the horizon. When population density is low, subsistence agriculture and local forest and coastal resource extraction can be environmentally sustainable. With higher population density, sustainability disappears. The demographics of population growth may determine the level of impact. If rural youth abandon the village for the cities, urban intensification will concentrate the impacts and backcountry ecosystems may survive. On the other hand, secondary effects, such as loss of traditions and abandonment of subsistence systems, may pave the way to large-scale habitat conversion by foreign economic interests. ■



2 History

Exploration, Colonization, and Natural History Study

THIS CHAPTER REVIEWS the exploration and western colonization of New Guinea, including the early trading history, Western voyages of discovery, the plume trade, natural history expeditions, colonialism, and postcolonial scientific activity.*

EARLY HISTORY

Preceding pages: Vista across Manokwari Bay up into the heights of the Arfak Mountains. The Arfaks were the first mountains visited by Western explorers in search of novel birds of paradise. Odoardo Beccari and Luigi D'Albertis were the first to make that trek. Naturalists still head to the Arfaks today but have the advantage of a jeep road that takes them high into the interior.

Opposite: On expedition! New Guinean naturalist-guides trek through the mossy forest uplands of the Arfak Mountains of the Bird's Head of WNG. The guide in the foreground is carrying a waterproof pack adorned with firewood and is holding a black palm bow (unstrung) and a quiver of arrows.

The New Guinean Region, though isolated from the Western world, established trade with Asia nearly 6,000 years ago. The evidence for this is the presence of betel nut husks in a 5,800-year-old archaeological site on the coast of New Guinea. The "nut" of the Betel Palm (*Areca catechu*), chewed for its mildly narcotic properties, originated in Southeast Asia and therefore must have been traded east to New Guinea, where it subsequently became established through active propagation and widespread use. By 4,000 years ago trade from New Guinea had extended westward to the Middle East. Dongson culture bronze kettledrums from Vietnam (2,200 years old) have been recovered from Lake Ayamaru of the Bird's Head, providing evidence of early trade routes between Southeast Asia and New Guinea. Products such as massoi bark (from a species of *Cinnamomum* tree) and trepang (dried sea cucumber) from New Guinea were popular with Asian traders. Cloves from the Spice Islands (centered on the Moluccas—now Maluku—west of New Guinea) have been found in an archaeological site in Syria dating to ca. 1,700 years ago. Traders from the Majapahit empire of eastern Java reached Fakfak (in the Bird's Neck of WNG) in the 14th century.

* This chapter is built upon the work of Beehler and Mandeville (2017), Frith and Frith (2008, 2010), Frodin (2007, 1988), Swadling (1996), Frodin and Gressitt (1982), and Gilliard (1969), plus others in references section.

A featured commodity in this east–west trading system was the prepared dried skins of plumed male birds of paradise, which likely dominated trade as early as 2,000 years ago. (Note: a trade "skin" is a whole dried bird with its feathers intact and the organs and flesh removed.) The plumes, because of their rarity outside the New Guinean Region and their beauty, grew to be much in demand for ornate headgear worn by Asian royalty. By the year 250 CE, spices had become the focus of the trade, which centered on the Spice Islands. The Portuguese discovered the source of these spices in 1512. At this point, Portuguese explorers brought back to Europe an array of spices as well as the first dried skins of birds of paradise from their forays to the western verges of the New Guinean Region. A small number of these trade skins made their way to European courts, always eager for novelties from afar. Thus began the Western world's long fascination with exotic items from the New Guinea and the Aru Islands—especially plumes of birds of paradise.

THE VOYAGES OF DISCOVERY

Portuguese traders voyaging from a base established in Goa on the western coast of India opened the Malay Archipelago to trade with Europe in the early 16th century. In 1511, Antonio d'Abreu and Francisco Serrano were the first to sight mainland New Guinea. By 1521 traders had a Malay base of operation in Amboina (now Ambon) in the Moluccas. The trade focused on spices, such as cloves and nutmeg, but upon their discovery of the availability of the gorgeous plumes of the birds of paradise, traders expanded their cargo to include these precious objects unknown to the West. Local traders told the Western voyagers that the birds were wanderers from celestial paradise, presumably to hide the true source of these valuable trade goods. As a result of these voyages, Westerners came to believe that the spices were to be found mainly west of New Guinea and that the great island itself was neither a welcoming place nor a place with ready access to sought-after riches. Early on, it was not known that the precious plumes of the birds of paradise came from New Guinea itself.

Juan Sebastián Elcano, who completed Ferdinand Magellan's circumnavigation of the globe, returned to Spain in September 1522 in the tattered *Vittoria*, the surviving vessel of five that started their great journey out of Seville three years earlier. Only 19 members of the original crew of 277 survived to return to Spain; Magellan died in a battle on Cebu Island in the Philippines. On board was precious cargo: two skins of the Lesser Bird of Paradise, the first species of bird of paradise to be seen by the Western world. These two trade skins were a gift from the sultan of Batchian (now Bacan) to the king of Spain.

Jorge de Menezes, a Portuguese explorer, reached Biak Island and the northern coast of the Bird's Head in 1526–27. He named the region "Ilhas dos Papuas," or land of the fuzzy-haired people (from *papua*, a Malay term) and is thus credited with the European discovery of western New Guinea. He later served as the Portuguese governor of Ternate, an important trading base in the Spice Islands of the Moluccas, just west of New Guinea.

The Spaniard Alvaro de Saavedra Ceron made landfall on an island north of mainland New Guinea (probably Yapen Island) in 1528 and named it "Isla del Oro," or island of gold. He stayed a month here, he reported, on an island populated by "naked black people." The gold he referred to in his name for the island was more likely a reference to the golden plumes of the Lesser Bird of Paradise that inhabits Yapen. In 1545, Yñigo Ortiz de Retez called in at the northern coast of New Guinea near present-day Sarmi and named the land "Nueva Guinea," because the people looked to him like the Africans he was familiar with from coastal West Africa.

In 1606, Luis Vaéz de Torres came from the east and sailed from Milne Bay, in the far southeast of New Guinea, westward along the south coast, passing unwittingly through the strait now bearing his name (Torres Strait—separating New Guinea from Cape York of Australia). In 1623, Dutchman Jan Carstensz, sailing off the southwestern coast of New Guinea, sighted the snows of the highest summit of the western central ranges, probably Mount Carstensz (now Puncak Jaya).

In the year 1700, the English explorer William Dampier traveled among the islands that fringe the northern coast of eastern New Guinea, and his ship, the *Roebuck*, made the first natural history collections from the islands. Dampier determined that New Britain was a separate island from New Guinea, and his name was given to Dampier Strait, which separates the two. In 1770, James Cook, in the *Endeavour*, proved the geographic distinctness of New Guinea as an island separate from New Holland (Australia) by sailing through Torres Strait—a distinction Torres was unable to make because he lacked sufficient geographic data at that time.

Pierre Sonnerat, serving as naturalist on the royal flute *Île-de-France*, visited the island of Gebe in the western NW Islands in 1772. At that time, the envoy of the raja of Salawati made a gift of specimens of several novel bird of paradise species. These were subsequently illustrated in Louis-Jean-Marie Daubenton's *Planches Enluminées* (1765–83) and discussed by Guéneau de Montbeillard in Georges-Louis Leclerc, Count de Buffon's *Histoire des Oiseaux* (1770–83). Thomas Pennant and Jacob Hermann subsequently provided the first scientific descriptions of these novel birds of paradise. Sonnerat's account of this voyage of discovery, unfortunately, included abundant embellishments of fact, including a claim of three species of penguins reputed to be from the island of New Guinea (penguins can indeed be found in Australia).

The French corvette *Coquille*, captained by Louis Duperrey, stopped on the eastern side of the Bird's Head at Dorey (now Manokwari) in July 1824, and the ship's naturalist, René Lesson, was able to collect birds on the New Guinea mainland. This was probably the first time a European naturalist observed a living and free-ranging bird of paradise in its jungle habitat.

In 1827, Jean René Constant Quoy and Joseph Paul Gaimard collected birds from the eastern Bird's Head while serving on the *Astrolabe* (which in fact was the *Coquille* renamed), captained by Dumont D'Urville. In 1828, the Dutch in the naval corvette *Triton* traveled the southern coast of western New Guinea as far east as the Digul River. It then returned to what is now named Triton Bay on the south side of the Bird's Neck and established Fort Du Bus. While traveling on the *Triton*, Heinrich Christian Macklott and Salomon Müller were able to collect 119 species of birds from the mainland of New Guinea, which included a number of new taxa. In 1846–47, John MacGillivray served as naturalist aboard the HMS *Rattlesnake*, which surveyed the eastern coast of Australia, the southern coast of eastern New Guinea, and the Louisiade Archipelago. These various voyages mapped the coastline of New Guinea and demonstrated the existence and locations of myriad fringing islands in the region.

COLONIALISM

In the year 1545, the Spanish explorer Yñigo Ortiz de Retez, aboard the *San Juan*, made landfall on the northern coast of New Guinea, just east of the mouth of the Mamberamo River. He planted a Spanish flag—the first formal colonial claim on the island.

The Spanish suffered a series of military and economic reverses that led the Dutch East Indies Company, in 1660, to take their place in the Spice Islands. In 1678, the Dutch flag was raised on the island of New Guinea. In 1750, the Dutch East India Company came to suffer a fate like that of the Spanish before them, and shortly thereafter, local Malay leaders attacked the Dutch installations. In 1793, the English established Fort Coronation at Dorey, on the eastern side of the Bird's Head Peninsula. This settlement failed after three years. The Dutch regained control over the Spice Islands in 1814. The early colonial period was one of instability and uncertainty for the Western powers, whose interests were largely economic.

As noted above, the Dutch established a fortified base, Fort Du Bus, on the south side of the Bird's Neck at Triton Bay in 1828. It was at this time that the Dutch sought to lay claim to sovereignty over the entire western half of southern New Guinea. This initiated the formal colonial era in New Guinea. Fort Du Bus was maintained for eight years but then was abandoned because of the depredations of malaria and other challenges to tropical colonial livelihood.

It was not until 1848 that the Dutch, by claiming the north coast eastward to Humboldt Bay (near present-day Jayapura), formally secured dominion over all of western New Guinea. The British raised their flag at Port Moresby in 1883, and the Germans theirs at Konstantinhafen in 1884. Thus 1884 saw the complete partitioning of the island of New Guinea into three: Netherlands New Guinea subsuming the western half of the island, German New Guinea the northeastern sector, and British Papua the southeastern sector. In 1888, British New Guinea was declared a crown colony, administered by William MacGregor, an adventurous naturalist who climbed Mount Victoria on the SE Peninsula in 1889—a stunning (even improbable) accomplishment for a colonial administrator. Most of the high summits of the Owen Stanley Range were climbed in the following few years, thanks to MacGregor's strong interest in exploration and natural history. By treaty with the Australians, the Dutch formalized their colonial claim to all of the western part of the island in May 1895. At this

Victorian bird plate featuring the male Crested Satinbird (*Cnemophilus macgregorii*); lithograph based on a painting by John Gerrard Keulemans. Courtesy: Biodiversity Heritage Library and Smithsonian Institution

Biodiversity research field camp in the Foja Mountains. It is boggy and muddy because of daily rains and the repeated tread of booted feet. These sorts of camps were a fact of life for early explorers making their way into the interior of New Guinea. Conditions are essentially the same for 21st-century researchers wanting to spend time in unexplored areas far from civilization.

point the entire New Guinean Region was under colonial dominion. In 1910, Hollandia (now Jayapura) became the seat of Dutch colonial governance over western New Guinea.

The Dutch maintained colonial rule over western New Guinea until 1963, when an Indonesian military force took control of this last portion of the Dutch East Indies. In 1969, a plebiscite held for western New Guinea, known as the Act of Free Choice, formalized Indonesian rule over western New Guinea. Most evidence points to the vote being a sham, and yet it achieved its mandate of consolidating all the former Dutch colonial territory under Sukarno, the leader of Indonesia's independence movement and its first president, and the Indonesian flag. British Papua (southeastern New Guinea) had been handed over to the Australians to care for (as Papua) in 1906. The Germans held northeastern New Guinea until the close of World War I, when it was transferred to Australian mandate by the League of Nations. In 1949, Australia amalgamated the northeastern and southeastern parts into a single territory, known as the Territory of Papua and New Guinea, which gained full independence in September 1975 as Papua New Guinea. Today, western New Guinea is managed as two provinces of Indonesia. Most decision making over western New Guinea takes place in Jakarta, although some level of autonomy was established in the year 2000 during the presidency of Abdurrahman Wahid (known popularly as Gus Dur). The Indonesian military, however, still maintains tight control over western New Guinea in the name of national security. As a result, foreign tourists and scientists have had difficulty obtaining visas to visit or conduct research in Indonesian New Guinea, popularly known around the world today as "West Papua." By contrast, eastern New Guinea (mainland Papua New Guinea) remains visitor-friendly, though not nearly as crime-free as its western counterpart. Today, most international naturalists and biodiversity scientists conduct their fieldwork in Papua New Guinea rather than Indonesian New Guinea.

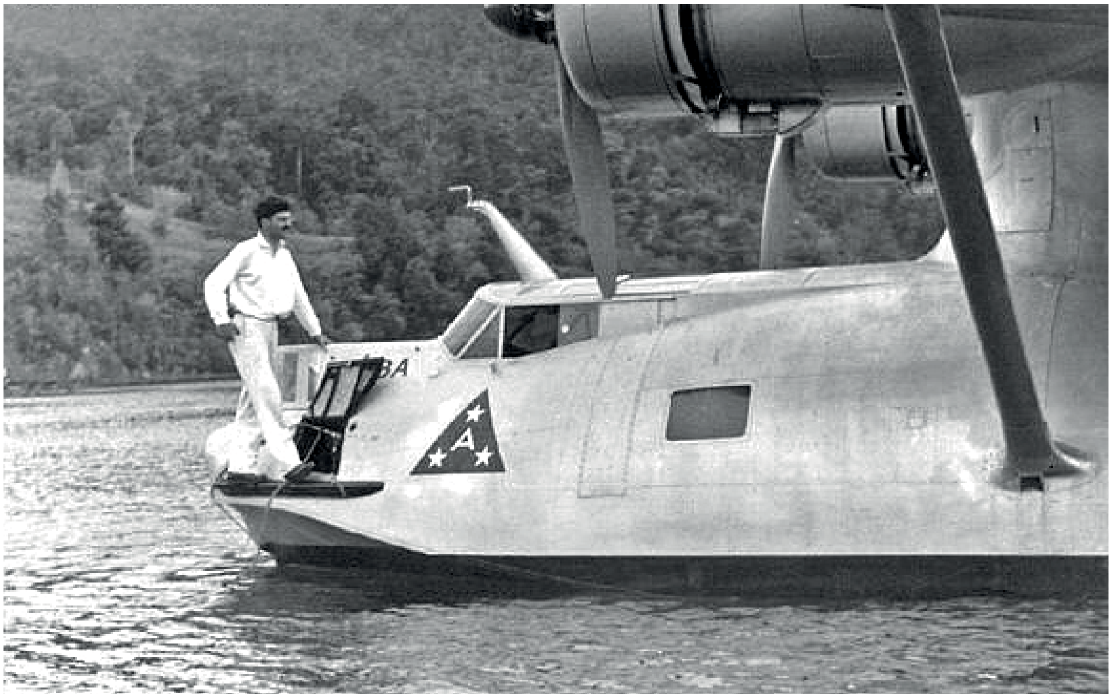
THE EXPEDITIONS

Most major expeditions to survey animal and plant life in New Guinea were mounted by colonial governments, although one series of major field trips was engineered by a rich American adventurer, and another was sponsored by an ornithological society. We review the most prominent and important of the expeditions below.

Predecessors to the great expeditions were field investigations by intrepid individuals. Alfred Russel Wallace made his way across the Malay Archipelago over an eight-year period, reaching the Aru Islands, the NW Islands, and the Bird's Head. He made field camps in all three locations in 1857–60. In the Aru Islands, Wallace observed the communal lek mating display of the Greater Bird of Paradise. He made field camps on the eastern side of the Bird's Head near Dorey (now Manokwari) and on Gam Island, adjacent to Waigeo Island, and collected birds and insects, mainly. This multiyear expedition led Wallace to write a paper outlining ideas about organic evolution by natural selection, which prompted Darwin to stop procrastinating and put out his own independently derived theory of evolution. Odoardo Beccari and Luigi Maria D'Albertis explored the Arfak Mountains of WNG in 1872, discovering several novel birds of paradise. D'Albertis in later years led several boat expeditions up the Fly River in ENG and first collected for Western science PNG's national bird, the Raggiana Bird of Paradise.

A young and bearded Ernst Mayr (right) with a field colleague in New Guinea in 1929. Mayr surveyed birds in the Arfak, Wandammen, Cyclops, Saruwaged, and Herzog (Snake River) Mountains during this, his first and only field trip to New Guinea. Image courtesy of the Ernst Mayr Library, Museum of Comparative Zoology, Harvard University

Dutch Expeditions The Dutch government sponsored seven major explorations of western New Guinea during the colonial era. In 1903, C. F. A. Wichmann led an expedition to the area around Humboldt Bay in WNG's northeast and to the far west (Bird's Head and adjacent islands) that included Hendrik Antoon Lorentz and Lieven Ferdinand de Beaufort as vertebrate collectors. In 1904–5, the Dutch Southwestern New Guinea Expedition focused on the southern coast (including Etna Bay and also Merauke). In mid-1907, with the Dutch military, Lorentz followed the Noord (now Lorentz) River from the southwestern coast of New Guinea with the objective of reaching the snows of Mount Wilhelmina (now Puncak Trikora). After failing to get above 2,300 meters in 1907, Lorentz returned in 1909 and, using the same route, ascended to above 4,000 meters. He turned back at the snow line. The summit of Puncak Trikora (4,750 meters) was reached in early 1913, on an expedition led



The *Guba*, an amphibious aircraft, and its owner and pilot, Richard Archbold, in Hollandia harbor (present-day Jayapura), Netherlands New Guinea, June 1938, at the start of the third Archbold New Guinea expedition—the greatest of all. Photo: L.J. Brass. Image courtesy of Frederick Lohrer, Archbold Biological Station

by Captain F. Herderschee—a major feat of exploration at the time. The great New Guinea expedition of 1920–21, led by A. J. A. van Overeem, surveyed the Mamberamo River and ascended to the summit of Doormantop (3,349 meters). A follow-up expedition in 1922, led by J. H. G. Kremer, with 800 men, ascended the Swart valley and crossed the western Baliem River, reaching Lake Habbema, in the Western Ranges. Finally, a Dutch expedition explored the Wissel Lakes (now the Paniai Lakes) and Etna Bay in 1939.

Joint British Ornithologists' Union and Wollaston Expeditions The Mount Carstensz snowfields of western New Guinea were a strong attraction for European explorers. In early 1910, a large party of explorers under the auspices of the British Ornithologists' Union initiated an expedition with the intent of exploring the mountains of the Western Ranges up to the summit of the highest point of the island. The team, led by Walter Goodfellow, made its first camp on the lower Mimika River in southwestern New Guinea. One of the zoological collectors, Wilfred Stalker, drowned in a river on the third day of the expedition (he was replaced by Claude Grant). This, plus the loss of numerous Javan and Dyak porters, were the misfortunes of this first effort. A broad expanse of lowland swamp impeded the progress of the expedition, and the team failed to ascend higher than 1,500 meters elevation. A second British team returned in 1912–13, led by A. F. R. Wollaston; it made its way up the Otakwa and Setekwa Rivers to the edge of the Carstensz icefield before being turned back by precipitous cliffs. The two British expeditions collected 3,400 bird specimens, deposited in the British Museum in London. The snowfield of Ngga Pulu was reached in 1936 by a small team led by Anton Colijn. The summit of Mount Carstensz (4,884 meters) was climbed in 1962 by Heinrich Harrer, Philip Temple, Russell Kippax, and Albertus Huizenga. The Carstensz glaciers were studied by two Australian-led expeditions in 1971–1973.

Scene from the second Archbold expedition to New Guinea, in the Southern Lowlands. After having to abandon plans to continue to higher elevations, the team crafted a series of rafts to float material down the Fly River. Photo: L.J. Brass, Archbold Expeditions Collection, Department of Mammalogy, AMNH, and Biodiversity Heritage Library

German New Guinea Expeditions (1886–99) The German Neu-Guinea Kompagnie expeditions first worked around the settlements of Finschhafen, Salamaua, Madang, and up the Sepik River (to the May River and the village of Ambunti), with naturalists Carl Hunstein and F. Grabowsky. The second effort, led by Carl Lauterbach, focused on the Ramu River (villages of Jagei, Usino, Annanberg). The final and greatest effort was the Kaiserin-Augusta-Fluss Expedition of 1912–13, led by Captain A. Stolle. The 18-month effort surveyed the Sepik basin by ship and launch and ascended into the foothills of the central cordillera. Vertebrates were collected by Joseph Bürgers, and the ornithological results were written up by Erwin Stresemann.

Whitney South Sea Expedition (1921–40) The Whitney South Sea Expedition collected birds for the American Museum of Natural History (AMNH), in New York, under the sequential leadership of Rollo Beck, Hannibal Hamlin, and William Coultas. This major ship-based effort was instigated by Leonard C. Sanford and financed by Harry Payne Whitney, a thoroughbred-horse breeder and philanthropist. Beck, an expert bird collector himself, hired Ernst H. Quayle and Charles Curtis to assist with collecting birds as well as plants. The expedition visited more than 400 islands in the South Pacific region and eventually returned with more than 40,000 bird specimens, many mammal and plant specimens, and an extensive collection of traditional cultural artifacts and photographs. Using the 75-ton schooner *France*, with many different scientists and collectors participating, the expedition visited islands throughout Micronesia, Polynesia, and Melanesia. Some land-based work was done subsequent to the selling of the decrepit *France* at the end of the expedition. This remarkable two-decade effort was administered by a committee at the American Museum of Natural History and became a focus for attracting funds for research on the biota of the Pacific islands. When Hannibal Hamlin replaced Beck as leader of the expedition, he collected on mainland New Guinea from Yule Island, as well as on the islands off southeastern New Guinea. Ernst Mayr, who had collected in a number of New Guinea localities in 1928–29, joined the Whitney expedition for several months in 1929–30, collecting in the Solomon Islands. The main focus of the Whitney South Sea Expedition in New Guinea was the SE Islands, including the Louisiade, Trobriand, and D'Entrecasteaux islands of the Milne Bay region.

Archbold New Guinea Expeditions (1933–62) Richard Archbold, an adventurous pilot and self-taught mammalogist, led three of the greatest natural history expeditions to New Guinea. As an heir to the Standard Oil fortune, he also was the financial backer of these efforts. Canadian-born Austin L. Rand served as primary ornithologist for all three main expeditions, which occurred pre–World War II. Leonard J. Brass was the lead botanist. The first Archbold expedition (1933–34) worked the hill forests and mountains of southeastern New Guinea, ascending to the high summit of Mount Albert Edward, followed by a visit to the coastal savanna lowlands of south-central New Guinea. This two-part expedition collected 3,400 bird specimens and 850 mammal specimens for the American Museum of Natural History and 2,500 plant specimens for the New York Botanical Garden.

The second Archbold expedition (1936–37) focused on the Fly River and enjoyed the assistance of an amphibious aircraft, flown by Archbold. The team ascended the slopes of Mount Mabiom, on the southern side of the Dap Range, collecting 3,633 bird specimens and 1,857 mammal specimens for the American Museum of Natural History and 2,000 plant specimens for the New York Botanical Garden.

The third Archbold expedition (1938–39) sought to complete a north–south elevational transect of western New Guinea from the lowland swamps of the Idenburg (now Taritatu) River up to the heights of Mount Wilhelmina (now Puncak Trikora). This expedition was conducted in partnership with the government of the Dutch East Indies. Thirty camps were established, ranging from the interior lowlands (Bernard Camp, elevation 49 meters) to the upper slopes of Mount Wilhelmina (Scree valley, at 3,797 meters). The team collected 4,846 bird specimens, 3,486 mammal specimens, 5,331 plant specimens, and ca. 100,000 invertebrates. The expedition also came upon a large population of people in the Grand Valley of the Baliem. These people, the Dani, had never had any contact with the West. The newspaper reports of this first encounter created a worldwide sensation, not unlike the reaction to the first contact with the substantial highland populations in the Wahgi valley by the Leahy brothers in eastern New Guinea a few years earlier (see below). Several smaller, postwar, Archbold-financed expeditions worked in eastern New Guinea but did not include Rand or Archbold and focused mainly on collecting mammals and plants.

Leahy Brothers Expeditions In their quest for gold, explorers Mick, Jim, and Dan Leahy, in March 1933, flew with Len Grabowski into the interior of eastern New Guinea and encountered the abundant and warlike agriculturalists of the interior Wahgi Valley, an area previously thought to be an unpopulated wilderness. Their discoveries led to mineral exploration and missionary penetration, followed by many subsequent zoological expeditions by American, Australian, and European teams.

Denison-Crockett Expedition S. Dillon Ripley served as zoologist for a 1937–38 expedition organized and led by Charis Denison Crockett and Frederick Crockett that combined physical anthropology with natural history surveys of far western New Guinea (NW Islands, Bay Islands, and Tamrau Mountains of the Bird's Head). The scientific team sailed the *Chiva* from Gloucester, Massachusetts, to what was then Dutch New Guinea, spending more than a year in the South Seas. This was Ripley's first overseas fieldwork. He would return to WNG in 1960 with his wife, Mary, and explore the NW Lowlands and Western Ranges, his collections going to Yale University's Peabody Museum of Natural History.

THE PLUME TRADE

Trade in the plumes of birds of paradise began centuries ago, and by 1500 European travelers were reporting on the presence of these plumes in the ornate headdresses of high officials in Turkey and Persia. In Europe, plumes were worn initially by male royalty. It was Marie-Antoinette who led the way for women to display feathers. Plumes in hats and headgear became popular in the 1830s among the wealthy and with time grew to become accessible to the middle class. The popularity of plumes of birds of paradise peaked at the beginning of the 20th century. An estimated 80,000 skins of birds of paradise were exported from New Guinea in 1913.

Trade skins of Raggiana Birds of Paradise (*Paradisaea raggiana*) on sale on sidelines of annual Mount Hagen cultural show. Many highland dancers ornament their headdresses with these orange plumes. Cash sale of plumes of birds of paradise is not legal in PNG, but the law is rarely enforced.

In 1830, in Ternate, Moluccas, M. D. van Renesse van Duivenbode founded a family trading company, later carried on by C. W. R. van Renesse van Duivenbode, which, among other things, obtained rare birds for European buyers—including both cabinet naturalists (collectors of natural history and anthropological curiosities) and plumassiers (dealers of ornamental feathers). The family rarely provided information on where its specimens originated, in order to protect its business. The younger van Renesse van Duivenbode played off the competition between museums, especially that between Lord Walter Rothschild's zoological museum at Tring, England (now part of the British Natural History Museum), and Adolf Bernhard Meyer's ethnographic museum in Dresden. The latter received the King of Saxony Bird of Paradise and Carola's Parotia in 1894. Tring received the Yellow-breasted Bird of Paradise (now placed in the satinbirds) and the Splendid Astrapia in 1895. Duivenbode somehow came into possession of specimens of the mystery-shrouded Golden-fronted Bowerbird in the 1890s. It was not until 1979 that Jared Diamond showed that this species was endemic to the Foja Mountains of western New Guinea. These isolated summits are perhaps New Guinea's most inaccessible upland area. How Duivenbode's team got bird specimens from the Foja Mountains in the 1890s remains a mystery.

The younger Duivenbode's son-in-law, Anton August Bruijn, sent Leon Leglaize to New Guinea in 1873 in search of birds of paradise. Leglaize brought back the Pale-billed Sicklebill and the Jobi Manucode, both species new to Western science. Bruijn's teams worked in New Guinea from 1871 to 1879; the birds he collected now reside in the Natural History Museum at Tring and the American Museum of Natural History in New York.

Aerial view of the Wahgi valley of the Eastern Ranges, showing the tidy geometrical Sweet Potato fields and the planted trees (many Casuarina), with the ridges of the Sepik-Wahgi divide in the background.

The plumes of birds of paradise drove the economy of the island during the colonial era and were also a driver of ornithological exploration. Each year in the first decade of the 1900s, tens of thousands of prepared skins of birds of paradise arrived in Europe and Great Britain. Many new species were collected first by the field teams working for the plume traders. This was recognized by the European cabinet naturalists, who pored over shipments of trade skins in search of novelties. In 1920, it was reported that copra (dried coconut) and bird of paradise plumes constituted the main source of income for Dutch New Guinea. Some of the apparently novel birds of paradise, described as new species at the time, subsequently proved to be rare and interesting hybrids—crosses between two distinct species of birds of paradise.

In 1948, plume trader Archibald Whitbourne met with ornithologist E. Thomas Gilliard at Whitbourne's plantation near Bootless Bay, in eastern New Guinea, and discussed the history of the last years of the modern plume trade in ENG, which continued up to World

War II. He and a local team had visited the forests behind Port Moresby annually in search of birds. In good years Whitbourne would collect 600 to 700 male Raggiana Birds of Paradise, receiving one pound sterling per skin. On the German side of the border to the north, the plume traders were more industrious. Adolf Batze of Lae reported to Gilliard that in a good year he would sell more than 10,000 skins.

Today the plume trade is mainly underground. In ENG there is a small but steady internal trade among rural villagers, with mainly highlanders buying plumes from hill and lowland tribes. Plumes are also sold in roadside markets to tourists. In WNG the trade appears mainly to be for surreptitious export to Southeast Asian countries, but there is also a lively domestic trade. The export trade is probably operated mainly by the Indonesian military, who have ready access to air transport.

THE INSTITUTIONS

Here we review the most important of the Western institutions that have fostered study of the natural history of New Guinea.

Walter Rothschild Zoological Museum, Tring, England The ultimate in natural history cabinets was that of Lord Lionel Walter Rothschild (1868–1937) of England. Born to wealth and privilege in the great European banking family, Rothschild grew to love nature, especially birds and insects. His father built for him a veritable museum on the familial estate in Hertfordshire to house his growing natural history collections, purchased from an array of the best field collectors of the day. Moreover, as a practicing cabinet naturalist, Rothschild employed the very productive bird curator Ernst Hartert and founded his own taxonomic journal, *Novitates Zoologicae*. Rothschild and Hartert studied and described a plethora of novel species from New Guinea. Tragically, to avoid a scandal caused by the threat of blackmail by a former mistress, Rothschild in 1932 sold his collection of 280,000 bird specimens (all but the cassowaries and several thousand birds retained and bequeathed to the Natural History Museum) to the American Museum of Natural History, assuring that museum's preeminence in bird collections from the New Guinean Region. Today the bird collection of the Natural History Museum, formerly in London, is located in Tring on what was the Rothschild estate. It includes a considerable collection of birds from New Guinea, assembled by curators and fieldworkers affiliated with the British Museum of Natural History before its bird collection was translocated to Tring (see below).

American Museum of Natural History (AMNH), New York When in 1932 Rothschild offered his vast bird collection for sale to Leonard C. Sanford, a trustee of the American Museum of Natural History, Sanford approached Gertrude V. Whitney, who provided funds for its purchase to honor the memory of her deceased husband, John Hay Whitney. This was a triumph for American ornithology and, in combination with the productivity of the Whitney South Sea Expedition and the Archbold expeditions, ensured that today this museum has the largest collection of birds from the New Guinean Region. The AMNH has been home to an array of important students of New Guinea ornithology: Ernst Mayr, Austin L. Rand, E. Thomas Gilliard, and Mary LeCroy. This museum also has major collections of mammals, herpetofauna, and arthropods from New Guinea. The major New Guinean plant collections are held at the New York Botanical Garden in the Bronx; smaller collections or duplicates have gone to the Brooklyn Botanic Garden and the Arnold Arboretum of Harvard University.

Natural History Museum, Tring Great Britain's largest museum collection of birds is housed at the Natural History Museum in Tring, on the former estate of Lord Lionel Walter Rothschild. It is home to the second most important collection of birds from the New Guinean Region. This collection was largely assembled by R. Bowdler Sharpe, at the British Museum of Natural History in London, but it also includes the results of two expeditions of the British Ornithologists' Union and the Rothschild bequest mentioned earlier. The collection was moved from London to Tring in 1971.

Rijksmuseum (Naturalis), Leiden, Netherlands Because of the Netherlands' long colonial affiliation with western (once Dutch) New Guinea, the national museum in Leiden houses the third most important collection of birds from the New Guinean Region, and the most important single collection from western New Guinea. It also houses important collections of New Guinean plants, mammals, and arthropods. Naturalists collecting for Leiden included H. A. Bernstein, D. S. Hoedt, and C. B. H. von Rosenberg.

German Collections The natural history museum in Berlin (Museum für Naturkunde) and the Senckenberg Natural History Collections of the Dresden Museum of Zoology also assembled important natural history collections from New Guinea, thanks to Germany's colonial history in the northeastern sector of the island. The German collections were assembled by Anton Reichenow, A. B. Meyer, Carl Hunstein, Carol Wahnes, Erwin Stresemann, and Ernst Mayr, among others.

Bernice P. Bishop Museum, Honolulu, Hawaii The Bishop Museum sponsored a series of small field expeditions to various parts of New Guinea, both east and west, during the period 1967–89. Abid beg Mirza led the most productive of these. Many bird and mammal specimens collected now reside in the vertebrate collections in Honolulu. These bird and mammal collections served as vouchers for the main focus of the museum's field collections—invertebrate ectoparasites (fleas, ticks, lice, flies), which were studied and described by Robert Traub of the US Department of Agriculture, based at the National Museum of Natural History (NMNH; Smithsonian), Washington, DC. In addition, J. Linsley Gressitt, chair of the Bishop Museum's Entomology Department, fostered extensive collection of arthropods from the New Guinean Region and also founded the Wau Ecology Institute in the interior of central ENG (see below). Finally, Pieter van Royen made widespread botanical collections in ENG and WNG and published an alpine flora in 1980–1982,

Australian National Wildlife Collection (ANWC), Canberra Based in Australia's capital, the ANWC is held by the Commonwealth Scientific and Industrial Research Organization (CSIRO). It includes the nation's premier museum collection of birds of New Guinea (more than 10,000 specimens). Most collections come from PNG. The ANWC was

World War II vintage Japanese fighter plane undersea wreck and clownfish attending their protective anemone. Plane wrecks in various stages of decay lie scattered across New Guinea and its offshore waters, from mountain summits to deep sea. Photo: Jürgen Freund/naturepl

formally established in 1976, but its roots trace back to the 1950s. In parallel, CSIRO Division of Land Research carried out surveys of land systems across PNG and lodged major collections of plants with The Australian Herbarium in Canberra. CSIRO was assisted by numerous researchers from the Australian National University's School of Pacific Studies, which pioneered archaeology and environmental studies across ENG.

Zoological Parks and Live Collections There was an intense desire by owners of zoos and menageries in Europe, the United Kingdom, and the United States to obtain living bird and mammal species from New Guinea for display and captive propagation. Alfred Wallace brought two living male Lesser Birds of Paradise to London in 1862. By 1908 the zoo in London owned 10 species of living birds of paradise. Private collections in Great Britain exceeded this number. Walter Goodfellow, Wilfred Frost, Fred Shaw Mayer, and Wilfred Stalker collected many live New Guinean birds for exhibit in England. Chester Zoo, in Cheshire, England, has held important collections of birds of paradise. Lee S. Crandall made an expedition to eastern New Guinea in 1929 to procure live material for the New York Zoological Society in the Bronx. This important zoo obtained 22 species of birds of paradise for its collections during that period. Donald Bruning brought birds of paradise back to the New York collection in the 1970s and 1980s, successfully breeding the Lesser and Red Birds of Paradise. In the 1950s, Sten Bergman collected live birds in New Guinea and kept them in Sweden, where he bred the King Bird of Paradise. The Taronga Park Zoo in Sydney, the Honolulu Zoo, and the Taman Mini Bird Park in suburban Jakarta have maintained important collections of birds from New Guinea, while the Jurong Bird Park in Singapore is perhaps the most successful steward of captive birds of paradise as well as other birds from New

Guinea at the time of this writing. In Papua New Guinea, the Hallstrom wildlife collection at Nondugl was shifted in 1967 to Baiyer River to become the Baiyer River Sanctuary. The sanctuary, which housed birds, mammals, and other vertebrates, was situated on a flat patch of upland rainforest in the valley about an hour's drive north of Mount Hagen town. It prospered under the guidance of the Fred Shaw Mayer, Graeme George, K. David Bishop, and Roy and Margaret Mackay until the early 1980s.

Papua New Guinea Bird Society (PNGBS), Port Moresby The PNGBS, founded in 1965, encouraged bird-watching in Papua New Guinea, primarily by resident expatriates, and published a newsletter, from 1965 to 1997, and a journal, the *Muruk*, from 1986 to 2007. The bird society ceased to operate around 2000, but the journal *Muruk* has continued to be published sporadically in electronic form, thanks to the efforts of field ornithologist and PNG resident Phil Gregory. The two publications constitute the most important source of field observations in eastern New Guinea post-1965. The PNGBS was an important Port Moresby–based institution, and over the years was led by a range of leading field ornithologists: Roy D. Mackay, Harry L. Bell, William S. Peckover, Brian Coates, Brian Finch, Roger Hicks, Mike and Helen Hopkins, and Phil Gregory, who collectively made a substantial contribution to our knowledge of the bird fauna of the region. Bell, in particular, conducted important ecological fieldwork on a bird community in the monsoon forests north of Port Moresby.

Wau Ecology Institute (WEI), Papua New Guinea New Guinea's first independent biological field station was an outgrowth of an entomological field operation initiated in 1961 by the Bernice P. Bishop Museum in Hawaii. Beetle expert J. Linsley Gressitt was the driving force for this effort, which spanned the years 1971–2007. Located on the SE Peninsula in the upland valley of Wau, famous for its 1920s gold rush, the institute served as a base for a number of research biologists who enjoyed ready access to humid forest ranging from 950 to 2,800 meters elevation. The most important research sites were located on Mount Missim (northeast of the station), Mount Kaindi (south of the station) and Abid's Camp on the Bulldog Road, farther south on the wartime track headed toward the central divide and thence into the Lakekamu basin. Various American doctoral students conducted their dissertation field research while based in Wau at the institute. The WEI was also the base for fieldwork by scores of additional field biologists and naturalists. It ceased operation as a research center in the year 2007.

Christensen Research Institute, Papua New Guinea Situated on Jais Aben property north of Madang town, in northern PNG, this institute operated from 1985 to 1997. Founded through the financial support of Diane Christensen and the Christensen Foundation of Palo Alto, California, the station fostered biological field research in PNG, offering a series of paid fellowships for international researchers. Biologists who visited or worked out of Christensen included Paul Ehrlich, Jared Diamond, Luis Baptista, and John P. (Jack) Dumbacher.

Conservation International's Rapid Assessment Program Established in 1990, CI's Rapid Assessment Program ("RAP" for short) sponsors and carries out biodiversity field expeditions to little-known and under-surveyed forests, reefs, and aquatic habitats around the world. The objective of RAP is to provide biodiversity data to decision makers to further the cause of nature conservation. By 2011 more than 60 RAP expeditions had been conducted, leading to the discovery of more than 1,000 species of plants and animals new to science. Forest-focused RAPs to the New Guinean Region have included expeditions to the Lakekamu basin, the Wapoga River highlands, the Mamberamo basin and Cyclops Mountains, the Foja Mountains, and the Kaijende and Hewa highlands and Muller Range. Reef-focused RAPs have surveyed areas in the SE Islands and the NW Islands, proving the global importance of these ecosystems.

Wara Serra Field Station, Papua New Guinea Located east of Haia village in the Crater Mountain ecosystem of central Papua New Guinea, this field station was established in 1990 by researchers Andrew L. Mack and Debra Wright while serving with the Wildlife Conservation Society. Mack and Wright conducted doctoral and postdoctoral field research there, focusing on the ecology of the Dwarf Cassowary. Many other field biologists and local and international students spent time and made observations at Wara Serra. The station closed in 2006.

TODAY AND THE FUTURE

More recently, the pace of natural history fieldwork focused on New Guinea has perhaps not met the rate of the preceding two decades, but the work that has been done has been groundbreaking, especially in the realm of molecular systematics (by scientists using DNA to divine evolutionary relationships among birds) and forest floristics. A combination of diligent field effort and work in the molecular lab has produced fascinating new insights on the evolution and biogeography of the biota of this great island. Advances in satellite data availability are also aiding survey work.

Field study in the New Guinean Region continues through the efforts of lecturers and graduate students from the two universities in western New Guinea—Universitas Cenderawasih (UNCEN) in Abepura and Universitas Negeri Papua (UNIPA) in Manokwari. In eastern New Guinea, field research in the recent past has been conducted by the Papua New Guinea Institute for Biological Research, based in Goroka, which often works with students and faculty at the University of Papua New Guinea in Port Moresby. Biodiversity studies are being carried out by the New Guinea Binatang Research Center in Madang (focused on Mount Wilhelm and the Wanang area of the Ramu valley) and by the YUS Conservation Project (based in Lae and focused on the YUS Conservation Area in the Saruwaged Range to the northwest of Lae).

The New Guinea Binatang Research Center (BRC) originated in July 1997 as a small research project cofounded by Vojtěch Novotny, Yves Basset, Scott Miller, and George Weiblen. The center started small, studying plant-insect relationships in local rainforests. It has grown in the 20 years since into a nongovernmental organization focused on biodiversity research and rainforest conservation, with its own campus, 35 research staff members, Mountain tents under a starry sky in an isolated campsite at Lake Habbema in the Western Ranges. Many opportunities for productive biological exploration remain in the more remote areas of New Guinea.

and typically 10 resident postgraduate students from PNG universities. The center is known internationally for training para-ecologists—research technicians recruited from indigenous rainforest communities. The research is always collaborative with local forest-dwelling communities. It also makes labor-intensive field research highly efficient, since para-ecologists are working in their home rainforest environment. The research based at the center led to a revised estimate of global insect diversity in the tropics, and the center's researchers also have detailed the structure of complicated food webs between plants, insect herbivores, and their predators. More recently the researchers have embarked on the study of biodiversity patterns along key environmental gradients, elevational and successional, in ENG. In the latest development, the center built a 45-meter-tall canopy crane near Baitabag village, allowing researchers ready access to an expanse of forest canopy.

Affiliated with BRC, the Swire Research Station in the Ramu lowlands carries out biodiversity research in a large tract (10,000 hectares) of Ramu River lowland forest, which the village elders of Wanang decided to conserve from logging. It was followed by the forest dynamics plot, a 1.0 kilometer by 0.5 kilometer section overseen by George Weiblen and Vojtěch Novotny, which is part of an international network of large vegetation plots under the aegis of ForestGEO. Joint teams of Wanang-recruited para-ecologists and BRC researchers monitor all of the plot's 288,000 plants with stem size greater than 1 centimeter. These have been mapped, numbered, and identified to one of 530-plus species present in the plot and are measured every five years. Study of this huge data set recently showed substantial tree mortality in the plot during the especially strong El Niño event in 2015, and the data set has also attracted diversity studies on insects, birds, and other research projects.

Another important model initiative is the YUS Conservation Area, managed by the Lae-based Tree Kangaroo Conservation Program (TKCP) with support from the Woodland

Park Zoo in Seattle, Washington. The YUS initiative focuses on conserving the endangered Huon Tree Kangaroo and its critical montane forest habitat on the Huon Peninsula. From its beginnings in 1996 to determine the status of the endangered Huon Tree Kangaroo in the wild, TKCP has evolved into a broad program supporting habitat protection as well as initiatives to enhance local community livelihoods and access to government services. Over the course of more than two decades, the program has grown to support a rural landscape of more than 121,000 hectares on the northern scarp of the Huon Peninsula, ranging from the coastal lowlands to the alpine grasslands of the Saruwaged Range. This area, called YUS because it includes the watersheds of the Yopno, Uruwa, and Som Rivers, also encompasses a large block of montane forest as well as more than 50 villages within the landscape. This is PNG's most successful landscape conservation initiative, all built around an endemic mammal listed on the IUCN's Red List of Threatened Species.

Some of the most important recent field surveys in New Guinea are little known because they have been carried out under the strict oversight of the environment departments of giant mining and petroleum companies. Many of the active biological fieldworkers who formerly conducted RAP expeditions are now participating in these company-driven activities in areas of economic interest to the companies. In these cases, the novel data will slowly be released to the scientific community.

An array of cutting-edge phylogenomic studies has been completed recently on the Papuan avifauna. This has brought the ornithology of New Guinea into the 21st century. The lab-focused molecular systematics aside, there will probably be a diminishing role by visiting international researchers and a growing role by local naturalists and researchers in the future. The major concern is that the relative paucity of resources (travel funds, equipment, funded programs) available to local students and researchers may hamper the field exploration and study of wildlife and forests in the decades to come. The governments of Indonesia and Papua New Guinea would be wise to invest in research and natural history study in order to ensure a strong cohort of conservation-minded naturalists are in place to advise the government on the prudent management of each nation's natural wealth. Collaboration between in-country and overseas researchers will remain the best means of making things happen for years to come.

The threat of growing scientific xenophobia in both Indonesia and Papua New Guinea might further hinder future international collaboration and the needed scientific collection of specimens for museums around the world for curation and long-term archiving and study. Researchers in country and abroad need to push back against the creeping tide of over-regulation that slows the pace of field-based science focused on the natural history of New Guinea. The biodiversity of New Guinea is a storehouse of knowledge that should be shared with the world at large and studied by those far and wide. So little is known, and there is so much to be learned. ■

3 Geology

Landforms, Rocks, and Tectonics

THIS CHAPTER DISCUSSES the tectonic history of the New Guinean Region, New Guinea's surface geology, sedimentology, and geological landforms, and the geological source of New Guinea's mineral and hydrocarbon wealth.*

First it should be noted that both New Guinea and Australia lie atop the northward-shifting Australian tectonic plate. The island of New Guinea looks like a distinct entity on the world map but is separated from mainland Australia by a shallow sea, less than 20 meters deep, that has periodically come and gone over the last million years, as sea levels rose and fell with global climate cycles. Australia and New Guinea were last connected by dry land fewer than 9,000 years ago—one reason their biotas are so similar.

In its present form as a large mountainous island in the tropical Pacific, New Guinea is geologically young. It is the product of the ongoing collision of two moving portions of Earth's lithosphere, the Australian and Pacific tectonic plates. Collision of these plates has produced the rising mountainous New Guinean landmass along the northern margin of Australia. Moreover, as the Australian Plate moved northward, New Guinea was formed by the accretion onto Australia's northern plate margin of a series of island arcs, microplates, continental fragments, and ophiolitic rocks. These historically distinct tectonic components now constitute the north coastal mountains east and west, the northern Bird's Head, the Huon Peninsula, and the northern flanks of the central cordillera and of the SE Peninsula. These all came together in the Tertiary (65–2.58 mya) or later, and New Guinea in its present form is no more than 5 million years old. Today, New Guinea's central cordillera and

Preceding pages: These extraordinary karst islands and convoluted peninsulas were formed by uplift and erosion of the western part of Waigeo Island known as Kabui Bay, in the Raja Ampat Islands.

Opposite: Tertiary deepwater sediments are exposed in the high alpine zone of Puncak Trikora (Mount Wilhelmina) of the Western Ranges. These show that the central cordillera of New Guinea is formed from marine rocks plowed up, compressed, and raised by a northward-moving Australian Plate.

* This chapter is informed by the following references: Baldwin et al. (2012), Davies (2012), Polhemus (2007), Löffler (1977), and others cited in the references section

north coastal ranges continue to rise, and active volcanos periodically erupt off the north coast of north-central ENG and on the northern margin of the SE Peninsula. This is a land of very active geological processes.

Many aspects of New Guinea's topography indicate geological youth: rugged high peaks of marine sediments, ungraded rivers, V-shaped valleys, waterfalls, cliffs, and frequent land slippage. This unstable topography makes road building difficult and frustrates regional development. The island is highly mountainous, with 66 percent of the land area more than 300 meters above sea level, and 14 percent higher than 1,500 meters. The central cordillera, which forms a chain that runs unbroken from the far southeast to the Bird's Neck, has only a few passes as low as 1,500 meters. Furthermore, in several regions, the cordillera broadens into a series of parallel ranges separated by high, flat, and agriculturally productive intermontane upland valleys. To the west and north of the central ranges are 21 outlying ranges of varying heights and extents—all the product of tectonic accretion of exotic terranes and collision of plates and microplates.

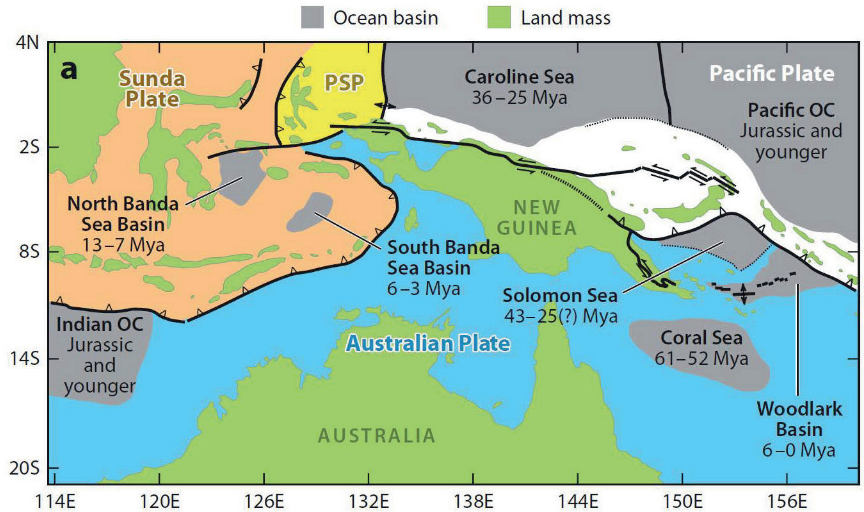
Although mountains dominate geographically, lowland regions are extensive. The four great river systems of the Fly, Digul, Sepik, and Mamberamo (including the Tariku, Taritatu, and Van Daalen) meander through broad humid floodplains that are vast mosaics of forest, swampland, and inundated grassland. The Sepik-Ramu and Mamberamo basins mark the separation of the recently accreted island arcs from the older (Paleocene, 66–56 mya) arcs that were accreted to the northern flanks of the central cordillera.

To the north and east of New Guinea, the waters are deep, with trenches off the south of New Britain plunging to 9,519 meters. These northern trenches are tectonic subduction zones, where one lithospheric plate is underthrust beneath the other. The seas to the south and west of New Guinea are shallow, mainly with depths of under 100 meters. In geologically recent times, when sea levels fell, land bridges connected the New Guinean mainland to five of the large satellite islands (Aru, Misool, Salawati, Batanta, and Yapen) as well as with Australia.

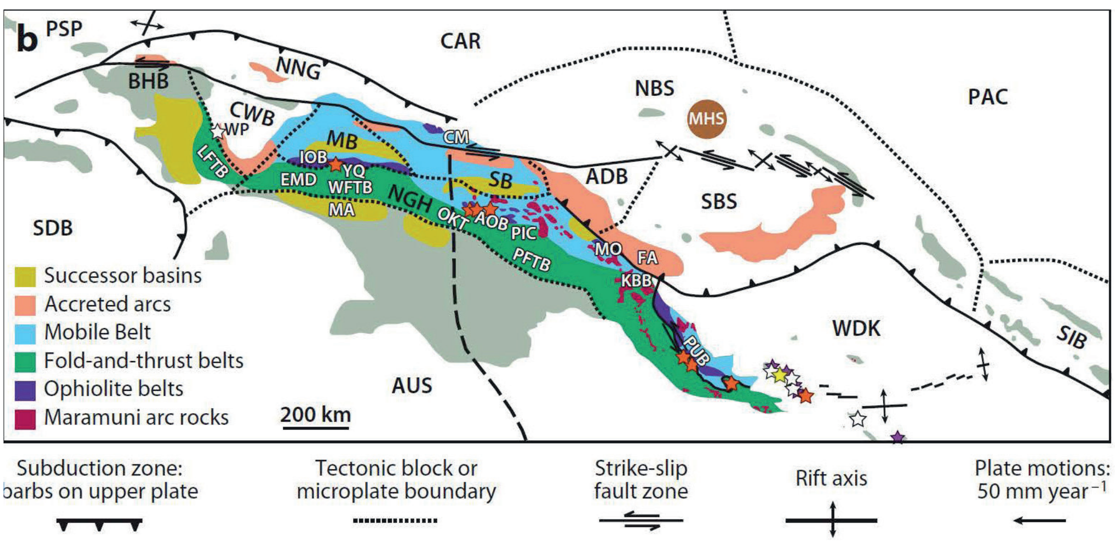
Today, small ice caps top Puncak Jaya (Mount Carstensz). The ice caps of Ngga Pilimsit (Idenburg Top), Puncak (Mount) Mandala, and Puncak Trikora (Mount Wilhelmina) disappeared late in the last century. The remaining mountain glaciers of western New Guinea will disappear as the climate warms. New Guinea featured extensive glaciation in the Pleistocene. During the last glacial maximum, about 20,000 years ago, the snow line was as low as 3,500 meters. Today a hiker to the higher mountain regions of New Guinea can see glacial lakes, headwalls, and moraines—evidence of an icy past in this equatorial region. The island of New Guinea is the perfect place for the field geologist or naturalist wishing to experience, firsthand, the diverse wonders of past and ongoing Earth processes.

TECTONIC HISTORY

The Australian Plate was formerly known as the Indo-Australian Plate. Recent studies indicate that the Indian and Australian tectonic plates have exhibited separate histories for at least 3 million years. Australia began to rift from Antarctica 85 million years ago, entirely separating by 30 million years ago. Since that latter period of time, Australia has shifted ca. 30 degrees of latitude to the north-northeast. New Guinea itself has been molded by the more recent interaction between the northward-moving Australian Plate and the larger, westward-drifting Pacific Plate, several affiliated microplates, and the Banda Arc, the Sunda Plate, and the Philippine Sea Plate in the far west. The microplates, which include the Caroline, North Bismarck, Adelbert Block, South Bismarck, and Woodlark, have been compressed against the northern margin of the Australian Plate from the Cretaceous period (146–66 mya) onward. As a result of these complex plate interactions, the northern half of New Guinea now consists of a composite

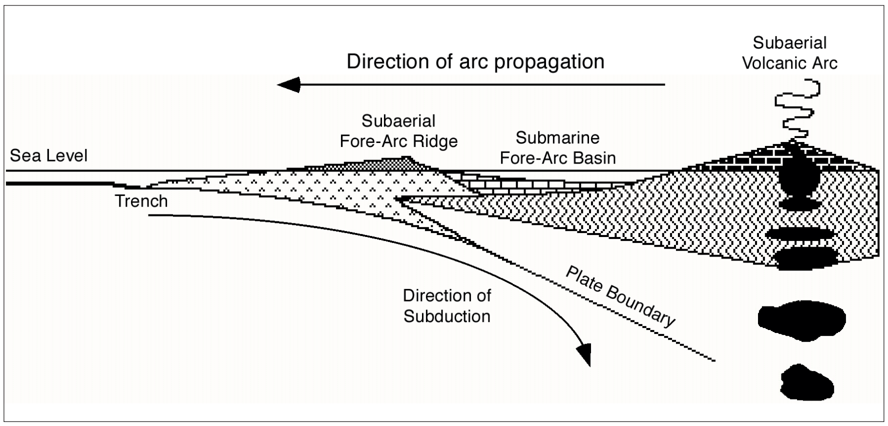


Above: Disposition of tectonic plates, landmasses, and ocean basins in the New Guinean and Australian regions. PSP=Philippine Sea Plate; OC=oceanic crust. Image courtesy of the Annual Review of Earth and Planetary Sciences and Suzanne Baldwin



New Guinea's geological landscape. Abbreviations: ADB=Adelbert Block, AOB=April ultramafics, AUS=Australian Plate, BHB=Bird's Head block, CM=Cyclops Mts., CWB=Cenderawasih block, CAR=Caroline Microplate, EMD=Ertsberg mining district, FA=Finisterre Arc, IOB=Irian ophiolite belt, KBB=Kubor & Bena blocks, LFTB=Lengguru fold-and-thrust belt, MA=Mapenduma anticline, MB=Mamberamo basin block, MO=Marum ophiolite belt, MHS=Manus hot spot, NBS=North Bismarck Microplate, NGH=New Guinea highlands block, NNG=North New Guinea block, OKT=Ok Tedi mining district, PAC=Pacific Plate, PFTB=Papuan fold-and-thrust belt, PIC=Porgera intrusive complex, PSP=Philippine Sea Plate, PUB=Papuan ultramafic-belt ophiolite, SB=Sepik basin block, SDB=Sunda block, SBS=South Bismarck Microplate, SIB=Solomon Islands block, WP=Wandammen Peninsula, WDK=Woodlark Microplate, WFTB=Western fold-and-thrust belt, YQ=Yeleme quarries. Image courtesy of the Annual Review of Earth and Planetary Sciences and Suzanne Baldwin of ca. 30 exotic terranes that have accreted to the Australian continental craton at various times over the last 30 million years, and the boundary of the Australian Plate lies just south of the central cordillera in central New Guinea today. The zone of contact north of the central cordillera is perhaps the most geologically complex on Earth. As S. L. Baldwin, P. G. Fitzgerald, and L. E. Webb (2012) write about it: "[New Guinea's] geodynamic evolution involved microplate formation and rotation, lithospheric rupture to form ocean basins, arc-continent collision, subduction polarity reversal, collisional orogenesis, ophiolite obduction, and exhumation of (ultra)high-pressure metamorphic rocks." These tectonic processes have been critical in producing the mineral and petroleum riches now being harvested across the breadth of New Guinea.

In the interaction between the Pacific and Australian Plates, the Pacific Plate is shifting west-southwest with respect to the Australian Plate at a rate of ca. 110 millimeters a year, with a convergent component of ca. 70 millimeters per year across the New Guinean Region. The Pacific Plate is Earth's largest and is 180 million years old. The Australian Plate includes the Australian continent, the Lord Howe Rise, the Norfolk Rise, parts of western New Zealand, and surrounding ocean basins such as the Coral Sea. The remnants of various microplates and island arcs lie between the two plates north of New Guinea, and the interaction between the major and minor tectonic components is very complex from northwest to southeast. The Sorong Fault (also called the Yapen-Tamrau-Sagewin Fault), a long strike-slip fault (where the two plates move horizontally relative to each other), ranges from the sea north of the current Adelbert Mountains westward along the northern margins of the north coastal ranges and Yapen Island through the top of the Bird's Head just south of the Tamrau Mountains and in the water gap between Salawati and Batanta Islands.



The island arc scenario in simplified cross section. The subducting plate is on the left side of the figure and the overriding plate on the right. As the subducting plate slides under the overriding plate, sediments are scraped off of its upper surface and accumulate to form the fore-arc ridge. As the plate continues to subduct more deeply, it melts at depth to form magma, which rises upward and erupts through the overriding plate to create a volcanic arc. A submarine fore-arc basin lies between the fore-arc ridge and the volcanic arc (Polhemus 2007, 140). Image courtesy of Dan Polhemus; originally reproduced in *Ecology of Papua* (Marshall and Beehler 2007)

The seafloor is spreading at the southeastern tip of New Guinea (witness the split "tail" of easternmost New Guinea forming Milne Bay). The spreading expands as one travels east-northeast toward the central Solomon Islands—where one finds the most rapidly extending active rift system on Earth, the Woodlark Rift. The northern side of the Woodlark Microplate is diving under the South Bismarck Microplate, forming the New Britain Trench. The complex interactions between the northern edge of the Australian Plate and the various island arcs and microplates associated with the moving Pacific Plate create the kind of tectonic and seismic activity that characterizes the entire Pacific Ring of Fire, named as such because of the presence of active volcanoes and earthquakes along such areas of subduction. The most important feature in this collision is the island arc.

Island Arcs Chains of volcanoes formed at convergent plate boundary zones when oceanic lithosphere is subducted beneath continental lithosphere, island arcs display a pattern of features, beginning with a trench along the leading edge of the arc where one plate dips beneath the other. This is followed in turn by a fore-arc ridge, which represents the crest of a wedge of tectonic debris scraped up by, or stuffed beneath, the overriding plate. Behind the fore-arc ridge is a shallow fore-arc basin, separating the ridge from a parallel volcanic arc that forms above the steeply dipping portion of the subducting plate, where partial melting leads to rising magma that powers the volcanic action. We can see components of island arc systems in the region. For instance, note the line of active volcanoes forming a graceful northwest-to-southeast arc that forms islands in the Pacific ranging from the north coast of ENG to the north coast of New Britain. This arc's back-arc basin, in the northern Bismarck Sea to the north of the line of volcanoes, is a site of active seafloor spreading. To the south of New Britain is the deep trench that is the site where the Woodlark Microplate subducts under the South New Britain Microplate. Because of the complexity of the interaction of oceanic crust and continental crust in the New Guinean Region, not all the classic components of the island arc are readily visible.

NEW GUINEA'S GEOLOGICAL PROVINCES

New Guinea was formed by contact and compression when the northward-moving Australian Plate contacted the Pacific Plate and associated microplates and island arcs. Portions of what is now New Guinea rose above the sea, and some accreted terranes have remained dry land for possibly as long as 70 million years (though most are much younger). These have been incorporated into the body of today's New Guinea, and presumably contributed colonizing flora and fauna to the great island. Modern New Guinea achieved an elevation of 2,000 meters by 8 million years ago. Mountain building may have reached 4,000 meters elevation by 5 million years ago. This period included magmatic intrusion and substantial strike-slip faulting. Plate tectonic and mantle processes continue to this day, as New Guinea continues to evolve as a substantial mountain province. What we see today includes three major tectonic zones from south to north, described below.

Australian Craton The Australian craton is the stable and seismically and tectonically inactive expanse of earth's crust sitting atop the Australian Plate. This craton encompasses the southern half of New Guinea and is characterized by undeformed sedimentary rocks, mainly of Triassic age (252–201 mya), overlaying a basement of Precambrian (before 541 mya) rock. The northern margin of the craton remained passive and undeformed into the Cretaceous period. During this period, most of the craton was undersea, except for a north–south ridge (the Tasman Line) that extended to present-day border ranges of the north coast. This ancient ridge has produced the east-west drainages of New Guinea's major catchments that are visible today (the Sepik and Fly flowing eastward, the Taritatu and Digul flowing westward). To the east of the line are Phanerozoic (541–0 mya) sediments

Rural villagers traveling cross-county on a walking track, part of the network that crisscrosses the YUS uplands area of the Huon subregion of ENG. Notice the mix of coarse grasslands, regenerating forest, and old-growth forest (darkest patches in the highest areas). Also notice the grass airstrip in the lower right background. The YUS area is in the Saruwaged Range, one of the fastest-rising mountain systems on Earth—and, due to that speed, one of the most rugged landscapes in New Guinea.

and to the west older Precambrian sediments. The Darai limestone of Oligocene–Miocene (30–15 mya) age that underlies the Kikori River basin also formed as a coastal carbonate platform banked against the eastern flank of this north-south ridge. It rests on top of Cretaceous shales. The Bird's Head during this period was a detached fragment of Australian craton that separated in the Mesozoic (240–66 mya). Other fragments separated in eastern New Guinea, including a portion of the SE Peninsula. The Fly Platform is the most obvious component of the Australian craton in New Guinea today. This is a broad stable shelf of terrestrial clastic sediments lying over limestone deposits.

Fold Belt The fold belt lies just to the north of the Australian craton and includes Australian sediments compressed, folded, and uplifted by the early Cenozoic (which began ca. 66 mya) arc collision, presumably resembling what is happening today on the northern margin of New Guinea. The fold belt is, in essence, the bulk of today's central cordillera, and is made up of cratonic rocks and accreted island arc remnants with some intrusive volcanics. The highest summits of the central cordillera expose rocks of the Australian craton deformed by several episodes of island arc collision during the Tertiary. The very highest summits of New Guinea are uplifted marine limestone. This is similar to the condition seen along the southern margin of Asia, where the summit of Mount Everest, the highest on Earth, is also Tertiary uplifted marine limestone.

Mobile Belt To the north of the fold belt lies the mobile belt, comprising accreted arc terrane material sutured onto the Australian Plate by the collision with the Pacific Plate and associated microplates during the middle Tertiary. These uplifted sediments, which range from the Tamrau Mountains in the far west (Bird's Head) to the Foja Mountains, Bewani Mountains, Adelbert Mountains, and mountains of the Huon Peninsula, are separated from the central cordillera by a series of distinct lowland transform fault basins ranging from northwest to southeast—Mamberamo, Sepik, Ramu, Markham. They have also been extensively sliced and sheared along the northern margin of the central mountains by strike-slip faulting, which has currently taken the place of direct subduction in accommodating the motion between the Australian and Pacific Plates.

MOUNTAIN BUILDING

Mountainous New Guinea evolved through two major episodes of plate collision. The central cordillera was elevated to its current position by 5 million years ago through collision with several island arcs, oceanic plateaus, and microplates. The set of north coastal ranges, from the Tamraus east to the Finisterre and Saruwaged Ranges of the Huon, are island arc terranes that have been elevated to their current position in the last million years. The mountainous Huon Peninsula (the Finisterre Arc) is reputed to feature one of the fastest-rising mountain ranges on Earth, uplifting at a rate of ca. 3 millimeters per year.

VOLCANISM AND VOLCANIC ERUPTIONS

Modern Volcanism Today, volcanism is found only in eastern New Guinea's northern margins and SE Peninsula, in association with plate contact with island arcs or obducted seafloor. Active volcanoes appear in two places along the northern edge of Australia–New Guinea. The first is in a curving line from Vokeo Island (just offshore from Wewak, northwestern ENG) southeastward to the north shore of New Britain and east-northeastward to Mount Ulawan on the north coast of east-central New Britain. Between these two endpoints lie more than 19 active or recent volcanoes in a graceful curving arc of islands. The second is found along the northern coast of the eastern sector of the SE Peninsula. Its products include Mount Lamington, an active stratovolcano, the Hydrographer Mountains volcano, much like Lamington but extinct, the Managalase Plateau complex of volcanic centers, and Sesara volcano. Farther southeast stand Mount Victory and Mount Trafalgar, as well as Waiowa volcano, at the foot of the Gorupu Mountains. These southeastern volcanoes range in age from 5 million years old to recent.

Volcanic eruptions produce ashfalls that generate fertile soils but also threaten communities downwind of the eruption. The 1951 eruption of Mount Lamington, just south of the town of Popondetta, known for its Oil Palm plantations, was infamously destructive. At the time, the numerous local and expatriate residents of Popondetta did not even rec-

Observers offshore from erupting Manam volcano on 8 December 2018. Manam Island is one of the active volcanoes strung in a line along the north shore of ENG. Photo: Jhay Mawengu, Royal Papua New Guinea Constabulary. Courtesy Smithsonian Institution Global Volcanism Program

ognize Mount Lamington as volcanic. It erupted without warning. The eruption, geologist Ernst Löffler (1977) writes: "included catastrophic nuées ardentes—explosions producing deadly hurricanes of incandescent volcanic ash lubricated by the gases given off by the ash and exploding lava fragments. Within minutes all living matter in the area of some 223 square kilometers in the vicinity of the volcano was destroyed, and there was no escape for the 3,000 people living there." Ashfalls reached the capital, Port Moresby, 120 kilometers southeast across the high Owen Stanley Range. Buried ash sequences suggest this volcano has been active for more than 100,000 years.

The last major eruption of Long Island (just north of the Huon Peninsula), in ca. 1700, ejected a volume of ash equal to that of Krakatoa and created a "time of darkness" recorded in traditional histories of a number of New Guinean traditional societies that lay under the ash plume. Geologist R. J. Blong has written about the detective work that went into reconstructing the events, which took place without any Western eyewitnesses and were recorded only in the New Guinean oral tradition. Village stories speak of three days of darkness, during which heavy ashfall destroyed gardens and other vegetation, leading to widespread famine and death in many ENG highland areas southwest of the eruption. These devastating events were recorded in the oral tradition by societies as far as 240 kilometers from the volcano.

Ritter Island, some 30 kilometers east of Long Island and near the western tip of New Britain, suffered a catastrophic collapse of its main volcanic cone in 1888 that essentially obliterated the island and launched tsunamis as much as 14 meters high, which struck the New Guinea coastline along the Huon Peninsula and elsewhere, drowning many people.

The ashfall, however, was not nearly as substantial and widespread as that produced by the Long Island eruption.

Pleistocene Volcanism A cluster of now-dormant volcanic peaks in central ENG were active in the Pleistocene. These include Mount Giluwe, Mount Kerewa, Mount Ialibu, Mount Hagen, Doma Peaks, Mount Karimui, Crater Mountain, Mount Michael, Mount Bosavi, Mount Favenc, Mount Duau, and Mount Murray. All appear on the northern side of the spine of the central cordillera except the last four, which are clustered in the southern foothills of the central cordillera. Dates derived by the potassium-argon (K-Ar) method from Mount Giluwe indicate its last main eruption may have been 200,000 years before the present. Its repeated lava flows built a dome even higher than Mauna Kea (Hawaii) and 40 kilometers across at its base, reversing the flow of the Wahgi River. There are no modern or Pleistocene volcanoes in WNG; these are found only east of the Tasman Line.

BASINS, MAJOR FAULT LINES, AND EARTHQUAKES

Basins and associated fault lines in the New Guinean Region delineate the front edge of the Australian Plate and the point of contact between the advancing plate and the accreting arcs and microplates to the north.

Mamberamo Basin This lowland, in the northern sector of WNG, lies to the south of the arcing Van Rees and Foja Mountains and the northern flanks of the Western Ranges of the central cordillera. This is a successor basin filled with sediments cast off the northern scarp of the central cordillera.

Aerial view of the mighty Mamberamo River, flowing through foothills just west of the Foja Mountains and just north of the main Mamberamo basin, of the NW Lowlands. Photo: Bruce Beehler

Sepik-Ramu Basin The eastern counterpart of the Mamberamo basin, on the eastern side of the Tasman Line, the Sepik-Ramu basin is hemmed in by the ENG north coastal ranges to the north and the Eastern Ranges of the central cordillera to the south.

Ramu-Markham Fault This fault aligns with the subduction zone where the Australian Plate dives underneath the Adelbert Block and the Finisterre Arc and extends eastward into the Huon Gulf and the Solomon Sea to form the boundary of the Woodlark Microplate.

Sorong Fault Also called the Yapen-Tamrau-Sagewin Fault, this left-lateral strike-slip fault extends along the northern fringe of today's New Guinea, defining the boundary between the North Bismarck Microplate and the Adelbert Block in the far east. It ranges westward north of the north coastal ranges of ENG and the Foja Mountains of WNG and along the northern fringe of Yapen Island, the southern scarp of the Tamrau Mountains of the Bird's Head, and the Sagewin Strait, which separates Batanta Island from Salawati Island.

Earthquakes Earthquakes rock New Guinea's northern margins with regularity. These are mainly associated with and concentrated along the great fault lines that range from the Sagewin Strait in the west to the Ramu-Markham Fault and the Finisterre Arc mountains in the east, and extend east along the length of New Britain and the northern Solomon Islands. New Guinea accounts for a substantial portion of the world's earthquakes. Minor earthquakes and tremors are commonplace, especially near the faults that mark New Guinea's northern margin. A major earthquake in the Torricelli Mountains in 1970 denuded 60 percent of the slopes, exposing bedrock. With New Guinea's abundance of mountain slopes, severe seismic events can seriously impact standing forest. Archaeologist J. P. White noted that such events, combined with ENSO-induced drought and periodic frost, cause major periodic disturbances to the original forest habitat.

Tsunamis When earthquakes take place in waters offshore, tsunamis strike New Guinea. The tsunami of 17 July 1998 at Aitape, PNG, was caused by an earthquake with a moment magnitude of 7.0 and a maximum Mercalli intensity of VIII (severe). The quake lasted 19 seconds, from a depth of 27 kilometers; it occurred on a reverse fault 4 kilometers north of Sera village and caused a large undersea landslide, which generated the tsunami that struck the coast. At Aitape, the main shock was followed, some minutes later, by a loud boom, sounding like thunder. A few minutes after that there came a roaring sound. Three 4-meter-high waves struck the beach between 10 and 25 minutes after the quake. The maximum height of the waves when striking the shore was estimated to be 15 meters. The worst-hit area was a 30-kilometer coastal strip running northwest from Aitape to the village of Sissano. The tsunami killed more than 1,600 people, injured 1,000, and rendered 10,000 homeless. Several villages in the path of the tsunami were completely destroyed and others extensively damaged. The tsunami waves uprooted entire buildings and transported their foundations 45–60 meters. The village of Arop was situated on a narrow spit between the coast and Sissano's lagoon. It was directly in the path of the tsunami and received the worst hit. Legends of earlier calamities have been confirmed by coring near Arop, which indicates earlier tsunamis at 800 and possibly 1,400 years ago.

ROCKS OF AGES

Given the complexity of New Guinea's tectonic history over the past 75 million years, and the interaction of so many distinct lithospheric elements and arcs, it is not surprising that the island features rock of all types and ages, from Precambrian to present. An exploring geologist studying rock facies exposed in stream cuts and other exposures may come upon the full array of Earth's rock types, continental, oceanic, and mantle-derived.

The oldest rocks known from the island are Precambrian basement rock typical of the Australian craton, which underlies much of the southern half of New Guinea west of the Tasman Line. Devonian-Silurian (444–359 mya) marine sediments intruded by Permian-Triassic (299–201 mya) igneous rocks are found on the Bird's Head. Jurassic (201–145 mya) marine sediments appear on the southern scarp of the Bismarck Range of ENG. Jurassic low-grade metamorphics dominate the summit heights of the western Owen Stanley Range. Jurassic ultramafic rocks are exposed on the northern scarp of the SE Peninsula, due east of Wau in ENG. Cretaceous marine clastic sedimentary rocks are exposed in the southern Kubor Mountains of central ENG. Cretaceous basalt and low-grade metamorphic rocks appear on the north coast of the SE Peninsula, southeast of Lae.

Eocene era (56–34 mya) gabbro, an intrusive igneous rock, can be found east of Port Moresby in southeastern ENG. Eocene sediments and volcanics appear farther to the east on the SE Peninsula. Miocene era (23–5.3 mya) limestones reach the surface on the southern slopes of ENG's Eastern Ranges. Miocene marine sediments underlie the Gulf of Papua and parts of the Kikori River basin and are exposed on the southern scarp of the western sector of the SE Peninsula. These sediments today result in spectacular karst topography in the foothills of the western Owen Stanley Range. Pliocene epoch (5.3–2.6 mya) marine clastic sedimentary rocks are exposed on the northern scarp of the Adelbert Mountains of northern ENG and in the Ramu-Markham basin. Pliocene pyroclastics and marine and terrestrial sediments underlie the Gulf of Papua and contribute concentrations of gas and oil to PNG's national wealth. Northeast of Mount Bosavi (an extinct outlying volcano of Pleistocene age) more than 2,500 meters of Pliocene terrestrial sediments dominate. Quaternary era (which began 2.6 mya) terrestrial clastic sediments blanket the Fly Platform of southwestern ENG. Pliocene and Quaternary volcanic rocks abound on the northern slopes of the eastern sector of the SE Peninsula.

Exposures of ultramafic rocks, remnants of Earth's upper mantle, are unusual and particularly well exposed in New Guinea along the northern flanks of the central cordillera, the Cyclops Mountains, north of Lake Trist, and the Ajule Kajale Range. They form the base of ophiolites that together with oceanic crust have been pushed upward and over an existing emergent landmass in the course of tectonic collision in which oceanic lithosphere is overthrust above continental lithosphere (plate obduction). They are typified by exposures of serpentine minerals and have an unusual chemistry often high in nickel, iron, and magnesium, which makes them poor for agriculture—and able to support only stunted forests of little timber value—but of particular interest to mining companies.

CURIOUS LANDFORMS

Coral Reef Terraces On the northern seaboard of the eastern Huon Peninsula of ENG, more than 20 individual terraces of ancient coral reef rise 600 vertical meters. Known as the "Huon coral staircase," these terraces reveal sea level maxima at ca. 7.5, 30, 40, 60, 85, 107, 125, 140, 185, and 220 thousand years ago. The data accord with rapid ongoing uplift along the coast.

Limestone Topography *Sinkholes* and *caves* are commonplace in many parts of the New Guinea uplands dominated by *doline karst* (limestone) surface geology. They also can appear in volcanic rock (especially as lava tubes). Sinkholes also appear in ultramafic surface rock in the Lake Trist and Bowutu Mountains area of the northeastern upland portion of the SE Peninsula as well as the Cyclops Mountains. There are large areas of karstic landscape scattered along the southern slopes of the central cordillera in the Eastern and Border Ranges of ENG. Bibima Cave in Chimbu Province of PNG was measured to be 500 meters deep—making it one of the deepest caves in the Southern Hemisphere. The Muller Range of the Border Ranges of ENG also features large caves and huge sinkholes, associated with underground river systems. This area includes the Atea Cave, more than 300 meters deep. There are also caves reported from Normanby and Fergusson Islands in the SE Islands region of ENG. In WNG caves are reported from Misool Island, the Bird's Head, the Onin Peninsula of the Bird's Neck, the Baliem region of the Western Ranges, and the Star Mountains of the Border Ranges. A 335-meter vertical sinkhole (Lomes Longmot) has been mapped in the Bird's Head, and a 3.2-kilometer-long cave (Nomonkendik Cave) has been mapped in the Fakfak region of the Onin Peninsula.

Limestone-dominated areas also include *pinnacle karst* and *tower karst*, which has reached its greatest expression in the southern slopes of the central cordillera of central and western ENG. These areas include many variations of karst landforms, some forming jagged and narrow vertically protruding sheets of limestone rising above the forest. Some

Below left: A view looking southward to the grassland-covered "Huon coral staircase"—an age-graded series of coral reef benches serially uplifted on the northern side of the Huon Peninsula (see explanatory text on this page). Photo: Eric Lindgren

Below right: Coastal limestone cave with stalactites, NW Islands. Surface limestone deposits are commonplace across the New Guinean landscape, especially in the NW Islands, the southwestern Bird's Neck, the Bay Islands, and the Southern Lowlands.

of these areas, termed *labyrinth karst*, are essentially impossible to travel though. On northern Biak Island, the forest rests atop eroded limestone that features abundant small, sharp projections that make walking through the forest a challenge. This is also the case in parts of Misool Island.

Mud Volcanoes Known from the NW Lowlands, south of the Van Rees and Foja Mountains (Lake Bira exhibits several), mud volcanoes are areas of active extrusion of mineral-rich muds that rise from a single central vent and have a circular structure. These are associated with the major fault that runs parallel to these ranges.

MINERAL AND PETROLEUM WEALTH

Gold, Silver, and Copper The Ertsberg, Grasberg, Ok Tedi, and Porgera gold and copper deposits all appear to have been created by Miocene-Pliocene volcanic and magmatic intrusions into the New Guinea highlands block, typically located today at it highest elevations. Some of these magmatic rocks contain porphyry copper and gold deposits that are among the most valuable on Earth. All but the Porgera magmatic deposits are similar to arc rocks. The Porgera intrusives are similar to those of basalts of intraplate settings "formed from partial melting of garnet amphibolite in the lower crust" (courtesy Porgera Joint Venture). The Edie Creek lode, near Wau in ENG, has a similar high-cordilleran provenance, and has been continuously worked since the 1920s.

New Guinea today is famous for its giant open-pit gold mines. The first developed was the Freeport mine, which excavated the Ertsberg lode and then the Grasberg lode, not far from the summit of Puncak Jaya (Mount Carstensz). This is one of the highest and most isolated mines on Earth, and the engineering required to tap these riches almost defies imagination. Geologist Jean Jacques Dozy discovered the Ertsberg lode in 1938 while on an expedition attempting to ascend Mount Carstensz. Mining began in 1972 and continues to

Below left: Karst islands southeast of Misool Island (Raja Ampat Islands), with cliffs of deepwater sediments visible. This limestone topography is part of the Misool-Onin-Kumawa ridge, a long limestone anticline representing the deformed margin of the Australian continental shelf.

Below right: A mud "volcano" at Danau (Lake) Bira in the Mamberamo basin (NW Lowlands). This is a product of hydrothermal activity below this basin. Note the rings of successional vegetation surrounding the mud volcano. Photo: Bruce Beehler

The Porgera open pit mine, Enga Province, PNG. This is the largest operating gold mine in Papua New Guinea. Photo courtesy of Porgera Joint Venture

this day. The Grasberg mine is the largest gold mine on Earth and the second largest copper mine. In 2016, this mine produced 28 million grams of gold, 82 million grams of silver, and 482 million kilograms of copper.

The Ok Tedi mine, at the headwaters of the Fly River of western ENG, is another mountain deposit of gold and copper, known as the Mount Fubilan lode. This mine was opened in 1984. BHP Billiton operated the mine until 2013, when it was handed over to the

An isolated interior natural-gas exploration site upstream from Hepa, Gulf Province, PNG. New Guinea presents considerable logistical and social challenges for international companies seeking to extract petroleum or mineral resources from the interior. Photo: Ian Geraint Jones

PNG government as part of the settlement of a lawsuit. By 2005, 8.8 million tons of copper concentrate and 198 million grams of gold had been produced by the mine. The Porgera mine in the northern sector of the Eastern Ranges began harvesting gold in 1990 and continues to operate. Over that time it has produced 454 million grams of gold and 85 million grams of silver. A number of smaller mines extract gold from various deposits, mainly in ENG. Nickel and cobalt are mined from a deposit on the northern foothills of the Finisterre Range of the Huon Peninsula of ENG, in the Ramu nickel mine.

Petroleum and Natural Gas These fossil fuels have been found in economic quantities on Salawati Island (NW Islands), Bintuni Bay (western Bird's Neck), and the southern flanks of the Eastern Ranges of ENG. A consortium led by Chevron pioneered petroleum extraction from the Kutubu-Kikori area of the Southern Lowlands of ENG. Subsequently, allied natural-gas fields were developed by Exxon-Mobil from the upper Kikori (the Hides anticline). These are two of perhaps the largest petroleum/natural-gas projects in the Pacific. Another large project, the Tangguh liquified natural gas project in Bintuni Bay, led by BP, began production in 2009. It is tapping an estimated 800 billion cubic meters of natural gas, which is liquefied by chilling and then shipped to clients in East Asia.

Coal Deposits of coal are known from Gulf Province of the PNG Southern Lowlands, and coal reserves in WNG are being explored by South Asian mining interests.

Throughout New Guinea, hundreds of mineral-exploration leases are held by companies from around the world and are being explored for the next big strike. There is little doubt that in decades to come, many additional extractive projects will draw wealth from the ground in both WNG and the ENG. As with operations in a host of developing nations around the world, the big question is whether these internationally operated mining bonanzas will enrich or impoverish the local societies inhabiting New Guinea. Let us hope it is the former. ■

4 Climatology

Climate, Weather, and Seasons

Preceding pages: Rain or shine, rural women travel cross-country as part of their weekly work regime related to gardening and food provision. Umbrellas are popular in rural New Guinea because of the incessant rains. Photo: Ulla Lohmann

Opposite: A female Ribbon-tailed Astrapia (*Astrapia mayeri*) feeding on the fruit of a *Schefflera* plant in the falling rain at high elevation on Mount Hagen (Eastern Ranges, ENG). Rain is a nearly daily activity high in the central range.

NEW GUINEA'S EQUATORIAL POSITION, its east-west-trending high mountain cordillera, its physical proximity to Australia, its surrounding warm tropical seas, and its position near the eastern nexus of the El Niño–Southern Oscillation (ENSO) waters determines much about the region's daily weather and its annual seasons, as well as its interannual climate variability. The mass of New Guinea itself acts as a global heat engine that influences regional and global climatic patterns. This chapter offers a review of New Guinea's climate system and its role in the greater climate cycles that influence weather through the tropical Pacific.*

New Guinea's equatorial position in the ocean's Western Pacific Warm Pool promotes a warm and humid climate. However, mountains capture much of the rainfall and cause considerable variation in precipitation from site to site. Temperatures range widely, and while hot afternoons are experienced along the coast, frequent nocturnal frosts occur on the higher mountains above 3,350 meters elevation. Note that temperature decreases with increasing elevation, and snowfall occurs above 3,780 meters elevation and accumulates above 4,000 meters. Thus, monthly mean temperatures range from 26°C in Lae (at sea level) to 21°C in Wau (1,219 meters) to 7.7°C at the treeline on Mount Wilhelm (3,841 meters). Daily maximum temperatures along the coast are ca. 30°C–32°C, and the daily minimum is ca. 23°C.

Fog and cloud cover affect the local climate. In many locales, the mornings are clear and bright, clouds form on the mountains by midday, and rain showers often fall in the early afternoon or the late afternoon. Those doing fieldwork in lowland rainforest can feel

* Key sources for this chapter include McAlpine et al. (1983), Prentice and Hope (2007), and other publications appearing in the references section.

the humidity build through the afternoon hours—reaching nearly unbearable levels before the rain falls. The interior of lowland rainforest reaches 100 percent humidity most nights, even during the dry season. In montane regions, clouds often settle on the ridges, and a distinct cloud line forms on the mountainsides. This cloud line is usually at or above ca. 2,000 meters along the central cordillera but occurs at lower elevations (in places, as low as 1,000 meters) in the smaller, isolated ranges such as the low north coastal ranges of ENG. Forest above the cloud line features heavy growth of epiphytes on trunks and limbs of the trees and is thus called "cloud forest" or "moss forest."

Weather varies year to year: one year may have a protracted dry season; another may produce record rainfall. This is in part because New Guinea is strongly affected by the ENSO system, which influences the weather over much of the tropical western Pacific. The ENSO has two distinct active phases. El Niño events bring drought, whereas La Niña events bring persistent rains (most years see neither of these). Temperature shows minor seasonal variation, and there are greater extremes in the dry months, when cloud cover is reduced. The most severe highland frosts occur during the austral winter (July–September). The important determinant of temperature in New Guinea is elevation.

Frost glistens on an alpine grass and herb field. This is common in the height of the dry season (the austral winter). Photo: Bruce Beehler

TYPICAL WEATHER

A typical New Guinea day in an interior valley such as Goroka (ca. 1,500 meters elevation, surrounded by mountains of more than 3,000 meters elevation), in ENG, frequently starts with ground fog at dawn; the fog quickly dissipates to produce a sunny morning. Then clouds build on the nearby mountain summits, and a brief bout of heavy local rainfall follows in the afternoon. Evenings often see mist or clouds settling on nearby mountain summits. These clouds then drop into the interior valleys as the dawn approaches. On some evenings, steady rain begins at dusk and continues through the night. After dawn, the low mists burn off and mid-morning can once again be sunny and clear. Such local circulations are commonplace in the interior rain shadows—places such as Wau, Bulolo, Goroka, Wamena, and Mount Hagen. Along the coast, early afternoon conditions may be hot and humid, whereas at mid-montane elevations, midday temperatures can be delightful and warm with low humidity.

In the wetter and more mountainous areas (Tembagapura, Tari, Tabubil, Wabo, Crater Mountain) on the southern slopes of the central cordillera, some days of the year may be as described above, but many others may be dominated by clouds, mist, and long periods of steady rain, especially at night but also for many hours in the afternoon. This is a gift from the warm and shallow Arafura Sea, which sends abundant humidity northward to the central cordillera.

Of course, New Guinea is large, physiographically heterogeneous, and thus there is no truly typical weather, and microclimates dominate, as they do in the Hawaiian Islands. This is because of the complex interaction of winds, warm coastal waters, and mountain systems.

RAINFALL

New Guinea features some of the rainiest places on Earth. Most localities receive more than 3,000 millimeters of rain per annum and have a rather long rainy season and somewhat brief dry season. In the drier zones, the annual dry season peaks in July-August, whereas in the rainier zones the dry season peaks in January-February. Rainfall conditions in New Guinea are all about locality and physiography and position relative to mountain chains and the sea. A few kilometers can mean the difference between wet and dry conditions. Port Moresby has many sunny days and in some years suffers prolonged drought that threatens peri-urban agricultural production as well as availability of water in settlements.

A rickety footbridge spans a flooding river in the uplands of the Crater Mountain Wildlife Management Area. Heavy rainfall in this area produces sporadic flooding.

Lae, by contrast, has many cloudy days as well as days of persistent rainfall. Port Moresby lies in a rain shadow, and Lae lies at the head of the Huon Gulf in a wet zone, surrounded by a bowl of high coastal mountains that wring the humidity from the warm winds that rise as they come in off the gulf.

Annual rainfall ranges from moderate to very high across the island. For instance, Port Moresby (in a rain shadow) receives about 1,200 millimeters per annum, while the foothills of the Purari-Kikori drainage receive in excess of 8,000 millimeters annually. In general, the highest rainfall occurs in association with mountain scarps, especially foothills of high mountain barriers that catch the precipitation carried in off the warm seas by prevailing winds.

Seasonality In most regions, rain falls regularly throughout the year, though with moderately predictable seasons—when the annual likelihood of drought or abundant rainfall increases. In many regions, most annual precipitation falls between November and March (the northwest monsoon), but in some locales (such as Wewak, Lae, Wabo, Tari, Tembagapura) the greatest rainfall occurs from May to September (when the southeast trade winds predominate), and a lesser peak occurs during the end of the calendar year (during the northwest monsoon). Thus the wetter areas get rain from both dominant wind systems, whereas the dryer areas get rain mainly from the northwest monsoon.

The central cordillera, by blocking interactions with the southeast trade winds, has an important mechanical influence on regional rainfall. The southerly winds strike the southern scarp of the cordillera in the austral winter, and the northerly winds strike the northern scarp of the cordillera during the austral summer, in both cases bringing substantial local rainfall during those periods. In some localities, the positioning of the mountain barriers is such that rain falls during both of these intervals. The rainiest places are on the southern side of the central cordillera, which will capture humidity from the low-flowing southeast trade winds as well as the much higher-traveling northwest monsoon, carrying the humidity across the high central cordillera. In other words, the wettest spots in New Guinea really have no dry season. Some areas show remarkably consistent rainfall, with essentially no evidence of rainfall seasonality (e.g., monthly rainfall for Erave, ENG, from January to December, in millimeters: 304, 330, 330, 279, 279, 254, 330, 304, 330, 304, 229, 304). But such areas are exceptional. In Wau, in a mid-montane valley in east-central ENG, the driest month, June, receives 76 millimeters, and its wettest month, January, receives 229 millimeters.

Rain Shadows Areas of low rainfall created by quirks of local physiography or airflow, rain shadows appear most often along coasts protected from prevailing humid winds by high mountain walls or in interior valleys that receive winds that have already been stripped of their humidity by surrounding mountain barriers. In addition, a large expanse of dry lowlands is found in the southern bulge of New Guinea, far from rain-making topography and adjacent to the relatively dry Australian north. The driest sectors of New Guinea can be found in the NW Islands, the northern Bird's Head, the southern Bird's Neck, the Baliem valley, the Sentani area, the lower Sepik, the inner Mamberamo, several interior valleys in

the east (Bulolo, Wau, Wahgi, Markham, and Ramu), the Trans-Fly, the southern coast of the SE Peninsula, and the northern coast of the peninsula's terminus. These are all highly seasonal areas, with substantial dry seasons, mainly in the middle of the calendar year. The upland sites—Baliem valley, Wahgi valley, Asaro valley, Wau-Bulolo valley—have among the most pleasant climates to be found on the island and are favorable for subsistence crop agriculture (the latter three are famed for their fine Arabica coffee). In ENG, the combination of the nutrient-rich volcanic soils and the strong seasons makes for ideal living conditions. Farmers in WNG, where volcanics are lacking, achieve high productivity through ingenious composting systems, including Casuarina fallows.

Wet Zones Away from the low-rainfall zones, the bulk of New Guinea is wet the year-round, with only minor or unpredictable dry seasons. Within this major wet swath, there are rainfall hot spots. The very wettest zones are on the southern scarp of the central cordillera: south of the highest summits in the far west; south of the Border Ranges in the

Aerial shot looking down onto patchy low cloud over forest in a lower mountain valley in the interior of New Guinea. Ground fog and mist are common, especially in the early mornings.

Snow and sleet fall sporadically upon New Guinea's highest elevations. Photo: George Steinmetz

upper Fly; and south of the Eastern Ranges in the upper Purari catchment. It is also quite wet in the southwest of the Bird's Head, at the head of Cenderawasih Bay, and at the head of the Huon Gulf, around Lae city. The highest annual rainfall recorded from ENG is 8,712 millimeters, in Wabo. In WNG, meteorological data collected by the Freeport mine show that milepost 50 on the Timika-Tembagapura Road, at the base of the southern scarp of the Western Ranges, just south of Puncak Jaya, receives improbable amounts of rain, typically more than 8,890 millimeters per annum, ranging from 6,553 millimeters in a very dry year (1997) to 14,986 millimeters in 2017. This latter number is likely the highest annual rainfall ever recorded on Earth.

TEMPERATURE

Given its position just south of the equator and surrounded by warm seas, New Guinea shows very little seasonal variation in mean daily temperature. The most variation relates to daytime-nightime differences and changes related to elevation. The mean maximum temperature ranges from 32°C to 34°C in interior lowland basins to less than 15°C on the higher summits. Note that the hottest places in New Guinea are not along the coast but in the interior, away from the moderating influence of the seas. The combination of heat and humidity in the lowest areas in these interior basins makes conditions quite unpleasant in the late afternoon of a day without rain.

The greatest seasonal variation in temperature is found in the southernmost zones of the Trans-Fly and the SE Peninsula, where the austral winter shows some impact.

CLOUDINESS AND RADIATION

Certain interior montane sites in the southern catchment of New Guinea are among the cloudiest places on Earth. This can be linked in part to the presence of the Intertropical Convergence Zone, which produces convection that generates cloudiness and rainfall. Some coastal areas (such as Lae, ENG) are cloudier in the morning hours because of the propensity for nighttime rainfall. More areas are cloudiest in the afternoon. Fogs are commonplace in many mountain locations but are uncommon in the coastal lowlands. Some interior basins fog in during the rainy season. Solar radiation is fairly constant the year-round, but the diurnal cloud cover leads to local radiation varying on east- and west-facing slopes because the latter are cloudy when the sun is to the west in the afternoon. This may explain some differences in vegetation.

CYCLONES

Major cyclonic (hurricane-like) systems in the tropical Southwest Pacific typically do not reach New Guinea, but on occasion they strike the SE Islands of ENG or cross the SE Peninsula. Such storms typically develop in western Melanesia in November and April as tropical monsoonal depressions. Most track east and south of the great island. The most recent serious cyclone to strike New Guinea was Cyclone Guba, which arose in November 2007 as a weak low-pressure system in the Bismarck Sea and then crossed New Guinea southward to the Coral Sea, where it quickly rose to category 3. Flooding from this storm caused more than 200 deaths in Oro Province of PNG. Cyclone Annie in November 1967 struck the Louisiade Archipelago, causing deaths and losses of many boats. Cyclone Hannah in May 1972 struck the Tufi area on the north coast of the SE Peninsula.

CLIMATE CLASSIFICATION SYSTEMS

There are several different climate classification systems in use around the world. The Köppen system considers New Guinea to include regions meeting three categories: tropical rainy with no dry season, tropical rainy with a short dry season, and tropical rainy with a distinct dry season. The Holdridge system records representation from the following categories: tropical wet forest, tropical moist forest, tropical dry forest, tropical premontane wet forest, tropical premontane moist forest, tropical lower montane wet forest, and tropical montane wet forest.

MAJOR DRIVERS OF NEW GUINEA'S CLIMATE

The solar energy that strikes Earth is concentrated in the tropics, and the heat generated tends to rise and flow toward the poles. The combination of the heat-generating capacity of the great island of New Guinea with the nearby pool of warm equatorial waters of the surrounding tropical seas creates the energy that is a major driver of the El Niño–South Oscillation (ENSO), which influences weather patterns around the world. The interplay of atmospheric heat and its circulation and of oceanic temperature and its currents is the major driver of climate and weather in New Guinea and the entire tropical Pacific.

The position of the Australia–New Guinea landmass blocks the westward flow of surface waters across the Pacific, creating the largest heat source of the global circulation system—the Western Pacific Warm Pool. This is at the heart of the ENSO. Thus, ocean currents in the Pacific and their interannual variation help create the ENSO cycles that drive rainfall patterns around the world. These are influenced by surface winds and local currents that swirl around the great island. The dominant among these are the South Equatorial Current, the North Equatorial Current, the North Equatorial Countercurrent, the New Guinea Coastal Current, and the New Guinea Coastal Undercurrent. These mainly propagate north, northwest, and southeast of the island. The shallow nature of the Arafura Sea blocks any substantial movement of oceanic waters through the Torres Strait.

An El Niño occurs when the warm pool of surface water drifts eastward to the coast of South America, creating an extensive pool of warm surface water across the tropical Pacific. This is associated with high surface air pressure over the tropical Pacific and a weakened Walker Circulation (the east–west circulation of air in the lower atmosphere in the tropical Pacific, driving the Southern Oscillation of air pressure between the eastern and western Pacific). This leads to drought in the Southwest Pacific and wet conditions on the western coasts of South America and North America. Most famously, El Niño causes the failure of the anchoveta fishery off the coast of Peru, leading to economic losses and the death by starvation of millions of coastal breeding seabirds.

A La Niña occurs when the surface waters of the eastern Pacific remain cool, the surface air pressure is low, and the warm pool is concentrated in the western Pacific near New Guinea. When this occurs, the New Guinean Region is rainy, and drought dominates in the Western Hemisphere. These wet extremes also create threats in New Guinea to village life and the road system across the island—creating washouts and road-blocking landslides.

These Pacific-wide phenomena occur because of the complex and coupled interaction of Pacific surface waters, surface air pressure, trade winds, and the Walker Circulation, the details of which are too complex to explain here. Most years feature neither El Niño nor La Niña. The most extreme of these two phenomena occur only every 50 or 100 years. Some climate scientists believe that global climate warming will lead to more frequent occurrences of these two events.

The El Niño–Southern Oscillation is an irregular Pacific climatic phenomenon. Its periodic impact is huge in the New Guinean Region, which lies near the center of this oceanic system. A major El Niño, which occurs unpredictably every three to seven years, can seriously disrupt subsistence food production on the island, as happened in the New Guinea highlands during 1997–98. The severe drought was associated with heavy frosts at unusually low elevations, killing Sweet Potatoes and other crops, causing local famine. Fires broke out across the island, burning normally wet forests, even at very high elevations.

ENSO aside, the seasons in the New Guinean Region are driven by regional wind systems, oceanic currents, and the major circulation of heat and moisture across the face of the planet and at various altitudes above it. As noted above, heat and moisture converge at the equator (and thus over New Guinea) and rise to great heights and then flow back toward the poles. This major movement of energy and humidity drives much of the region's weather, modified by local wind surface systems that change with the seasons. In its most simplified, a southeast trade wind dominates in southern and eastern New Guinea from April to October, and a northwest monsoon dominates in the north and west from November to March. The interaction between these two dominant wind systems and the complex of mountain ranges on the island determines the climate found in particular locations.

The southeast trade winds are the surface expression of the Hadley Cell, in which high-altitude moist tropical air moves away from the equator and is replaced by drier air at sea level. The southeast trade wind develops in April but is always a relatively shallow system, reaching about 3,000 meters high at its maximum at ca. 5° south latitude in midwinter. It is thus blocked by the central cordillera, so that mountain and northern climates are dominated by local convec-

High-elevation grassland/shrubland with a stand of tree ferns in the morning mist; note heavy dew on spiderwebs.

tion through the southern winter. At this time cloud cover and rainfall along the southern slopes may be particularly heavy.

By October, the southeast trades weaken and the northwest monsoon season commences, lasting until March. At this time equatorial westerly winds develop to a height of 6.5 kilometers and cover New Guinea, bringing widespread rain depressions that last a few days at a time. Rainfall is generally heavier in this season. Frontal and local thunderstorms can develop throughout the year, with cloud heights up to 15 kilometers and very heavy precipitation.

GLACIATION AND PALEOCLIMATES

Two small tropic-alpine glaciers (North Wall, Carstensz) continue to persist atop the highest of the Western Ranges of WNG. Three additional high summits of the Western Ranges formerly featured glaciers in the 20th century; one (Puncak Trikora) disappeared in the 1950s, another (Puncak Mandala) in the 1970s, and a third (Ngga Pulu) in the 1980s. Before the end of the 21st century, New Guinea will be glacier-free.

These remnant glaciers remind us that we are still in an ice age. During the height of this most recent ice age—the Last Glacial Maximum, ca. 24,500–19,000 years ago—New Guinea's highest and most extensive ranges hosted around 5,400 square kilometers of ice caps and glaciers, which extended down to 3,500 meters elevation. Evidence of Pleistocene glaciation can be found in the high regions surrounding Puncak Jaya, Puncak Trikora, Puncak Mandala, the Star Mountains, Mount Kumbivera, Mount Giluwe, Mount Hagen, and Mount Wilhelm, as well as the highest summits of the Finisterre Range, the Saruwaged Range, Mount Albert Edward, Mount Scratchley, and Mount Victoria. Mount Giluwe, an extinct Pleistocene shield volcano with a large high-elevation dome, supported an extensive snowfield encompassing 187 square kilometers and extending to as low as 3,170 meters. In an earlier advance, ca. 60,000 years ago, some of Giluwe's valley glaciers reached 400 meters in thickness. Terminal moraines mark the extent of this snowfield, and recessional moraines mark oscillations in the process of snowfield diminution. Mount Giluwe's ice cap was gone by 9,000 years ago (as were all ice caps on New Guinea). It appears that most but not all of New Guinea's extant glacial features accord with the final Würm or Wisconsinan glaciation in the Northern Hemisphere. In WNG there is evidence of three minor ice advances occurring since 2,900 years ago.

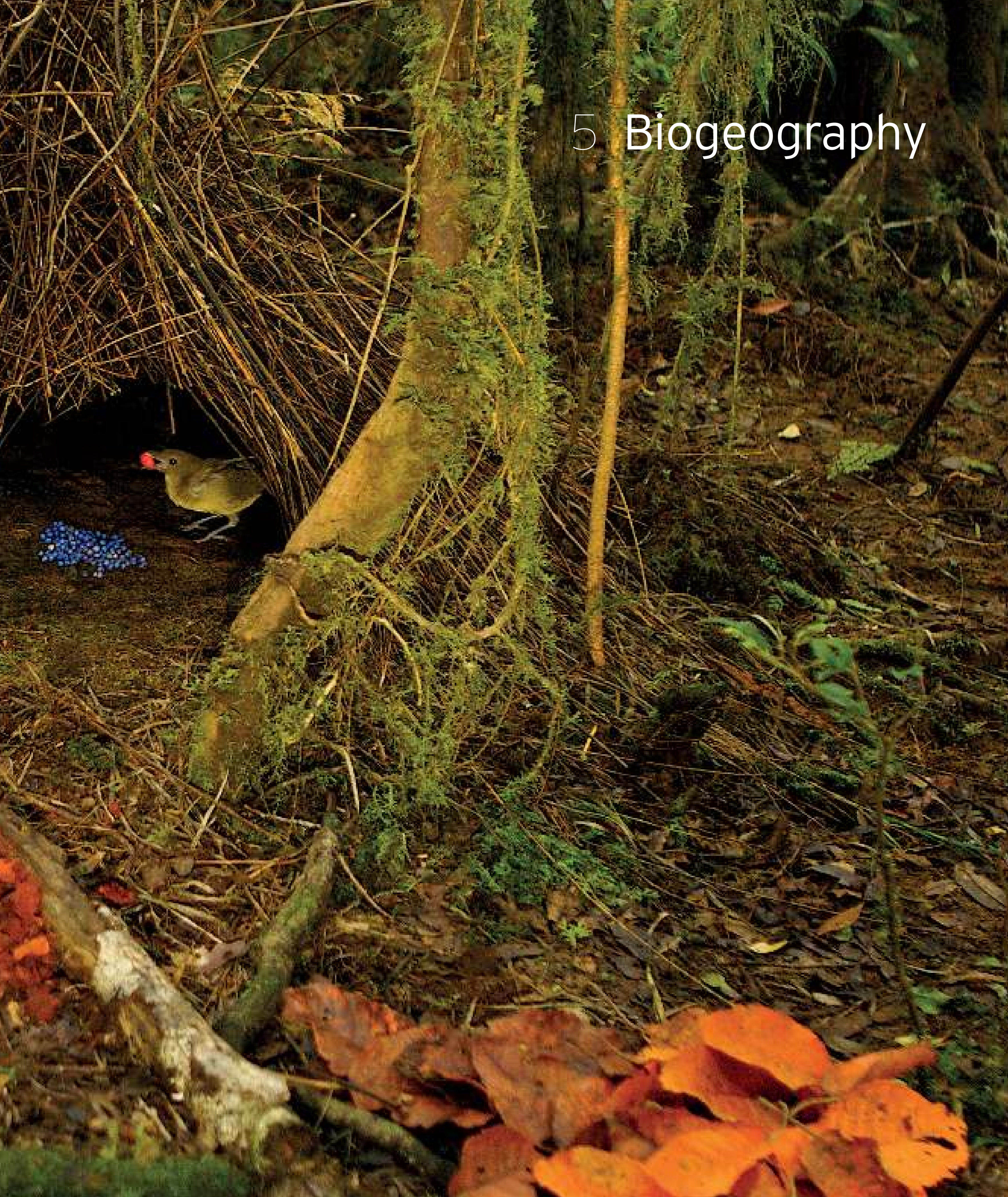
Afternoon weather in the lowlands often produces huge cumulonimbus clouds that generate heavy rains. In Port Moresby, this is most common in the rainy season, evidenced by the verdant vegetation surrounding Papua New Guinea's national parliament building (built to approximate the lines of a Sepik spirit house). Photo: Bruce Beehler

CLIMATE CHANGE

In interviews regarding garden productivity, local rural agriculturalists in the YUS area of the Huon Peninsula (ENG) uniformly reported witnessing a changing climate. These respondents noted that they were struggling to manage agricultural output because of substantial changes in monthly rainfall seasonality and cloudiness. They traditionally initiated new gardens at the end of the dry season, but they now found that this no longer arrived predictably, and that rainfall was scattered through the year in an unpredictable fashion. The burning of high-elevation subalpine forests during severe El Niño events is yet another example of climate change. Finally, malaria is reported from higher elevations as mosquitoes range higher with warming.

Of course, additional and much more high-profile impacts have been reported. For instance, the inhabitants of the Carteret Islands of PNG are being translocated off these low-lying islands north of the tip of the SE Peninsula because of impacts of sea level rise (in tandem with subsidence of the atoll). Expect more and more examples to arise in the decades to come. ■

5 Biogeography



Geography of Life on New Guinea

Previous pages: A male Vogelkop Bowerbird posturing with a red fruit in its mouth inside its tepee bower. The songbirds (passerines) originated in Australia, and the bowerbirds are one of the many passerine lineages that evolved in the region. Australia and New Guinea share this bird fauna.

Opposite: An adult Palm Cockatoo in the canopy of a *Terminalia* tree. The cockatoo lineage is mainly confined to Australia and New Guinea, ranging west into the Moluccas and north to the Philippines but not crossing Wallace's Line into Sundaland.

BIOGEOGRAPHY IS THE STUDY of the geographic distribution of life on Earth. Biogeographers seek to describe the processes that foster the distributions of species, genera, families, and higher-level groupings across the face of the planet. These biogeographic processes include dispersal, the counter tendency to remain sedentary and not disperse, barrier formation that hinders dispersal, isolation, speciation, and species and population extinction. Biogeography seeks to explain why some lineages are widespread whereas other lineages are confined to a small portion of the globe. New Guinea is a fascinating test case of biogeographic principles mainly because of its close tectonic association with ecologically distinct Australia and because of the long geographic isolation of the tectonic plate that carries both New Guinea and Australia.*

New Guinea is positioned at the critical junction between Asia and Australia. The flora and the arthropod fauna of New Guinea show important linkages to South and Southeast Asia (known as Malesian or Indo-Malayan distributions), whereas the mammal and bird faunas are most strongly defined by their Australian roots and show substantial differences from those of Asia. Some ancient lineages, such as the Antarctic beeches and araucaria conifers, exhibit biogeographic links to South America, which hearken back to an undissected Gondwanaland, when Australia, Antarctica, India, Madagascar, Africa, and South America were all part of a single southern continent. Understanding the biogeography of New Guinea is akin to solving a puzzle or unraveling a riddle. A major question is: To what extent have geological processes determined the current composition of New Guinea's

* Sources for this chapter include Beehler and Pratt (2016), Beehler (2007b), Diamond (1972, 1975), Mayr and Diamond (2001), and other publications appearing in references section.

biota versus to what extent have recent migrations and ecological processes determined the content and nature of New Guinea's plant and animal life? This chapter will attempt to address that question, among others.

The chapter will work from the present backward in time to the distant past, first addressing ecological processes and then addressing geological processes, ending with an attempt to synthesis our findings. In this manner, we will work from current and ongoing events and processes in the distributions of animals and plants, and then back into geological time, to include the movements of continents and biotas. In doing so, we will refrain from letting the cart get in front of the horse. Before we do that, however, we will take a quick look at the history of the study of biogeography.

ORIGINS OF THE STUDY OF BIOGEOGRAPHY

The study of the geographic distribution of plants and animals across the globe had to be preceded by the science of naming and classifying Earth's plants and animals. The father of Western taxonomy (the science of classifying and naming species) was a Swede, Carl Linné (Carolus Linnaeus), who created the binomial (two-name) system we still use today. Linné gave the name *Paradisaea apoda*—"the bird of paradise without feet"—to the Greater Bird of Paradise, based on the trade skins he had observed, in which the legs had been removed to create more pleasing head-plumes for wear. *Paradisaea* is the genus name, and *apoda* is the species name. A genus is a grouping that encompasses one or more species. Hence we have *Paradisaea apoda* (Greater Bird of Paradise), *Paradisaea minor* (Lesser Bird of Paradise), *Paradisaea decor*a (Goldie's Bird of Paradise), and so forth. And when we look at the geographic ranges of these three species, we find each occupies a distinct or unique range; closely related species tend not to share the same geographies—a first lesson in biogeography.

The first biogeographer was Alexander von Humboldt, whose extensive travels in the Neotropics from 1799 to 1804 led him to theorize about the distribution of plants and habitats around the world and the importance of climate in determining both habitats and species distributions. The first major global analysis of animal geography was completed by an Englishman, P. L. Sclater, who recognized six major zoogeographic regions, including the very distinctive "Australian Region," which encompassed Australia and New Guinea.

A contemporary of Charles Darwin, Alfred Russel Wallace is considered by many to be the father of modern biogeography because of his major treatises on the subject of animal distributions. Wallace's early ideas about the mutability of species forced the ever-procrastinating Darwin to finally publish his earth-shattering *On the Origin of Species* in 1859. Both Wallace and Darwin are considered the fathers of organic evolution and natural selection. Much of the theories of Darwin and Wallace are based on the idea of evolutionary differentiation across space over time (allopatric speciation). The field of paleontology was blossoming during the mid- to late 1800s, and the recognition of ancient long-extinct floras

This longhorn (or longicorn) beetle is in the family Cerambycidae, which has a worldwide distribution. The entomologist J. Linsley Gressitt posited that several thousand species inhabit the New Guinean region. The white larvae of the larger species are a popular local food, often roasted or steamed in a bamboo tube. The relatively ancient lineages of arthropods and plants show more globally widespread distributions than the relatively younger lineages of birds and mammals.

and faunas distributed across the planet led to the idea of historical biogeography—adding new complexity to the field. Whereas Humboldt saw existing climatic (ecological) conditions as the main determinant of animal and plant distributions, paleontologists could report that floras and faunas came and went with time across the face of the Earth.

The greatest discovery of the earth sciences of the 20th century was Alfred Wegener's vision of the historical mobility of continents—plate tectonics. This was only finally widely accepted by the Western geological establishment in the late 1960s. For traditionalist senior scientists, the idea of drifting continents was simply too radical to accept. Finally the data trove supporting the truth of plate tectonics caused a rapid sea change, and the field of geology embraced it once and for all. And what a boon this was for the biogeographers, who had long struggled to explain, for example, the disjunct range of the fossil fern Glossopteris on either side of the Atlantic Ocean. We now know that those ranges were once continuous, before the Atlantic had rifted apart to create the vast ocean that exists today, seemingly permanent and immobile. Thus biogeography, ecology, climatology, paleontology, and geology were all wedded in the search for the truth about how the plants and animals on earth came to live where they do today.

Most recently, we have witnessed the rise of ecological biogeography, followed by the rise of panbiogeography and cladistic biogeography, leading to a strong synthesis of thinking that combines historical processes over millions of years and ecological processes operating as we speak. The crowning achievement of ecological biogeographers was the creation of the equilibrium theory of island biogeography, discussed in the next section.

ISLAND BIOGEOGRAPHY

Since New Guinea is an island, it is appropriate to have a discussion of island biogeography. Edward O. Wilson of Harvard University and Robert MacArthur of Princeton University in 1967 formulated the equilibrium theory of island biogeography, which sought to explain why islands of differing sizes and differing levels of geographic isolation from a mainland source biota support particular numbers of plants and animals. This work had been stimulated by Wilson's studies of ants in the islands and archipelagoes of the Southwest Pacific. This region hosts tens of thousands of islands small and large—offering Earth's richest natural laboratory on island life. MacArthur and Wilson's foundational theory was subsequently expanded by Ernst Mayr's and Jared Diamond's groundbreaking field studies of bird distributions on the islands of the New Guinean Region, the Bismarck Archipelago, and the Solomon Islands.

In its simplest form, MacArthur and Wilson's equilibrium theory shows that an island that is close to a mainland will have more species than an island that is far from a mainland. And that a large island will support more species than a small island. And that an island with high mountains will support more species than an island with low relief. Wilson and MacArthur hypothesized that these general patterns were a product of a balance between immigration of species to the island and extinction of populations of species living on the island. Near islands received more immigrants. Larger islands support larger and more extinction-resistant populations of more species. High islands support more kinds of habitats than low islands and thus can house more kinds of species with differing ecological niches. And, finally, small islands lose more species to extinction than large islands because of the vulnerability of small island populations.

These insights revolutionized the field of ecology in the 1970s, and the predictions of the theory were confirmed under a wide range of field and experimental conditions. This theory became the core theory underpinning ecological biogeography, which sought to explain the current distributions of plants and animals through the rules of population biology. Ecological biogeography explained small-scale patterns of biotic distribution but did not address the long-term evolutionary issues addressed by historical biogeography (discussed in a following section).

So what does island biogeography have to tell us about today's distribution of plants and animals in the New Guinean Region? It provides several scientific insights worth discussing. These are mainly the result of the work of Jared Diamond, most famous for his book *Guns, Germs, and Steel* but also the author of dozens of technical papers on island biogeography of birds of the Southwest Pacific.

Big Islands versus Small Islands Big islands host more species of plants and animals than small islands. In clusters of islands in an archipelago, there is a direct relationship between island area and species number. Thus New Guinea, the largest tropical island, hosts more breeding bird species than any other large island on Earth. This explains why

New Britain, at 35,742 square kilometers, is home to more bird species (127) than adjacent but smaller New Ireland, at 7,174 square kilometers (103 species), which has more than New Hanover, at 1,186 square kilometers (75 species). Likewise, Umboi Island, at 816 square kilometers, has more bird species (84) than nearby Long Island, at 329 square kilometers (54 species). The functional explanation is that (a) smaller islands support smaller populations of island species, which are more prone to extinction; and that (b) a large island is a bigger target to dispersing species and thus will accrete species over time more effectively than a small island (think of dispersing species as arrows being shot out over the sea from the mainland—the larger islands out in the sea are like larger targets, more easily struck by arrows fired in random directions).

Distant Islands versus Nearby Islands Islands receive their species mainly from some source, typically a large landmass such as a mainland. Islands distant from a mainland support substantially fewer species than islands close to a mainland (when other parameters are held constant). Thus Tagula (Sudest) Island, at 300 kilometers from mainland New Guinea, is home to 60 species of birds, and similar-size Normanby Island, at 26 kilometers from mainland New Guinea, is home to 107 species of birds.

High Islands versus Low Islands In the Southwest Pacific, islands with high mountains support more species than low islands—those without substantial relief. This is so for at least two reasons. High islands are more heterogeneous physically, producing more types of habitat. And because of the lapse rate (discussed in chapter 4), uplands are distinctly cooler, and when an island elevation exceeds 1,000 meters, its uplands support distinct and novel montane habitats, which offer niches for montane-dwelling species. Thus islands with high mountains are considerably more species-rich than low islands. Compare Goodenough Island (area 686 square kilometers; elevation above sea level 2,535 meters) with Woodlark Island (area 793 square kilometers; elevation 241 meters): although Woodlark is larger, as a low island it supports fewer bird species (34) than Goodenough Island (103).

The Blue-capped Ifrit (*Ifrita kowaldi*) is the sole species in a recently recognized bird family (the Ifritidae) endemic to the mountains of New Guinea. The ifrit, like the Hooded Pitohui (*Pitohui dichrous*), possesses toxic feathers and skin to provide chemical defense against predators.

Land-Bridge versus Oceanic Islands Land-bridge islands—those that were linked to the mainland during Pleistocene low sea levels—are home to many more species than oceanic islands (those that never had a land connection to the mainland). This is so for at least two reasons. First, the land-bridge island, before high sea level isolated it, had most or all of the species found on the adjacent mainland (when they were connected). The oceanic island lacks all the species that do not cross salt water (because of behavioral or physiological constraints) as well as some that do cross salt water but have not yet made it to the oceanic island because of the imperfect nature of dispersal. Presumably, on both island types (land-bridge and oceanic) some species that have colonized have subsequently gone extinct.

On the other hand, oceanic islands tend to feature more endemic species than land-bridge islands. This is because of the long isolation of the species populations on an oceanic island. Isolation leads to differentiation and the rise of new species. Land-bridge islands, because they once were part of the mainland, have had limited time for speciation to occur and thus rarely feature endemic species.

Our best comparison of a land-bridge island versus an oceanic island in the New Guinean Region is Biak Island (oceanic) and Yapen Island (land-bridge). They lie adjacent to each other in the Bay Islands area of WNG. Biak Island (including adjacent Supiori) is 2,455

The high-elevation tropic-alpine vegetation of New Guinea's central cordillera supports a number of alpine plant genera that also occur in far-flung mountain ranges of Europe and North America, such as this cinquefoil (genus *Potentilla*) from Lake Habbema (Western Ranges). These sorts of disjunct and widespread distributions have puzzled biogeographers.

square kilometers, and Yapen Island is 2,328 square kilometers. Biak-Supiori has 97 bird species, and Yapen has 131 bird species. Conversely, Biak has 7 endemic bird species and Yapen has zero. Yapen has a number of bird species that do not cross salt water (Green-backed Robin, Hooded Pitohui, and King Bird of Paradise), whereas Biak has none of these.

Tramp Species versus High-S Species In the Southwest Pacific, not all species are alike in their ability to colonize islands and to survive on the mainland. Diamond, studying birds, found that there are species that preferentially inhabit small islands that have relatively few other bird species (ca. 24–40 species); he called these "tramp" species. Examples of tramp species include the Melanesian Scrubfowl, Brahminy Kite, Metallic Starling, and Papuan Cicadabird. Diamond also found "supertramp" species, which inhabit *only* tiny islets with very few species (often as few as 10 species). Examples of supertramp birds include Floury Imperial Pigeon, Islet Monarch, Louisiade White-eye, Sclater's Myzomela, and White-chinned Myzomela. The world range of the Islet Monarch is a welter of small islands scattered around western, northern, and southeastern New Guinea—but only in a very few locations (along the north coast) has the species been recorded on the mainland of New Guinea. The fruit bat *Dobsonia pannietensis* exhibits a similar distribution—commonplace on offshore islands and absent from the adjacent mainland of New Guinea. These are island specialists—species that have evolved to prosper on small islands that are relatively species-poor. One explanation is that they are ecological generalists that have a broad niche and limited ability to deal with the competitive world of mainland rainforest faunas, with many species and lots of diffuse competition. The mechanisms that determine these curious distributions need study.

Diamond also recognized a cohort of species—some of which are found only on mainland New Guinea and others that have successfully colonized only large and high islands with many other species—that he called "high-S species" ("high-S" refers to a high number of species in the location's avifauna). These include the birds of paradise and the bowerbirds, which are found only on large and mountainous islands on and near New Guinea. It appears the high-S species need complex forest environments to become successful colonists of an island, whereas the supertramp species require small islands with simple habitats and few other species. Needless to say, these categories will benefit by much further study in the field.

Virtual Islands—Mountaintops Building on the island model, ecologists quickly adapted the theory of island biogeography to terrestrial settings, to "islands" of distinct habitat that are surrounded by large expanses of another type of habitat. These include mountain environments and are especially relevant in the tropics, where elevationally defined humid forest habitats can be found isolated high up on a mountainside or atop a mountain's summit. Specialized alpine vegetation on an isolated mountain summit will act like an island with respect to the number of alpine species it supports—mediated by distance from a source pool of species of that specialized habitat and by the size of the tundra-like habitat patch on the mountain summit. New Guinea hosts relatively few mountain summits with substantial alpine grasslands or shrublands. These are primarily confined to the highest summits of the SE Peninsula, Huon Peninsula, Eastern Ranges, Border Ranges, and Western Ranges. The last two of these subregions have the most and largest alpine habitats; as a result, most of the endemic bird species that are confined to this high-elevation habitat island are found in the Western and Border Ranges. The species endemic to these two subregions include: Snow Mountain Quail, Short-bearded Honeyeater, Orange-cheeked Honeyeater, Snow Mountain Robin, and Western Alpine Mannikin. By contrast, in the SE Peninsula, the high alpine grasslands/shrublands support but one local endemic—the Eastern Alpine Mannikin.

Climate Change, Mountaintops, and Extinction Combining their knowledge of the impacts of climate change with that of the influences of island biogeography helps conservationists detect threats to localized floras and faunas. For instance, increasing mean temperature in New Guinea has brought about the upslope shift of the ranges of montane birds. This was shown by the recent fieldwork of Ben Freeman and Alexa Class, who compared Jared Diamond's data on the elevational distribution of birds on Mount Karimui in the 1960s with their own recent survey data from the 2010s. The recent distributions tended to be skewed upslope—higher on the mountainside. Upslope movement of ranges typically leads to reduction in the range sizes of species (because high-elevation zones tend to be smaller than lower-elevation zones due to the roughly conical shape of the average mountain). Some mountaintop species may lose their specialized habitat through the impacts of climate change. This could lead to extirpation of localized populations and could threaten species with small ranges. Think of the Snow Mountain Robin, which inhabits only rocky alpine scree above 3,800 meters elevation on a few high summits of the Western Ranges. What will happen to the populations of this and other birds over the next century under a regime of increased climatic warming?

ECOLOGICAL BIOGEOGRAPHY

Ecological biogeography seeks to explain why some habitats support more species than other habitats (so-called beta diversity) and why species live where they do. It largely ignores historical and geological processes, and works in ecological time. In this section, we examine the distribution of plants and animals in New Guinea through this ecological lens.

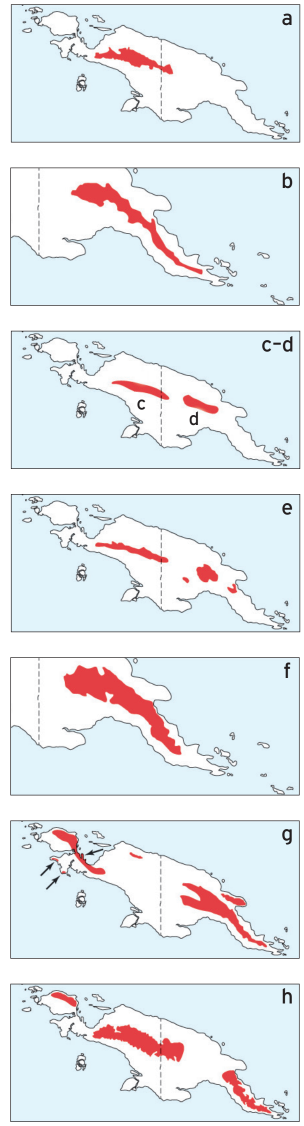
Bridge and Barrier Australia and New Guinea are at once the same and yet are two distinct entities. From geology we know that they both rest atop the same tectonic plate and that as recently as 9,000 years ago, when the level of the sea was substantially lower, they constituted a single expanse of dry land. So why are so many species exclusively either Australian or New Guinean? The answer is probably more ecological than geological. Australia harbors large expanses of savanna and other dryland habitats that support assemblages of dry-country species. New Guinea is home to a large block of equatorial humid forest that supports forest-dependent species. Today, we see a saltwater barrier separating New Guinea from Australia—the Torres Strait and the Arafura Sea—and yet there are many dry-country species whose ranges are widespread in Australia and that also include the southern dry bulge of New Guinea (the Trans-Fly), as if the current saltwater barrier were not there. Avian examples include the Blue-winged Kookaburra, Little Corella, Noisy Pitta, Little Friarbird, Noisy Friarbird, Blue-faced Honeyeater, Black-faced Woodswallow, Australian Magpie, Grey-crowned Babbler, Restless Flycatcher, Rufous Fantail, and Magpielark. This fauna also includes the following savanna-loving mammals: Northern Brown Bandicoot, Agile Wallaby, Brush-tailed Rabbit-rat, Delicate Mouse, Cape York Rat, Canefield Rat, Little Red Flying Fox, Papuan Sheath-tailed Bat, Bare-rumped Sheath-tailed Bat, and Eastern Brown Snake. These species inhabit a broad swath of highly seasonal dry habitat that is sometimes contiguous and sometimes not. Habitat is more important to these species' ranges than an ephemeral saltwater barrier.

We see the same pattern with land-bridge islands—exemplified by Yapen and Salawati Islands in WNG. Large numbers of the rainforest species that inhabit the mainland adjacent to these islands also inhabit the rainforest on those two land-bridge islands. Current high sea level isolates the islands today, but this was not always the case, and these widespread species were able to colonize the land-bridge islands without crossing any salt water.

Diamond's Drop-Out Model of Speciation The humid upland forests of the central cordillera are continuous from west to east, without any perceptible biogeographic barriers to distribution. And yet we see today ranges of montane forest birds that are broken up or incomplete along the cordillera. Look at the abutting ranges of the species pairs Splendid Astrapia/Stephanie's Astrapia and Short-bearded/Long-bearded Honeyeaters. Then consider the puzzlingly restricted ranges of Yellow-breasted Satinbird and Blue Bird of Paradise. Finally, look at the ranges of the Papuan Treecreeper and Black-billed Sicklebill, with the big hole in the middle.

In the first two examples we see closely related species pairs that replace each other geographically along the cordillera. And in the second set of examples, we see single species whose ranges mysteriously occupy only a portion of the cordillera, with one edge of the range coming to an abrupt stop in the absence of any visible physical barrier. Finally, the last two are widespread in the western and eastern sectors of the cordillera and yet absent from the central sector, where ample good habitat exists.

Diamond explained these distributions through his drop-out model of speciation. He argued that because of intense diffuse competition in the forest, species ranges that were widespread and continuous at an earlier time were subsequently dissected, and that some intermediate populations were extirpated from segments of forest by this effect of diffuse competition. For species that were widespread, it caused the range to be dissected into two, allowing for allopatric speciation to take place in the absence of biogeographic barriers. In other species, the population in the eastern or western portion of the species' range died out, and the species was confined to the eastern or western portion of the cordillera. The argument is compelling, but more study is needed to confirm the forces driving the patterns we see in these examples.



Range maps demonstrating Diamond's drop-out model: a. Splendid Astrapia, b. Stephanie's Astrapia, c. Short-bearded and d. Long-bearded Honeyeaters, e. Yellow-breasted Satinbird, f. Blue Bird of Paradise, g. Black-billed Sicklebill h. Papuan Treecreeper. Images courtesy of T. K. Pratt & B. M. Beehler, 2015, *Birds of New Guinea*, 2nd ed., Princeton University Press, Princeton, NJ

Dracula ant (*Amblyopone* species). The details of insular ant distributions in the New Guinean Region and islands to the north and east formed the initial basis for Robert MacArthur and E. O. Wilson's theory of island biogeography. Photo: Piotr Naskrecki

In yet other groups of species in the foothill forest (e.g., Banded Yellow Robin, Painted Quail-thrush), formerly widespread species have seen their expansive ranges broken up into a patchwork quilt, with many gaps in their ranges from east to west. The ecology of the forest and the intensity of competition for resources in the continuous forest have apparently led to species ranges being dissected and patchy.

Elevation Diamond highlighted the importance of elevation in the diversification of local avifaunas. Like a layer cake, a mountain can be divided up elevationally, and each elevational zone can be found to host a distinct bird community. Thus, in New Guinea, the bird community found at 3,400 meters elevation will be almost entirely distinct from that at 500 meters elevation (of the ca. 250 species in the two sample elevations, fewer than 10 species would be found in both). This is true in spite of the fact that the two communities are only 8–9 kilometers apart. This distinction lies at the heart of ecological specialization. One more thing about these elevationally distinct bird communities: These are created not by a series of ecotones or distinct barriers but by an overlay of clinal variation in various physical and biotic features of the environment and by competition from other species along the elevational gradient. And each species reacts uniquely to these factors. Therefore there are no major breaks in faunal communities along the cline—just a gradual appearance and then disappearance of individual species as one ascends the side of the mountain. Moreover, each mountainside will differ to some extent in the pattern of elevational distribution, as different species in the local avifauna react uniquely to the particular conditions on that mountainside.

Species-Pair Competition Diamond also found evidence for direct competition of species along the elevational cline. What he found, which was later amplified by the fieldwork of Ben Freeman, was that closely related songbird species sorted out elevationally and maintained abutting ranges along the elevational transect. Freeman found evidence for direct competition to maintain these nonoverlapping ranges. A similar pattern was found by ornithologists John Terborgh and John Weske in their work in the montane forests of the Andes of Peru. Prime examples of the competing New Guinean species pairs that sort along the elevational cline include Blue-grey and White-winged Robins, Chestnut-backed and Spotted Jewel-babblers, and Black and Dimorphic Fantails.

Other Take-Home Points Here it is useful to take a general overview of the geography of bird distributions across the island of New Guinea. We choose birds as a focus here for two reasons: it is the group the author is familiar with, and it is the best-known group for the New Guinean Region. First, the reader should be reminded that the subregions delineated in chapter 1 and used throughout the book highlight patterns of bird species distributions across the island. We recognize a Bird's Head subregion because a number of bird species are endemic or are largely endemic to that region (several also range into the adjacent Bird's Neck). So a review of our New Guinea subregions gives a sense of the pattern of range distribution for many birds (though many birds inhabit more than one of these subregions).

Here are some other generalities regarding bird geography in New Guinea. In simplest terms, the geography of New Guinea features a long linear mountain range with a ring of lowland habitat encircling the mountains. Thus the montane species tend to exhibit a linear pattern along the mountain cordillera, and the lowland-dwelling species exhibit a "ring" of populations circling the mountain range. German ornithologist Bernhard Rensch pointed out this ring-of-species phenomenon in the 1930s.

Lowland bird ranges tend to be widespread. Lowland birds break into four subsets: (1) those that occur both north and south of the central cordillera, (2) those that occur only north of the central cordillera, (3) those only south of the central cordillera, and (4) those mainly west of the western terminus of the central cordillera (in the Bird's Head and Bird's Neck). Thus the central cordillera stands as an important biogeographic barrier to lowland bird distributions.

For montane birds, the central cordillera hosts the largest number, and this cordillera is a center of differentiation for upland birds. One additional point needs to be made regarding the cordilleran species' distributions. For species exhibiting a mid-montane elevational distribution, their distributions tend to be "bilinear"—with a north-slope range and a south-slope range—two parallel narrow linear ranges that typically meet at each end of the cordillera (a very compressed "ring" that looks more like a double line).

North coastal ranges tend to have substantially fewer montane species than the central cordillera. It is apparent that most or all montane birds inhabiting the north coastal ranges were derived from parent populations in the central cordillera. The north coastal range population is either identical to that from the central cordillera, distinct at the subspecies level, or in some instances distinct at the species level from the population on the central cordillera, but in all cases the nearest relative appears to be the population living on the central cordillera. The assumption is that the montane bird populations inhabiting the north coastal ranges are younger than those found on the central cordillera. Also regarding the north coastal ranges, the highest ranges (Saruwaged Range, Finisterre Range, Arfak Mountains) have the most montane species, and the lowest ranges have the fewest montane species.

The Bird's Head and the Bird's Neck are tectonically distinct terranes from the main body of New Guinea, with distinct tectonic histories, and as a result support a relatively large number of endemic bird species (12 species endemic to the two subregions). No other sector or subregion or pair of subregions supports a comparable number of endemic bird species.

When mapping species richness across the island of New Guinea, we have found that the largest concentrations of lowland and montane species cluster near the center of the island (the Border Ranges and the headwaters of the four great rivers—Fly, Digul, Sepik, and the Mamberamo system). Given the centrality of the area and its complex of river headwaters and high mountain massifs, this should not be surprising. By contrast, the bird fauna of the distal end of the SE Peninsula is substantially impoverished in species, again not surprising on traditional biogeographic principles.

The importance of ecological and current environments in bird distributions in New Guinea is most obvious with respect to the Trans-Fly, where the biota includes a mix of New Guinean rainforest species, which inhabit patches of gallery forest, and savanna species with strong Australian affinities, occupying the dry and seasonal habitats. Here current habitat tops current distributional barrier in the determination of what species occur in a distinct part of New Guinea.

HISTORICAL BIOGEOGRAPHY

In contrast to ecological biogeography, historical biogeography takes the long view and seeks to explain how a region's biota evolved—with a focus at the familial or generic level rather than the species or subspecies level. Instead of ecological time, the time frame here leads into geological time. Questions answered by this approach might be, for instance: Why are there wallabies in Australia but not Europe? And why are elephants in Thailand but not New Guinea?

Gondwanaland The megacontinent Pangaea broke in two some 200 million years ago. Laurasia was the northern fragment (Asia, Europe, North America). The other, Gondwanaland, included, at the time of this break, South America, Africa, Antarctica, Australia, proto–New Guinea, India, and Madagascar. Dinosaurs roamed these lands and their forests of ancient conifers. Monotremes (see chapter 11) can be traced back 110 million years through fossils, and DNA molecular-clock estimates trace monotremes back 220 million years, during a time when Gondwana was still associated with Laurasia. So it is not a huge surprise that the oldest marsupial known is 125 million years old and from China—indicating that both marsupials and monotremes (the two oldest mammal lineages) may have Pangaean roots rather than Gondwanan ones. Modern birds (the Neornithes) can be traced back perhaps 65 million years. Many ancient avian lineages died out during the end-Cretaceous extinction event, with newer lineages evolving to take their place after that catastrophe.

The breakup of Gondwana took place in stages. Australia–New Guinea/Antarctica/India broke from Africa ca. 150 million years ago. Australia–New Guinea started to break from Antarctica about 85 million years ago, was largely distinct by 50 million years ago, and was totally isolated by 30 million years ago, when it continued its drift northward toward Southeast Asia and the westward-moving Pacific Plate.

Isolation Australia–New Guinea had no land connection to any other continent after 30 million years ago. Splendid isolation allowed the existing biota on this island continent to evolve with minimal interchange with other biotas. It is this long period of isolation that allowed Australia–New Guinea to give rise to the cassowaries, the fruit-doves and lorikeets, the songbirds, the kangaroos, the wombats and koalas, and more.

Endemism Isolation produces endemism. The island biogeographic principles are in play here as well, and large and profoundly isolated landmasses generate large endemic biotas. The longer the isolation, the deeper the endemism. Thus endemism grades from species to genus to family to order as time and isolation persist. The two most famous post-Gondwanan continental isolates are Madagascar and Australia–New Guinea. Today Australia–New Guinea is home to 18 endemic families of plants, 24 endemic families of birds, perhaps 3 endemic families of amphibians and reptiles (depending on systematic treatment), and 16 endemic families of mammals. By comparison, Madagascar is home to 8 endemic families of plants, 5 endemic families of birds, 3 endemic families of amphibians and reptiles, and 6 endemic families of mammals.

Because New Guinea is only *ecologically* isolated from Australia (equatorial and humid environments versus temperate and dry environments), New Guinea itself is home to no endemic plant, amphibian, reptile, or mammal families, and only 7 endemic bird families (all of which are tiny and recently recognized families of one or several species). Historically, New Guinea needs to be studied as a major component of the Australian biota.

A ripe nutmeg (*Myristica* species) fruit. The edible red aril covers the large dark seed (the nutmeg) set inside of a tough woody capsule that opens only partially when ripe. Species of birds of paradise have the ability to handily extract these fruits, digesting the nutrient-rich aril and regurgitating the large seed in the forest, acting as important seed-dispersal agents. Photo: Bruce Beehler

Vicariance versus Dispersal Until the 1980s, historical biogeography was initially dominated by practitioners who believed dispersal was the dominant process in the organization of Earth's distinct biotas. At the time, it was thought that the position of the continents was fixed; plants and animals had to cross water gaps to reach any unoccupied landmass. During the 1950s, Leon Croizat created a new school of study that he named panbiogeography. Prior to the understanding of continental drift, this study was rooted in the existence of obvious trans-ocean-basin distributions, global distributions, and the breakup of widespread species into smaller-ranged successor species through a process known as vicariance (usually through the intervention of some geological or geographic barrier to dispersal). Croizat identified transoceanic "tracks" that implied some former biotic connection across ocean basins. Though unable to explain the mechanism by which the ranges (mainly of plants) came about, Croizat stubbornly insisted that these were biologically significant, and indeed predicted the coming of plate tectonics. Croizat's work was universally scorned (his book-length works were self-published), and only later was his quirky brilliance recognized (much the same can be said for the inventor of plate tectonics, Alfred Wegener).

The gigantic Klinki Pine (*Araucaria hunsteinii*) is New Guinea's tallest tree. It is a member of an ancient conifer family with Gondwanan connections. Living species of *Araucaria* inhabit New Guinea, Australia, New Caledonia, Norfolk Island, and southern South America. Photo: Bruce Beehler

In the 1980s, building on Croizat's panbiogeography and the German zoologer Willi Hennig's cladistic systematics (which objectively defined evolutionary relationships among lineages through the identification of "shared derived characters" rather than similarity), cladistic biogeography came into being. This discipline denied the importance of dispersal in the evolution of biotas, and elevated vicariance and plate movement and partition as the main forces driving biotic evolution on the planet. Vicariance is a process in which widespread parental species ranges are dissected by the rise of physical or ecological barriers that reduce gene flow and promote speciation. Vicariance processes stress sedentary populations and their dissection, leading to speciation. Here we had a solution to the riddle of the trans-Atlantic distribution of the *Glossopteris* flora. Its range was bisected by the opening and spread of the Atlantic Ocean.

Subsequently, the rise of molecular systematics has tempered the extremism of cladistic and vicariance biogeographers, uncovering thousands of examples of dispersal-driven biotic diversification. Today both dispersal and vicariance are acknowledged as important to the process of speciation and biotic evolution.

Diamond's drop-out model for speciation of birds in the central cordillera of New Guinea relies on sedentary species ranges, the rise of distributional barriers, and classical vicariance in the process of cordilleran speciation. Speciation in lowland forests also postulated the development of barriers to dispersal to break up widespread species into multiple successor species (prime examples being the crowned pigeons and the *Chalcopsitta* streaked lories). It seems vicariance is the process that best matches the differentiation of the New Guinea mainland avifauna.

By contrast, the colonization by species of the geologically youthful north coastal ranges probably exemplifies a type of dispersalism allied to climate fluctuations during the Pleistocene. After New Guinea rafted northward to contact and plow up an arc terrane (e.g., the Foja Mountains), this new mountain range received its montane avifauna through a rather passive dispersal. During a Pleistocene cold spell, the ranges of montane species on the central cordillera were greatly lowered elevationally, presumably spreading out into extensive lowland habitats. When the cooling ceased and warming returned, the lowered and widespread populations ascended nearby mountains in search of appropriate habitat as the climate warmed. These populations would have reoccupied both the central cordillera and the rising north coastal range by simply moving gradually upslope with changing conditions. When full warmth returned, there were now two isolated montane populations—one in the central range, the other in the north coastal range.

Some theoreticians insist on the importance of plate tectonics to the current distribution of animal and plant taxa in the New Guinean Region. This postulate may indeed hold for the ancient lineages of invertebrates and plants but probably does not apply to the relatively young bird and mammal lineages. Deep and ancient lineages of very old groups indeed probably rafted with moving continents and continental fragments. But the distributions of plant and animal *species* in New Guinea are the product of the later Tertiary and Quaternary processes. The mountainous New Guinean landmass as we know it today is very young—ca. 5 million years old. The accretion of microplates and island arcs at the northern edge of New Guinea as the Australian Plate advanced northward added nothing more than oceanic sediments and island-poor biotas to an already rich Australian biota. Australia was where the action was, and the formation of the islands of Wallacea (apparently through the Miocene) created the corridor for biotic exchange between isolated Australia–New Guinea and the Asian mainland. The songbird lineage that initially evolved in Australia in the Oligocene burst out of Australia, using the Wallacean corridor, to embrace the world and apparently did not depend upon a substantial New Guinea to diversify. Instead, New Guinea has served as a refuge for the montane and humid forest lineages that originally evolved in Australia, but the island was not a generator of lineage diversification. Witness that the only seven bird families endemic to New Guinea (Cnemophilidae, Melanocharitidae, Paramythiidae, Rhagologidae, Eulacestomatidae, Ifritidae, and Melampittidae), all recently recognized, are young and very species-poor. New Guinea has seen substantial local species radiation, but this is almost certainly a relatively recent process.

To wrap up, today New Guinea is indeed a great species-generator of plants and animals, which diversify and radiate outward to nearby islands and landmasses. Moreover, New Guinea is the mainland from which most nearby islands and island groups receive their plants and animals. Species disperse from New Guinea out to the islands west, north, and east. In addition, New Guinea and Australia have witnessed three pulses of biotic interchange, based on large-scale environmental change and allied rising and falling of global sea level. New Guinea, during its period of great cordilleran uplift, contributed to substantial biotic diversification in Australia–New Guinea in the late Miocene–early Pliocene. And today, New Guinea remains home to the wealth of the tropical, humid-forest plant and animal lineages that evolved in the late Tertiary on Australia during periods of warmth and humidity there. There is little doubt, however, that Australia itself is the main long-term generator of biotic wealth emanating from Australia–New Guinea. Those important humid-forest upland lineages of animals (and plants?) that abound on New Guinea's central cordillera, the Bird's Head uplands, and the Huon uplands all probably evolved at an earlier time on the Australian craton. ■

6 Botany

The Vegetation and Flora

IN 2003, A TEAM OF SCIENTISTS organized by Conservation International identified New Guinea as one of three of Earth's major wilderness areas (the others being the Congo basin and Amazonia). One of the reasons for this remarkable designation was New Guinea's abundant rainforests and its stupendously rich flora, which we review in this chapter. For the naturalist, New Guinea boasts two globally significant features: a diversity of high and complex mountain ranges and a broad expanse of equatorial humid forest. Certainly, the interplay between the mountain landscapes and the forested environment makes New Guinea of particular interest to ecologists and tropical biologists. It draws field researchers as a bright flame attracts moths.

The study of New Guinea's flora remains in its youthful stage. There are a thousand doctoral field projects awaiting future students of New Guinea's floral diversity. Better knowledge of the vegetation and the flora is needed to guide the delineation of protected landscapes as well as to guide cost-effective and environmentally benign management of New Guinea's forest estate. For the visiting birder and amateur naturalist, New Guinea's wealth of vegetation and its hyper-diverse flora provide a fascinating backdrop when hunting for birds of paradise, bowerbirds, birdwing butterflies, and those elusive possums and tree kangaroos. Here we provide a simplified summary of New Guinea's vegetation and its flora, focusing on the major habitats and the most important and prominent plant families.*

Previous pages: Looking up into the misty canopy of montane forest in the Arfak Mountains of the Bird's Head at 2,000 meters elevation. The radial sprays of *Pandanus* tree leaves are distinctive.

Opposite: Upper montane grassland with tree ferns. This patch is the product of some form of disturbance—burning, perhaps. This vista exhibits the variable nature of montane vegetation caused by patch disturbance. In the far background, note the various landslide patches and stand of dead canopy trees.

* Sources for this chapter include Takeuchi (2007), various chapters by R. J. Johns and collaborators in Marshall and Beehler (2007), and Paijmans (1976), as well as other citations in References.

THE VEGETATION

With New Guinea's generally humid and warm equatorial climate, it is not surprising that the native vegetation cover for most of the island is closed-canopy tropical forest. This is the default vegetation type over virtually the entirety of New Guinea, except in the alpine zone above 4,000 meters, in the seasonally dry south-central bulge of the Trans-Fly, and a few other small rain-shadow zones scattered about the island where annual dry-season fires promote the persistence of non-forested grasslands, woodland, and savanna. New Guinea is an island characterized by its rainforests and montane forests. Perhaps most remarkable is that New Guinea remains largely forested in spite of human occupation of the island for at least 47,000 years. Indigenous New Guineans can thus be heralded as perhaps the first and most successful forest conservationists on Earth (though this is perhaps partly an inadvertent result of social and cultural constraints to forest exploitation).

The bird's nest fern *Asplenium phyllitidis*. Bird's nest ferns are common epiphytes in the interior of New Guinea's humid forests.

New Guinea's forests are species-rich, with minimal stand dominance by particular tree species and with substantial disturbance-driven variation from site to site, even within single catchments. One-hectare survey plots of forest typically support between 70 and 200 species of trees larger than 10 centimeters diameter at breast height. It is thus difficult to characterize the forest types of New Guinea by taxonomy. Instead, forest types are delineated by elevation, rainfall, and structure. In general, New Guinea's forests can be termed tropical humid forests. Tree species of the following families are important components of this tree flora: Podocarpaceae, Nothofagaceae, Moraceae, Lauraceae, Elaeocarpaceae, Rubiaceae, Fabaceae, Myrtaceae, Meliaceae, Myristicaceae, Sapindaceae, Euphorbiaceae, Phyllanthaceae, Combretaceae, Sapotaceae, Annonaceae, Clusiaceae, and Rubiaceae, among others.

Today, in spite of various forms of human disturbance and development, more than 65 percent of New Guinea remains cloaked in closed-canopy humid forest. When one flies across New Guinea, the typical view out the window of the airplane or helicopter is of continuous expanses of forest broken only by stream clearings and the occasional swidden garden or small traditional hamlet. New Guinea has relatively few cities and is largely rural and forest-dominated. That said, in certain highland areas, the interior upland valleys (e.g., Painai, Ilaga, Baliem, Tari, Mendi, Wahgi, Asaro) are heavily deforested and populated by agriculturalists and their networks of gardens, coffee plantations, and fenced or walled homesteads. Moreover, anthropogenic grasslands are widespread in certain long-cultivated interior upland valleys and in some low-rainfall areas (the middle Sepik, Safia-Pongani Gap, Lake Sentani). Natural grassy savannas dominate in south-central New Guinea (the Trans-Fly). Other areas feature mangroves, swamp forest, and alpine vegetation.

Regarding the dominant humid forest, site-to-site variability makes it difficult to characterize types—in fact, because of historical impacts, edaphic (soil-based) constraints, and climate, each humid forest "type" in New Guinea encompasses considerable internal variation as one type grades into another. It is safe to say that botanists and plant ecologists can provide exceptions to any proposed classification. Be that as it may, there are a series of traditionally recognized forest and non-forest habitat types, which we review below.

A mature strangler fig in forest interior with a thicket of palms at its base. These stranglers can replace the host tree they started life on, grow to become super-canopy emergents, and produce prodigious numbers of small fruits that are consumed by large numbers of birds and bats.

MAJOR NATURAL HABITATS

Lowland Rainforest In New Guinea, expanses of lowland rainforest are found in the major river basins, especially in the upper Sepik, the Fly, the Digul, and the Mamberamo-Tariku-Taritatu, as well as at the base of the southern scarp of the central cordillera. These forests under good conditions in alluvial bottomland are tall and luxuriant, with canopy heights from 35 to 45 meters and emergents (e.g., *Octomeles sumatrana*) topping 50–70 meters. The canopy of this alluvial lowland forest is often irregular and broken, except where there has been uniform stand regeneration after some disturbance. Large-buttressed trees are prominent. These forests can be very species-rich, with 1-hectare plots supporting more than 150 species of trees. Palms, pandans, rattans, and climbers add to the complexity of this magnificent habitat type. Unlike the great dipterocarp forests (rainforest dominated by species of the family Dipterocarpacae, most of which have been decimated by loggers or razed for Oil Palm plantations) found in Sundaland to the west, the New Guinean rainforests typically lack strong species dominance, although certain groups may collectively dominate in a specific area. The dipterocarps, so important for timber enterprises in Southeast Asia, are relatively species-poor in New Guinea and dominate only in geographically restricted areas where some ecological disturbance has occurred.

The most common tree species at the 50-hectare Wanang plot in the Sepik-Ramu of ENG are *Pometia pinnata* (Sapindaceae), *Intsia bijuga* (Fabaceae), *Mastixiodendron pachyclados* (Rubiaceae), *Celtis latifolia* (Cannabaceae), *Pimeliodendron amboinicum* (Euphorbiaceae), *Gnetum gnemon* (Gnetaceae), *Neonauclea obversifolia* (Rubiceae), *Vitex cofassus* (Lamiaceae), *Erythrospermum candidum* (Salicaceae), and *Pterocarpus indicus* (Fabaceae). That said, the Wanang plot features 536 species of trees with stems larger than 1 centimeter. In addition, New Guinea's lowland rainforests include many species of mahogany (Meliaceae), legume (Fabaceae), laurel (Lauraceae), fig (Moraceae), guava relatives (Myrtaceae), and nutmeg (Myristicaceae), as well as a host of lesser-known families. Some particular species or genera of trees seem to be found in virtually every lowland forest, such as: *Pometia pinnata*, *Intsia bijuga*, *Endospermum medullosum*, *Octomeles sumatrana*, *Gnetum gnemon*, *Celtis* species, *Pterocarpus indicus*, *Cerbera floribunda*, *Sloanea* species, *Aglaia* species, *Dysoxylum* species, and *Elaeocarpus* species. Also common and widespread are understory plants such as *Pittosporum sinuatum*, *Morinda umbellata*, *Donax canniformis*, *Diplazium cordifolium*, and *Asplenium nidus*. Still, each forest tract surveyed seems to have its own unique mix of species, and forest plots vary substantially even within a single basin. Ridgetop forests are often distinctive, with stands of dipterocarps dominating. Experts believe most New Guinean forests (even "old growth" forests) are secondary, the product of a wide array of historical disturbances, some anthropogenic, others natural.

Hill Forest Hill forests dominate the New Guinean landscape between 500 and 1,500 meters elevation, mainly because so much of New Guinea is rugged, with ridges rising sharply from the lowlands into the mountains. New Guinea overflights by bush plane are impressive

Opposite: Flowers of *Dendrobium* cf. *lineale*, a common and widespread lowland orchid species. The family Orchidaceae is the most species-rich of any plant family in New Guinea, with no fewer than 2,850 species in the region.

Upper montane forest tree (a *Syzygium*?) with multiple mature ant-plant epiphytes visible on different branches. The hollow bulbous stems of these curious-looking members of the Rubiaceae provide nesting sites for ants, frogs, and presumably other animal species.

because they provide abundant vistas of punishingly steep and remote interior forested country that few humans ever visit. It is because of this inaccessibility that the forest flora of the island is incompletely known. The forest of this zone is typically lower-canopied and smaller-boled and has fewer palms and climbers than forests in the alluvial lowlands. Family composition is largely similar, but certain montane families such as Cunoniaceae start to appear, whereas lowland-lovers, such as the nutmegs, decline. Two species of the genus *Araucaria*, the Hoop Pine and the Klinki Pine, sporadically inhabit these upland forests, usually between 300 and 1,600 meters elevation. These magnificent southern conifers of the ancient gymnosperm family Araucariaceae are among New Guinea's tallest trees and are always emergents, towering above the surrounding vegetation. It is also in these hill forests that the oaks tend to make their first showing, with a series of species of acorn-producing *Lithocarpus* and a *Castanopsis*. The ridge-top *Castanopsis acuminatissima* forest is one of New Guinea's most distinctive forest subtypes, noted for its pleasant aspect and for the variety of birds of paradise that inhabit it. Typical hill forest tree genera include *Magnolia*, *Agathis*, *Prunus*, *Sterculia*, *Teijsmanniodendron*, *Helicia*, *Calophyllum*, *Elaeocarpus*, *Litsea*, *Cryptocarya*, *Castanopsis*, *Araucaria*, and *Syzygium*. In the understory one finds *Antidesma*, *Aglaia*, *Saurauia*, *Timonius*, *Ixora*, *Urophyllum*, *Lasianthus*, *Garcinia*, *Psychotria*, *Aceratium*, *Harpullia*, and *Phaleria*, among others.

As one ascends to higher elevations, one finds gradual changes in forest structure and species composition. In mountainous country, the variables of slope, drainage, and natural succession brought about by landslips produce mosaics of vegetation types. These higher-elevation hill forests are species-rich, although they lack the extreme diversity of the lowland and lower hill forests. Oaks, myrtles, laurels, and members of the Elaeocarpaceae are particularly common, whereas figs, legumes, palms, and lianas are fewer. The characteristic flat spreading canopy of *Albizia* provides a clear elevational marker, as it drops out at around 1,200 meters.

In the low hills on the southern side of the central cordillera above Timika is a very poor heath forest growing on "white sand" soils. This forest is both structurally bizarre and taxonomically distinct—an open dwarf forest populated by species of podocarps typically known from higher elevations.

Grey-streaked Honeyeater (*Ptiloprora perstriata*) forages at the flowers of a wild ginger in the montane forest. Honeyeaters are important pollinators of montane forest epiphytes.

Montane Forest This formation can be found mainly between 1,500 and 3,000 meters elevation. In areas of very high rainfall, this forest type may appear as low as 1,000 meters, and under very favorable conditions it may extend up to 3,400 meters. Usually above 2,000 meters elevation the montane forest takes on a mossy aspect, due to the epiphytic growth upon many of the trees, with mosses and liverworts dominant ephiphytes. This mossy forest is physiognomically very distinctive, although it is difficult to characterize taxonomically. The forest remains relatively species-rich, with oaks, Antarctic beeches, and podocarps, but is most distinctive in its profusion of epiphytic plants—orchids, ferns, bryophytes, and rhododendrons and other ericoids. The favorite forest type of many visiting naturalists, it has been called a "Papuan wonderland." At the higher elevations, the profusion of moss is almost hard to believe. Even the floor of the forest is thickly covered, and in some cases there is virtually no solid ground but instead a combination of moss, roots, and root mats underlain by gaps and tunnels. Traversing this on foot cross-country can be quite a challenge to the naturalist or explorer.

Among the conspicuous trees of the montane forest is the southern beech species group (formerly in the genus *Nothofagus* and now in *Trisyngyne*; originally treated as an beech and now placed in the family Nothofagaceae); in some areas southern beech forms dominant stands, especially on ridges. Conifers (family Podocarpaceae) and myrtles increase in importance with increasing elevation, and the forest structure becomes simplified, with a thin canopy and a prominent understory. But in some areas one can find grand podocarp forests with canopy heights exceeding 40 meters. These grand forests feature species of *Decaspermum*, *Dacrydium*, *Phyllocladus*, *Dacrycarpus*, and *Podocarpus*, all festooned with orange-colored moss and abundant epiphytic orchids, rhododendrons, and ferns. Other tree genera and species typical of the montane forest include *Xanthomyrtus*, *Falcatifolium*, *Pittosporum*, *Quintinia*, *Polyosma*, *Astronia*, *Astronidium*, *Ascarina*, *Zygogynum*, *Schizomeria*, *Daphniphyllum gracile*, *Sphenostemon papuanum*, *Pullea glabra*, and *Galbulimima belgraveana*.

A stunted *subalpine forest*, much like the elfin forest of the high Andes—occurs at high elevations, especially in exposed locations and in areas with very high rainfall. This formation becomes dominant above 3,200 meters elevation, leading up to the tree line. This is dwarf forest, usually with a canopy height of no more than 10 meters, dominated by sapling-size trees, heavily encrusted with moss, typically of the genera *Pittosporum*, *Rapanea*, *Xanthomyrtus*, *Elaeocarpus*, *Schefflera*, tree *Vaccinium* and *Olearia*, *Amaracarpus*, *Papuacedrus*, and *Dacrycarpus*, among others. The trunks of these trees are often twisted and gnarled, and this, too, presents a challenge to off-trail foot travel through the habitat. The tree flora is much impoverished in comparison with that at lower elevations, and light gaps can be filled with thick, nearly impenetrable tangles of the scrambling bamboo *Nastus productus*. In areas of disturbance and openings, shrubby erecoid heaths of the genera *Rhododendron*, *Dimorphanthera*, *Vaccinium*, *Gaultheria,* and *Trochocarpa* are prominent, with contributions from *Coprosma*, *Schefflera*, and *Myrmecodia* ant plants. Tree ferns (*Cyathea*) can be common and are non-forest dwellers adapted to frosty grasslands.

The flowers of this Flame of the Forest vine (family Fabaceae) brighten many river edges in lowland New Guinea. Photo: Bruce Beehler

Alpine Ecosystems At elevations varying from 3,650 meters to 4,200 meters, one encounters the timberline, above which alpine shrubbery and grassland begin to dominate the landscape. Viewed from a distance, the *Deschampsia* grasslands appear inviting; however, this tussock-grass habitat is usually swampy and waterlogged, and it can be treacherous underfoot, especially in flat basins. Shrubs such as *Coprosma*, *Gaultheria*, *Vaccinium*, and *Rhododendron* are common at forest edges or in protected sites. In many sites, this high-elevation shrubland has been heavily damaged by inadvertent wildfires set by traditional hunters during El Niño droughts.

Here, dwarfed, shrub-like rhododendrons, myrtles, and other plants mix with the two dominant gymnospermous trees that persist at this high elevation—*Dacrycarpus compactus*, a robust podocarp, and *Papuacedrus papuana*, a cypress. Open grassland tends to dominate in the basins, dwarf forest thickets on the basin edges, and the more grand *Dacrycarpus* stands on the protected slopes. Frost is common at this elevation, and the occasional short-lived snowfall occurs during the austral winter. Rocky scree and small bogs dominate on and around the alpine summits above 4,500 m, where a few tropic-alpine herbs and shrubs manage to dwell—including genera such as *Ranunculus*, *Potentilla*, *Drapetes*, *Hebe*, various daisies, and *Astelia*.

The preceding paragraphs have briefly treated New Guinea's dominant dryland vegetation along an elevational gradient. Additional specialized habitats of restricted distribution are scattered about the region. These include mangrove and other coastal forests, swamp forest, seasonal monsoon forest, savanna, wetlands and marshes, and anthropogenic grasslands. They are discussed below.

Mangrove Forests The trees that make up this unique forest type inhabit the coastal intertidal zone, with their roots resting in brackish or salt water. Many mangrove forests are quite unusual-looking, the trees characterized by stilt roots and other distinctive adaptations to their hydrologically challenging environment. Extensive tracts of mangrove forest dominate coastal areas in Bintuni Bay, the Asmat, and the Waropen coast of WNG, as well as areas in the Western and Gulf Provinces of PNG—especially at the head of the Gulf of Papua in the deltas of the Fly, Turama, Kikori, and Purari Rivers. In northern ENG, expanses of mangroves are found near the mouths of the Sepik and Ramu Rivers. Fringe mangroves are common elsewhere in many coastal localities. The habitat features species of *Rhizophora*, *Avicennia*, *Camptostemon*, *Bruguiera*, *Xylocarpus*, and *Sonneratia*, among others. Finally, monocultures of Nipa Palm (*Nypa fruticans*) can dominate low-lying areas facing estuaries that receive daily flooding of brackish water.

Swamp Forest Swamp forest takes various forms in poorly drained and seasonally flooded bottomlands in interior basins and in backwaters associated with major river systems in the alluvial lowlands. Lightly inundated areas often support tall and diverse forests, with particularly large, buttressed canopy tree species. Typical canopy tree genera of the wooded swamps include *Barringtonia*, *Terminalia*, *Albizia*, *Pometia*, *Octomeles*, *Alstonia*,

Opposite: A female birdwing butterfly (*Ornithoptera chimaera*) forages at a two-toned flowering rhododendron (*Rhododendron zoelleri*).

Diospyros, *Carallia*, *Syzygium*, and *Campnosperma*. Permanently inundated swamps are sometime dominated by *Campnosperma brevipetiolatum*. Palm swamps, dominated by true Sago Palm (*Metroxylon sagu*; not the cycad of the same name), screw pines (*Pandanus*), or Nipa Palm are commonplace in the vast deltaic areas of the major rivers (e.g., the Digul). These grade into herbaceous marshlands where inundation is the prevalent condition. Swamp forests dominate anywhere drainage is poor and rainfall or floodwaters accumulate, Aerial view of an extensive expanse of alluvial lowland rainforest, backed by foothills. These lowland tracts are among the most remarkable of New Guinea's forests, very biodiverse in tree species and wildlife. This is the "jungle" that must be visited to get a sense of the richest of New Guinea's interior.

and here one finds distinctive but diverse forests with many rainforest species, as well as the economically important Sago Palm and various species of *Pandanus*.

Strand Forest New Guinea coastal beaches feature a distinctive strand forest of *Pandanus*, *Casuarina*, and *Heritiera*, often with coconut and other palms.

Seasonal Monsoon Forest This forest type, typified by the prominent presence of seasonally deciduous trees, occurs at the edges of the drier savanna zones, especially northwest of Port Moresby and in the Trans-Fly. In the southern coast of the SE Peninsula one encounters closed monsoon forest that grades southward into *Melaleuca* woodland and *Eucalyptus* savanna. The monsoon forest is dominated by species of *Bombax*, *Tetrameles*, *Acacia*, *Terminalia*, *Flindersia*, *Acacia*, *Syzygium*, *Banksia*, and *Grevillea*.

Savanna Grassy savannas predominate in a few rain-shadow zones in New Guinea. By far the largest of these is in the Trans-Fly of southernmost central New Guinea (in both WNG and ENG). Small patches also can be found in the SE Peninsula around coastal Port Moresby, the Safia-Pongani Gap, and Raba Raba. These savannas are characterized by tree species of the genera *Eucalyptus*, *Melaleuca*, *Albizia*, *Rhodamnia*, *Tristania*, *Xanthostemon*, and *Syzygium*, with an understory of grass of the genera *Themeda*, *Imperata*, and *Ischaemum*. This vegetation predominates wherever there is a long and severe dry season and regular dry-season fires.

Wetlands and Marshes These wetlands—some seasonal, others permanent—support mainly grasses, rushes, and reeds and are home to many of the region's waterbirds and freshwater fish fauna. ENG counts more than 5,000 lakes larger than 0.10 hectare. Most of these are lowland water bodies, associated with river floodplains. They include herbaceous swamps, oxbows, and backwaters. The botanist K. Paijmans recognized a number of freshwater herbaceous wetland vegetation types: herbaceous swamp that includes sedges, herbs, and ferns; *Leersia* grass swamp, dominated by several species of grasses and a few herbs; *Saccharum-Phragmites* grass swamp, in shallower water than the preceding and with very tall grasses; and *Pseudoraphis* grass swamp—seasonally dry, low marshes with typically dense, creeping stands of *Pseudoraphis spinescens* that are extensive in southwestern ENG.

Paijmans also recognized mixed swamp savanna and Melaleuca swamp savanna, the latter peculiar to the middle Fly and Strickland of ENG. In the montane zone, Paijmans recognized a sedge-grass swamp and a *Phragmites*-grass swamp, both of which occur in upland interior valleys in areas of poor drainage. G.S. Hope has noted the formation of peat-forming swamps in these situations.

Anthropogenic Grasslands Coarse grasslands dominate in places where human settlements have been long present, their inhabitants setting fires annually during the dry season. The repeated fire and swidden (slash-and-burn) gardening leads to the loss of fertile soil and prevents recolonization by woody vegetation. The grasslands are composed of several robust grass species such as *Themeda triandra*, *Themeda intermedia*, *Ischaemum polystachyum*, *Paspalum vaginatum*, *Miscanthus floridulus*, *Saccharum robustum*, and species of *Imperata* and *Arundinella*, typically standing 1.0–1.5 meters high when mature. These grasslands are most common in the most densely populated parts of the island (coastal lowlands, interior upland valleys), where fire is annually deployed through the habitat for various purposes (habitat management for agriculture, hunting, recreational pyromania). The presence of areas of grasslands in regions otherwise dominated by humid forest is a clear indication of long human occupation. Examples include: the Baliem and Ilaga valleys, the Sepik basin, the Wahgi valley, the Snake River valley, and the interior upland valleys of the Huon Peninsula. Anyone who has carried out patrols or cross-country excursions in the populous interior of New Guinea will have memories of following foot tracks over grassy hill and dale for long hours under a beating sun or heavy rainfall. The experience is not pleasant but is indeed memorable.

ENVIRONMENTAL DISTURBANCE

New Guinea is a land in flux. Significant chronic disturbance is produced by ongoing mountain-uplift in contest with rainfall-driven erosional processes, as well as by periodic volcanism, human-caused and naturally occurring fire regimes, plus El Niño droughts and frosts. Over the long history of human occupation, swidden (slash-and-burn) agriculture has disturbed large swaths of habitat, most of which quickly regenerates back to forest after the gardens are abandoned. Thus historical disturbance is a dominant factor dictating the distribution and pattern of today's vegetation. Much of what appears to be "virgin" rainforest is, in fact, the product of recent and not so recent natural and anthropogenic patch disturbance and manipulation to encourage tree crops.

An open view of the glade-like ridgetop forest in the hill region of the northern slopes of the Tamrau Mountains of the Bird's Head. Note the prominent tree buttressing and the leaf-littered ground. This is a forest that has probably been overbrowsed by an introduced population of the non-native Rusa Deer, now a popular game animal for the local communities. What impact has the deer had on the forest's ecology? Photo: Bruce Beehler

Human-related alteration of the environment has produced significant changes. Most prominent are the anthropogenic grasslands (discussed above) that have developed in long-settled interior valleys of the highlands and in some lowland areas. Demands for housing materials, commercial timber, and firewood all act to create large areas of open habitat near permanent settlements. With increasing development, the tracts of grassland surrounding settlements expand, displacing the local forest. The populous highland valleys are now largely treeless, except for the occasional planted stand of *Casuarina*, *Eucalyptus*, or *Pinus*. Lowland areas in the Sepik, Strickland, Markham, and upper Ramu valleys are dominated by old, human-created grasslands.

Western industrial development is also creating substantial impact on the landscape. Oil Palm is increasingly popular, leading to the conversion of large tracts of lowland rainforest to palm monocultures. Oil drilling, gas extraction, and mining operations have led to localized forest disturbance across areas of exploitation as well as large-scale pollution with heavy metals and silt of a number of important river systems. Industrial-scale selective timber extraction is most prevalent in ENG, especially in the Southern Lowlands but also in the Sepik-Ramu and near Vanimo. More on these issues appears in chapter 18.

THE FLORA

Floristically, New Guinea is remarkable, estimated to support more than 15,000 species of vascular plants, notably some 2,850 species of orchids, 167 rhododendrons, 2 species of the great and ancient *Araucaria* conifers, and the towering Rainbow Eucalyptus

(*Eucalyptus deglupta*) as well as the magnificent and valuable New Guinea Kauri, often called "kauri pine" (*Agathis labillardieri*). Dipterocarp trees (family Dipterocarpaceae) are relatively uncommon but appear in abundance in certain patches, the result of some natural disturbance regime. Other important timber trees include *Intsia bijuga* (called *merbau* in WNG and *kwila* in ENG), *Pometia pinnata* (*matoa* in WNG and *taun* in ENG), *Pterocarpus indicus* (known as "rosewood"), and *Dracontomelon* ("black walnut"), among others.

Published estimates of the number of species in New Guinea's flora vary widely—from 11,000 to 20,000-plus. Newer estimates using ferns and orchids as samples for extrapolation indicate as many as 25,000 species could be present in the New Guinean Region, but based on current data the best number appears to be 15,000 species. That said, it will be decades before sufficient fieldwork and herbarium analysis has been completed that will allow this number to stabilize. Most needed is work focused mainly in WNG. To understand the disparity in botanical effort between west and east, note that the herbarium in ENG holds 400,000 mounted collections, whereas the one for WNG has a mere 30,000 mounted collections. That said, both regions remain seriously undercollected, with major geographic gaps in knowledge. Every field trip, even to areas with a collection history, produces range extensions and often taxa new to science.

The number of plant families for New Guinea stands at 260 (none endemic). The number of genera stands at 1,750. These figures indicate that although species richness is very high, the flora is not hugely diverse taxonomically, and that because New Guinea is young, it is rich in young species that recently differentiated on the island. About half of these families it shares with Australia, and half it shares with Malesia. Although New

Rocky alpine tussock grasslands below the summit of Puncak Trikora (Western Ranges). These sorts of grasslands are favored by the Alpine Pipit (*Anthus gutturalis*) and Tawny Grassbird (*Megalurus timoriensis*). The small woodland grove in the background probably features the conifers *Dacrycarpus compactus* and *Papuacedrus papuana*.

Guinea has no endemic families, approximately 59 plant genera and ca. 9,000 species are endemic to the New Guinean Region. At the generic level, New Guinea shares more genera with Malesia than with Australia. Many shared Malesian genera abruptly end their eastern range in New Guinea and do not range into Australia or its affiliated islands. Of New Guinea's 1,750 genera, 608 do not extend into Australia, and 711 of Australia's 1,604 genera do not range into New Guinea. New Guinea's montane plant genera, however, show closest affiliation to Australia.

Among vascular plants, a relatively small number of families dominate the New Guinean Region. In the lowlands the most important families include the Anacardiaceae, Annonaceae, Arecaceae, Burseraceae, Combretaceae, Euphorbiaceae, Phyllanthaceae, Fabaceae, Elaeocarpaceae, Achariaceae, Malvaceae, Meliaceae, Monimiaceae, Moraceae, Myristicaceae, Rubiaceae, and Sapindaceae. In New Guinea, the Dipterocarpaceae is a minor family: only a few species of *Anisoptera*, *Hopea*, and *Vatica* are present.

In montane habitats the most important groups are the cryptogams (lichens, mosses, and ferns), gymnosperms (conifers), and among angiosperms (flowering plants) the Araliaceae, Cunoniaceae, Ericaceae, Nothofagaceae, Gesneriaceae, Lauraceae, Primulaceae, Myrtaceae, Orchidaceae, Pentaphylacaceae, Urticaceae, Winteraceae, and Zingiberaceae. Diversity falls sharply at elevations above 2,500 meters. However, endemism is highest in the montane zone as a result of environmental change induced by rapid rates of geological uplift.

In any account of the New Guinean flora, the ferns (pteridophytes) and orchids require particular comment because of their extraordinary richness. With an estimated 3,000 species, New Guinea has nearly 30 percent of the world's fern diversity and more than twice as many pteridophytes as the rest of Malesia. Equally remarkable are the ca. 2,850 orchid species, of which 86 percent are endemic. There are only 13 plant genera in New Guinea with 100 or more species, and the Orchidaceae has four of them. Ironically, although ferns and orchids collectively account for almost one-fourth of the island's floristic diversity, they rarely receive attention from forestry surveyors or even from most collectors. Many new orchid species remain to be discovered and described. Future collectors can also take note of New Guinea's surprising lichen inventory (an estimated 2,000-plus species; only 1,200 having been named).

In the region's fern families with completed revisions, there are no genera with more than 100 species. The genus *Cyathea*, represented by 86 species, has the highest tally. *Selaginella* is probably the largest of the groups awaiting revision (55 species in New Guinea and the Bismarck Archipelago).

Lichens generally consist of small- to moderate-size genera, but *Pertusaria* (presently with 70 species) may reach the century mark after existing collections are given a full accounting. Prior to its reorganization into smaller genera, *Parmelia* sensu lato would have included ca. 150 New Guinean species. Lichen expert A. Aptoot surveyed a single fallen tree in New Guinea that produced 173 species of lichens.

For angiosperms, *Syzygium* and *Ficus* are the only large genera (100-plus species) composed primarily of tree species (as opposed to shrubs or treelets). *Myristica* has 98 species in New Guinea, of which 74 have been discovered or described within the past two decades. Because of the restricted-range endemism in this genus, it is very likely that future exploration will move the tally for this genus substantially upward. Many of the species are known only from the original collection locality. With ca. 80 species, *Elaeocarpus* is the next richest tree genus.

Most of the larger genera consist of understory or epiphytic plants. *Schefflera* (currently being broken up into several genera) is the colossus among woody epiphytes, with 180 species present in New Guinea. Conservatively estimated at 120-plus species, *Cyrtandra* is unusual in being overwhelmingly composed of undescribed species. Currently with 61 species, the ginger genus *Alpinia* does not approach the century mark, in spite of its importance and apparent diversity in New Guinean understories.

Among vining plants, *Freycinetia* is the principal genus of note, featuring at least 134 species. As with the genus *Myristica*, mentioned above, most species are known only from the locality of original discovery.

The dominance of non-tree taxa in the New Guinean flora is reflected in elevational patterns of beta diversity. Although tree species counts generally decline with elevation,

Aerial view of a lowland swamp forest, with a mix of Sago Palm (*Metroxylon sagu*) and broadleaf trees.

the work of botanists Wayne Takeuchi and Martin Golman demonstrates that total richness on New Guinean elevational gradients is highest in the montane uplands, mainly because of the increasing contribution from epiphytes and shrubs. Similar patterns have been reported for the Neotropics.

Phytogeography Phytogeography is the study of plant geography. Aside from the strong Australian element, New Guinea's flora includes a subset of the flora of the phytogeographic region of Malesia, identified in 1950 by C. C. G. van Steenis, which includes Sumatra, Peninsular Malaysia, Borneo, Java, the Philippines, Wallacea, the Lesser Sundas, and New Guinea. This distribution of the New Guinean Region's flora best aligns with that of the arthropods and is quite distinct from the mainly Australian affinities of the birds and mammals. In essence, the biogeographic barriers of Wallace's and Weber's Lines substantially influence the distribution of the mammals and birds but not the insects and plants. One might infer that the more widespread latter two groups are either better dispersers or perhaps that the great age of their lineages has allowed them sufficient time to surmount the biogeographic barriers separating Southeast Asia from Australia–New Guinea. From a reading of the chapter on geology and plate tectonics (chapter 3), it is clear that the complex movement of landmasses, island arcs, and plates has produced complicated

Fringing mangroves giving way to coral reef, Gam Island (Raja Ampat Islands). New Guinea has some of the largest mangrove forests in the world, especially along the great island's southern coast, where they occupy vast river deltas and trap the silt coming down from the mountains. Here, mangroves fringe limestone islands, growing in clear waters where corals can also flourish.

distributions of plants and animals. A number of arthropods and plants show disjunct distributions that include New Guinea and the Philippines—evidence of this complex and poorly understood history.

Endemism The island of New Guinea as a whole has long been regarded as a hot spot for biotic diversification, and ongoing work of the *Flora Malesiana* (*FM*) project provides increasing support for this view. Compilations from completed *FM* revisions show more endemic species from New Guinea than from any other Malesian area, with a pronounced concentration of such taxa in the northern half of the island. R. J. Johns estimated that 60–70 percent of the plant species known from New Guinea are endemic. The lichen flora appears to have the highest endemism of any tropical area in the world. *Flora Malesiana* revisions for angiosperms have yielded the following species-endemism percentages for the major Malesian centers: New Guinea, 54 percent; Borneo, 37 percent; Philippines, 28 percent; Malay Peninsula, 14 percent; Sulawesi, 14 percent; Sumatra, 11 percent; and Java, 5 percent. Regional endemism lies mainly in the largest (unrevised) plant families, so the estimates above are probably conservative. This is demonstrated by comparison with the then-current percentages from 1995: New Guinea, 45 percent; Borneo, 30 percent; Philippines, 20 percent; Malay Peninsula, 11 percent; Sulawesi, 9 percent; Sumatra, 8 percent; and Java 3 percent. The relative standing among areas, as reflected in the preceding data sets, is probably more reliable than the numbers themselves. Due to the many deficiencies in current knowledge, island summaries are subject to considerable uncertainty and include a fair amount of conjecture.

Ferns and Lycophytes Ferns and their allies the lycophytes share the characteristics of dispersal by spores and possession of internal vascular tissue; this distinguishes them from the mosses and liverworts, which lack internal vascular tissue, and the seed plants, which lack spores. The ferns have a history that leads back to the Cretaceous or earlier. The heritage of one New Guinean family (Matoniaceae) has been traced back to the Triassic. Ferns are widespread through New Guinea. They range in size from tiny to huge. One tree fern has a 14-meter-tall trunk. A ground fern (the King Fern, *Angiopteris evecta*) exhibits fronds 7 meters long; seen in the rainforest, it reminds naturalists of the time of the dinosaurs. An expert estimate (by B. S. Parris) is that New Guinea supports roughly 3,000 species of ferns and lycophytes of the world's total, which may approach 20,000 species.

Ferns and lycophytes inhabit all vegetation zones in New Guinea, from mangrove swamps to alpine shrublands. Lowland and hill forest is fern-rich, but the highest concentration of species occurs in the mid-montane elevations. Ferns (especially tree ferns) are also prominent in the upper montane and subalpine zones, but these zones are not as species-rich. The ferns of New Guinea show their closest affiliation with those of Malesia. Sixteen percent of species are endemic to New Guinea, most of which are montane.

Gymnosperms Gymnosperms in New Guinea, though few in species, are distinctive and prominent members of the vegetation. Three of the five orders of gymnosperms occur in New Guinea: the Gnetales, the Cycadales, and the Coniferales. The Gnetales are represented by a single genus, *Gnetum*, whose 30 species are widespread globally in the tropics and subtropics. At least five species inhabit New Guinea, including the well-known *Gnetum gnemon*, which produces an edible seed as well as edible leaves. In WNG, the seed is flattened and fried to make the potato-chip-like snack known as *krupuk*. Throughout New Guinea, the leaves of the tree are steamed and eaten as greens, and in pidgin the species is known as *tulip* ("two leaf").

The cycads superficially resemble short tree ferns or small palms. They are widespread in the tropics and subtropics. Several species inhabit New Guinea and can be found in grasslands and lowland and hill forests. The order Cycadales can be traced back to the Permian (299–252 mya), and during the Jurassic (201–145 mya), cycads were an important part of that ancient flora.

Three families of the Coniferales inhabit New Guinea today—the Araucariaceae (the monkey puzzle trees), the Podocarpaceae (the plum pines), and the Cupressaceae (the cypresses). The Araucariaceae includes the araucarias (*Araucaria*) and the kauris (*Agathis*). As mentioned earlier, the araucarias are represented in New Guinea by two magnificent conifers that rise high above their hill forest canopies, standing out like ancient sentinels of a different epoch. These are the Hoop Pine and the larger and more imposing Klinki Pine. The latter is the tallest tree in New Guinea, the putative record height approaching 89 meters. The genus has a remnant Gondwanan distribution, being found in New Guinea, New Caledonia, Australia, and southern South America, but had a cosmopolitan distribution in the Mesozoic. The kauris, also called "kauri pines" or "dammar pines," are prodigious rainforest conifers of considerable timber value, like the araucarias. These great conifers are distinctive when aged, exhibiting a trunk with a diameter that can exceed 4 meters. The *Agathis* genus, represented by three species in New Guinea, ranges from Peninsular Malaysia east to Australia, New Zealand, and New Caledonia.

Key Angiosperm Woody Plant Genera Several genera among the flowering plants merit listing here because of the number of species found in the New Guinean Region. Certainly, the genus of figs, *Ficus*, with ca. 150 species in New Guinea, would be a key genus for its many species, its importance as a food plant for many vertebrate species, and for the prodigious nature of its largest strangler trees. The various species of strangler figs are wonders of New Guinea's rainforests, with their great networks of stems and roots forming a vast superstructure of connected wood but without a formal trunk to speak of. Stranglers form when a bird or fruit bat drops a fig seed high in the canopy of a mature tree. The seed germinates on the canopy branch and then sends its sinuous roots snaking down the tree to the ground. Once rooted in the ground, the strangler begins to send out a net of additional stems and roots that eventually entirely covers the trunk of the parent tree and also sends leafy branches upward to shade out the parent. With time, the strangler kills the parent and takes over the space where the parent lived, with dozens or scores of aerial roots reaching down to the ground to provide its own support, now that the parent tree has been killed.

The canopy tree genera *Sloanea* and *Elaeocarpus* (Elaeocarpacae) are an important component of lowland and lower montane forests. Mature species of *Sloanea* exhibit large basal buttresses and produce woody capsular fruits favored by birds of paradise. Various species of *Elaeocarpus* are also an important component of the forest, dropping their dark blue spherical fruits to the ground to be consumed by cassowaries and other ground-foraging vertebrates. The mahogany genera *Dysoxylum*, *Chisocheton*, and *Aglaia* are species-rich and serve as important fruiting trees for birds of paradise and fruit-pigeons. They also produce beautiful timber. Nutmegs of the genus *Myristica* range from the lowlands to the mid-mountains. Small and large trees produce capsular fruit important to birds of paradise and imperial pigeons.

Aerial vista of the Trans-Fly's flooded savanna, with a mix of inundated grasslands, woodland, and forest. Photo: K. David Bishop

Laurels of the genera *Cryptocarya* and *Endiandra* are large hardwood trees of lowland and montane forests. They produce large crops of big-seeded drupes that are favored by fruit-pigeons and cassowaries. Oaks of the genera *Castanopsis* and *Lithocarpus* are prominent members of hill and lower montane forest. *Castanopsis* produces a capsular fruit, much like that of a beech, which is popular with Blue-collared Parrots, among other birds. Some lower montane ridgetops are thickly infested with *Castanopsis*. These trees have a tendency to blow down, breaking at the base of the trunk. When this happens, the roots produce suckers, or volunteer shoots, that quickly grow to replace the fallen parent tree. In New Guinea, the true acorn-bearing oaks reside in the genus *Lithocarpus*. These produce acorns like the familiar ones known from Northern Hemisphere woodlands. The largest acorns of one New Guinea oak grow to 5 centimeters in diameter.

The genus *Rhododendron* is represented in New Guinea by 167 species: 111 species in WNG and 87 in ENG. All New Guinean species belong to the "vireya" division of the *Rhododendron* genus. Most species inhabit the mossy montane forest above 2,000 meters elevation or subalpine shrublands. Some of the species grow epiphytically in the montane forest canopy or near the ground in clearings caused by landslides and treefalls. That said, the various *Rhododendron* species range from a tiny alpine-dwelling dwarf herb with recumbent vegetation rising no more than a few centimeters above the soil (*R. saxifragoides*) to a robust woody treelet with gorgeous red flowers as large as 10 centimeters across the corolla, often seen growing profusely high in the mossy canopy of giant podocarp trees of the Huon Peninsula (*R. hellwigii*).

Rhododendrons are beloved around the world by gardeners and horticulturalists, and many species are now in cultivation. New Guinea supports what is perhaps the most wonderful adaptive radiation known of these attractive flowering shrubs, which have dispersed and evolved rapidly to occupy a wide range of niches offered by the great island. Although the genus is primarily montane and forest dwelling, individual species can be found in virtually every natural habitat on the island. Researcher Peter Stevens has written about the adaptive radiation of rhododendrons, especially with respect to flower color and morphology and their relationship to animal-pollinator and pollination ecology. In particular, the rhododendron species with small red tubular flowers are pollinated by honeyeaters of the genera *Melidectes* and *Melionyx*; the species with long and narrow white tubular flowers are pollinated by sphinx moths (Sphingidae); and the species with large, broad white flowers are pollinated by bats.

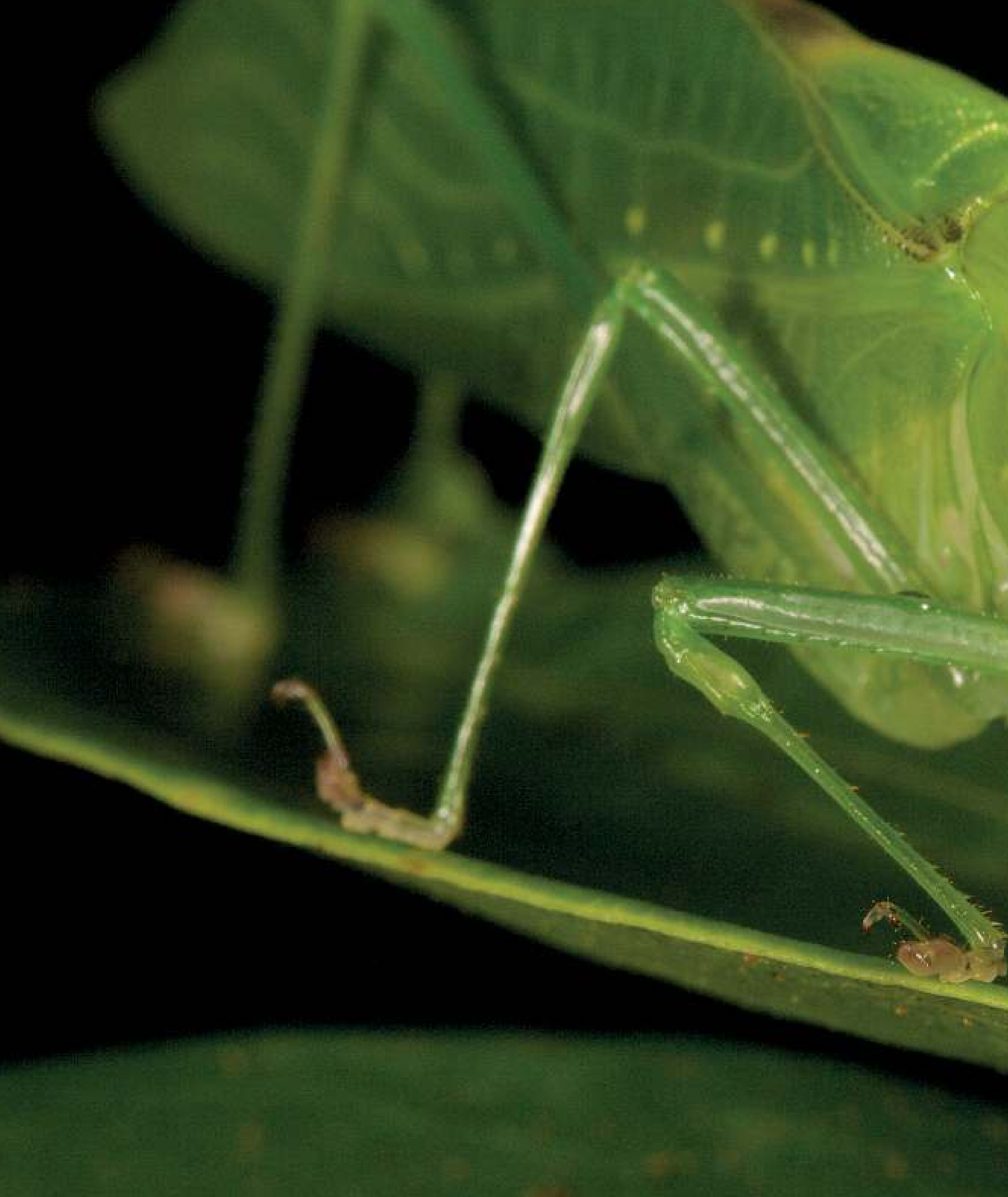
Orchids If the rhododendrons of New Guinea are fabulous, the orchids are simply out of this world. New species of this hyper-diverse family continue to be collected and described from New Guinea. Of course, the comparison is not fair, because *Rhododendron* is but a genus while the orchids compose a family. The family Orchidaceae comprises 25,000 species—constituting the largest family of flowering plants—and has a global distribution. New Guinea is home to ca. 2,850 species of orchids (only the northern Andes has more), and thus New Guinea supports 11 percent of the world's orchids. Of the world's 800-plus genera of orchids, ca. 130 genera are native to New Guinea. The Orchidaceae today is recognized as having five major evolutionary lineages, treated as subfamilies. All five of these lineages are represented in New Guinea. The level of species endemism is high—ca. 86 percent of the species are endemic to the New Guinean Region.

Although most orchid species are tropical, the family ranges from north of the Arctic Circle to Tierra del Fuego. Orchids are terrestrial or more commonly epiphytic herbs or sometimes vines. Some species lack chlorophyll and are saprophytic. The size of the orchid plant varies from tiny (a few centimeters) to huge (weighing hundreds of kilograms, in the case of old individuals of the species of the genus *Grammatophyllum*, which occurs in New Guinea). The prime habitat is the canopy of humid montane forest—which New Guinea has in abundance. Eighty percent of New Guinea's orchids are epiphytes. Even though the mountain zone is the orchids' prime habitat, species can be found in coastal beach forest and even in mangroves (they are scarce in dry savanna country). Orchids range up to 4,000 meters elevation. Species richness peaks at between 1,000 and 1,500 meters elevation. Orchids are abundant at even greater elevations, but species richness is not as high. Some species specialize on living on tree ferns that inhabit subalpine grasslands above 2,700 meters. Finally, karst formations are known to be rich in orchids.

As mentioned above, New Guinea's orchid species exhibit 86 percent endemism. By comparison, the family exhibits 74 percent endemism in the Philippines and 31 percent endemism in Java. Endemism in New Guinea is less impressive at higher taxonomic ranks (i.e., above the level of genus). In New Guinea, the preponderance of orchid species inhabit the central cordillera, and individual species tend to exhibit broad ranges east and west. The genus *Bulbophyllum* is especially species-rich in New Guinea. The Dutch botanist André Schuiteman once picked up a recently fallen branch in southern beech forest in the mountains. The branch was 40 centimeters long and 3 centimeters in diameter, and it hosted seven species of *Bulbophyllum*. These were mainly miniature orchids—of which New Guinea has many species. New Guinea also hosts more than 100 species of bird-pollinated orchids, including species in the genera *Mediocalcar*, *Epiblastus*, *Glomera*, *Calanthe*, and *Dendrobium*. As with the rhododendrons, most or all of these orchids are pollinated by species of honeyeaters.

A small epiphytic orchid—*Dendrobium subacaule*—on a fallen tree trunk. Small epiphytic orchids are abundant in the montane forests of New Guinea. Photo: André Schuiteman

Study of pollination specializations in New Guinea orchids will undoubtedly generate some remarkable findings, given the amazing variation in flower morphology. Many orchids are pollinated by insects. A stingless bee trapped in amber was found to be carrying pollen of a Miocene orchid—providing evidence for the age of this plant family as well as the origins of its coevolution with pollinating insects. Traditional use of orchids in New Guinea seems restricted to the harvesting of the tough yellow fibers of species of *Diplocaulobium*, which are woven into armbands and small string bags. These plants are cultivated in rural villages just for this purpose.



7 Invertebrate Life

Arthropods and Allies

THE ARTHROPODS CONSTITUTE the largest and, no doubt, the most poorly known single terrestrial animal group inhabiting New Guinea. This major invertebrate lineage includes the insects, spiders, scorpions, millipedes, centipedes, and crustaceans. Among the arthropods, the insects are probably best known and perhaps of greatest interest to the naturalist. And although the arthropods are the most species-rich invertebrate group in New Guinea, there are many other terrestrial invertebrate lineages well represented on the great island. New Guinea is home to mites, fleas, annelids, and flatworms, terrestrial mollusks, and other lesser-known invertebrate groups.*

New Guinea's insect fauna is so species-rich and yet so poorly known that there is no comprehensive taxonomic list of this group for the island. Entomologist Scott E. Miller has estimated 300,000 species for New Guinea's insect fauna. This is based on extrapolation from the patchy data available for the group. (The only major lineage that has received a comprehensive taxonomic review is the order Diptera—the flies.) The work of Vojtěch Novotny and colleagues on the leaf-eating arthropod fauna of New Guinea has led to the estimate that there are ca. 6 million plant-eating arthropods on Earth, giving us a sense of New Guinea's contribution to this number (5 percent of the global total).

In spite of New Guinea's relative geological youth, the insect fauna is very rich and approaches that of mainland Southeast Asia. When the two are compared, New Guinea exhibits fewer genera but typically more species per genus—evidence that there has been a lot of rapid speciation on the island. A study of cicada species' distributions highlighted areas of

Preceding pages: This large katydid, a favored food of birds of paradise, is a common forest dweller.

Opposite: A blue *Eupholus* jewel weevil on a fern leaf. Species of this weevil genus are common in lowland swidden gardens and edge.

* Sources for this chapter include Miller (2007), Marshall and Beehler (2007), Short (2008), Parsons (1991, 1998), Gressitt and Hornabrook (1977), Gotts and Pangemanan (2010), and additional publications appearing in the references section

endemism in the Bird's Head, the central cordillera, the north coastal ranges, the Southern Lowlands, and the SE Peninsula. These align pretty well with areas of endemism for birds.

New Guinea is home to a selection of large and showy insects. These are popular with collectors around the world, which has led to local insect farming and commercial collecting to satisfy the considerable global demand. The trade has been formalized in PNG and has been managed by a government entity known as the Insect Farming and Trading Agency, (based at the University of Technology in Lae since 2009). Private enterprises sell insects from WNG as well. The most popular collectibles are species of birdwing butterflies, large beetles, and oversize stick insects. The question regarding this trade has always been the same: Is it environmentally sustainable? Most of the specimens sold have not been truly farmed but instead are collected as pupae in the wild and hatched out in captivity.

A green, spiny stick insect. These harmless plant-eaters come in various forms, some quite large, and most closely resemble a stick, twig, or leaf. Some are mainly brown, and others are mainly green. Photo: Piotr Naskrecki

Ticks, Chiggers, Mokkas, and Lice These are widespread as ectoparasites in New Guinea. Ticks appear to be relatively uncommon as a pest of humans, but for fieldworkers, chigger infestation is one of the most unpleasant and annoying of the commonplace experiences. The problem is that the fieldworker does not know he or she is being infested until it is too late. Once the swelling and itching begin, there is little the sufferer can do besides applying some sort of palliative treatment. In some instances, chigger rashes may last several weeks. The chigger-generated dermatitis is mainly caused by infestation by an early instar (young nymph) of species of *Eutrombicula* chiggers. Reptiles appear to be the primary host for these species. If the chigger-bite sites are scratched, the possibility of acquiring a secondary staph infection is considerable—the result being a painful tropical ulcer (typically on the lower leg). Chiggers of the genus *Leptotrombidium* are vectors for the disease known as scrub typhus, tsutsugamushi disease, or chigger-borne rickettsiosis. This disease was widespread in New Guinea during World War II and caused many fatalities. Interestingly, *Leptotrombidium* chiggers do not cause the annoying dermatitis associated with the bite of *Eutrombicula*. The primary hosts for *Leptotrombidium* chiggers and for the disease are rats.

Butterflies This fauna includes some of New Guinea's crown jewels—the birdwings, which encompass the largest butterflies known. There are ca. 924 species of butterflies recorded for New Guinea. This compares with ca. 400 for Australia, ca. 4,000 from Africa, and ca. 4,800 from South America. New Guinea's butterfly fauna comprises five families and ca. 108 genera. Many species are endemic to the island, but there are also widespread species, such as the Monarch, which has a nearly worldwide range. The genus *Delias*, of the whites (family Pieridae), has explosively speciated in New Guinea and is represented there by 104 species. In spite of the small size of the butterflies, *Delias* is very popular with collectors because of the colorful and intricate patterns on the hind wings. Worldwide the genus has more species than any other (ca. 165) and ranges from Nepal to the Solomon Islands and Australia.

The true birdwing butterflies, members of the genus *Ornithoptera*, are represented in New Guinea by eight species. These very large swallowtail relatives are among the most marvelous of butterflies. The 13 species of the genus range from the Moluccas east through New Guinea to the Solomon Islands and south to Australia. The group's range is centered on New Guinea, and no other place on Earth has as many birdwing butterflies. Here we consider birdwings in the strict sense and do not include the genera *Troides* or *Trogonoptera*. The true birdwings are all sexually dimorphic (differently shaped) and sexually dichromatic (differently colored). The males are smaller and colorful—they tend to be patterned black, green, and yellow, with iridescence—and exhibit varied unusual wing shapes. The females are larger, patterned in black and white, sometimes highlighted with yellow and spots of red. The female wing shape is the same across the genus.

Birdwing butterflies lay their eggs on species of pipevine (Aristolocaceae), which provide the caterpillars with alkaloids that make them distasteful to predators. Presumably the adult butterflies possess this chemical defense as well—it would be expected of such showy and large insects. For naturalists, a firsthand encounter with one or more species of birdwing butterflies is among the highlights of any visit to New Guinea—along with seeing a bird of paradise in the wild. These butterflies—gliding slowly through the subcanopy of a forest opening, with the sunlight striking the iridescent colors of the wings—exemplify the glorious elaborations of nature's beauty.

A large female Giant Golden Orb Weaver (*Nephila pilipes*) consuming a green skink that blundered into its web.

Queen Alexandra's Birdwing Butterfly is the most wonderful of the birdwings. The male has a wingspan of 20 centimeters and the female a wingspan of 25 centimeters. The male's forewings and hindwings are narrow and elongate and handsomely patterned in iridescent blue-green and velvety black. This species is endemic to a tiny range (a mere 104 square kilometers) in the northern lowlands of the SE Peninsula—mainly in the vicinity of

A mother scorpion guards its offspring. Scorpions are commonplace in New Guinea but rarely seen, as they are very retiring.

Popondetta, Mount Lamington, and the Managalase Plateau. Locally not uncommon, the species can best be seen at the flowers of the non-native *Bauhinia* tree in village clearings and other openings in the forest. Seeing the male and female interact above one of these flowering trees is transformative—one is seeing nature at its most beautiful and extreme.

A colorful land crab from Batanta Island (NW Islands). It is not uncommon to find small crabs inhabiting the floor of lowland forest interior. Photo: Staffan Widstrand

A small lowland butterfly, *Delias lara*, of the whites family (Pieridae). The genus *Delias* has more species than any other in the region and is very popular with collectors, as many species are handsomely patterned in various colors.

Moths Members of the order Lepidoptera, like the butterflies, moths are found in New Guinea in abundance. An estimated 10,000 species of moths occur in the region. The second largest moth on Earth, the Hercules Moth, in the family Saturniidae, is widespread in New Guinea. This giant has a wingspan of 28 centimeters. The male, with its long tails, is the longest moth on Earth and has the greatest wing surface area, but the Atlas Moth of Southeast Asia has a slightly broader wingspan. New Guinea's rainforests are inhabited by a profusion of moths, mainly what are known as "micro-leps"—small and often plain and difficult-to-identify moths that forage on the diversity of plants that populate the rainforests.

Entomologists survey moths by hanging a white sheet in a forest clearing and shining a black light onto it. The moths at night are drawn to the light and settle on the sheet, where they can then be photographed or collected using forceps. This method is most productive on gloomy nights with cloud and mist. At these times, hundreds of species may be drawn to the sheet, most of them smaller than a centimeter in length. Whereas the wonder of the Queen Alexandra's Birdwing Butterfly derives from its size and beauty, the wonder of rainforest moth diversity derives from the profusion of species and their varied shapes and colors.

Beetles The beetles compose the order Coleoptera—reputed to be the most species-rich order of animals. Evolutionary biologist J. B. S. Haldane, on being asked what one could conclude as to the nature of the Creator from a study of his creation, is reported to have replied, "God has an inordinate fondness for beetles." According to entomologist and beetle expert J. L. Gressitt, the New Guinean Region is home to ca. 100 beetle families, comprising 25,000 species of the quarter million estimated for the world at large. Thus beetles are hyper-diverse in New Guinea, and as with the moths, most beetle species

are tiny—mainly under 5 millimeters in length. Collectors and beetle fanciers around the world love to exhibit the big and showy species that are the glory of the beetle world. New Guinea has these in numbers, boasting the largest or the most beautiful of certain lineages. Favorites include members of the stag beetles (Lucanidae), bessbugs (Passalidae), scarabs (Scarabaeidae), flower chafers (Cetoniinae), rhinoceros beetles (Dynastinae), metallic wood-borers (Buprestidae), longicorn beetles (Cerambycidae), leaf beetles (Chrysomelidae), and weevils (Curculionidae). The weevils, well represented in New Guinea in some very handsome and colorful forms (e.g., *Gymnopholus*, *Eupholus*), are reputed to be the most species-rich animal family on Earth. Perhaps the largest beetle in New Guinea is the longicorn beetle *Batocera wallacei*; some individuals have bodies 10 centimeters long and antennae 15 centimeters long.

Previous pages: A collection of moths made in just one night during an expedition into the foothills of the Foja Mountains near Kwerba village. Moth diversity in New Guinea is extraordinary, and many new species certainly remain to be described.

Opposite: Entomologist Henk van Mastrigt examines a tray of Hercules Moths (*Coscinocera hercules*) in his large insect collection at Sentani (NW Lowlands, WNG). This collection is now held by the Universitas Cenderawasih in Waena, a suburb of Jayapura, WNG.

Two color morphs of a giant horned lucanid beetle of the genus *Lamprima*. Oversize beetles are fairly common in New Guinea and are popular with collectors. Why does New Guinea have lots of large insects? Probably because it has lots of insects of all sizes (a product of sampling).

Stick Insects The stick insects, which make up the order Phasmatodea, are represented in New Guinea by many different species, including both very large and very well-camouflaged species. Some approximate a green branch and can be more than 25 centimeters long. Others are brown and include spiny or leafy outgrowths to approximate dead vegetation. One species, a member of the family Phylliidae, perfectly matches a yellowed leaf with insect-feeding damage. Some stick insects are recognized as agricultural pests. The species *Graeffea crouani* attacks coconut plantations.

Katydids Common in rainforests, katydids (family Tettigoniidae) grow to prodigious size in New Guinea. The species *Siliquofera grandis* is a large, green leaf mimic that may reach 10 centimeters in length. Another, similar species has the coloration of a dead and dried leaf. Katydids are common prey of arthropod-eating birds, especially the birds of paradise.

Cicadas The cicadas (superfamily Cicadoidea) are a plant-eating lineage of insects within the order Hemiptera—the true bugs. They are widespread in New Guinea's forests, and are an important part of the New Guinean soundscape. Some species begin their loud shrilling every night at dusk and have received the name "six o'clock cicada." New Guinea is home to ca. 150 species of cicadas. Each species has a distinctive and species-specific sound. This ancient lineage is known from Permian fossils.

Spiders Arthropods but not insects, spiders are arachnids, displaying eight legs, not the insects' six. New Guinea is rich in spiders, though they are poorly surveyed, and many of the region's species remain to be described. About 40 families—more than half of the world's known spider families—have been recorded in New Guinea, which hosts no known endemic spider families. There is no comprehensive taxonomic list of the region's spiders; Chrysanthus estimated that ca. 500 species of spiders had been described for New

A large millipede of the genus *Acanthiulus* from the Muller Range (Border Ranges, ENG). Millipedes are common inhabitants of the forest-floor leaf litter in New Guinea. When harassed, some species are known to exude a noxious fluid to avoid predation. Photo: Piotr Naskrecki

Papua New Guinean parataxonomists working with the massive rainforest moth collection at the Binatang Research Center, Madang (ENG). A large team of young field technicians makes large-scale biodiversity surveys of arthropods possible for an international alliance of scientists asking questions about the causes of insect abundance in the tropical rainforests of the world.

Guinea as of 1972. One must assume that this count included well under half of the existing species. Most New Guinean spiders are small, probably less than 5 millimeters long. New Guinea does host large spiders as well. The most commonplace large spider is *Nephila pilipes*, the Giant Golden Orb Weaver. It is widespread in gardens and other open habitats in New Guinea. The large female may grow as big as 15 centimeters across (measurement includes the long, spindly legs). This species is sometimes known as the bird-eating spider. On occasion, small songbirds or skinks do get caught in its very large web.

Crustacea Another arthropod group, Crustacea includes the crabs, crayfish, shrimps, lobsters, krill, woodlice, and barnacles. New Guinea is home to species from all these groups; best known are the crabs and crayfish. Here we focus on the non-marine forms (see chapter 15 for the reef dwellers). J. W. Short noted that the freshwater ecosystems of New Guinea support the most diverse assemblage of 10-legged crustaceans on Earth—mainly shrimps, crayfishes, and crabs. The single family of freshwater crabs (the Paratyhelphusidae) is represented in New Guinea by 16 species. Many of these small crabs are semiaquatic and burrowing. They can be encountered in the interior of lowland rainforest. About 15 species from the crayfish family Parastacidae are known in New Guinea. They are confined to the southern watershed of the island, but range up into the Baliem Valley and Paniai Lakes. Shrimps or prawns of the families Palaemonidae and Atyidae range in streams and rivers, up to an elevation of 1,700 meters. Species of these families range widely through the Indo-Pacific. ■

8 Ichthyology

Freshwater Fishes

NEW GUINEA IS FAMOUS for its rainbowfishes, small and colorful and much desired by aquarium hobbyists, but also boasts a wide range of freshwater and estuarine forms: sawfish, eels, herrings, catfishes, tandans, blue-eyes, giant perches (represented in New Guinea by the Barramundi), perchlets, grunters, flagtails, gudgeons, gobies, and more.*

Overall, New Guinea supports more than 2,700 species of freshwater and marine fishes. Although New Guinea boasts one of the richest marine fish faunas in the world (discussed in chapter 15), only ca. 458 species of native fishes have been recorded from the fresh waters of the great island, 100 of which are primarily estuarine. Thus, only about 350 species are exclusively freshwater dwelling and native to New Guinea. By comparison, Borneo features ca. 400 species of freshwater fishes, and the Amazon basin a whopping 5,600-odd species. In spite of its relatively impoverished freshwater fish fauna, New Guinea is home to a range of interesting and distinctive species and genera, which are treated in this chapter. At least 21 exotic freshwater species have been introduced to the island, and various major rivers are now inhabited by these species, creating peril for the endemic fishes.

The freshwater fishes of New Guinea came to the attention of naturalists only in the 1860s and thereafter, later than the birds. Given the difficult and dangerous conditions during the colonial period, most fish collections came from the coast and the lower navigable sections of the larger rivers. The Dutch took the lead on this ichthyological exploration, followed by the Australians. To get an idea of the state of New Guinean ichthyology, consider

Preceding pages: A Roberts's Goby (*Glossogobius robertsi*) from the Fly River watershed (ENG) and the Ajkwa River near Timika, in the western sector of the Southern Lowlands (WNG). Photo: Gerald Allen

Opposite: Aerial image of Lake Kutubu—home to more endemic fishes than any other lake in New Guinea. Photo: Gerald Allen

* Sources for this chapter include Allen (1991, 2007), Allison (2007b), and publications listed in references section.

that the work of Gerald Allen between 1979 and 2017 resulted in the description of 132 novel species of freshwater fishes. Presumably there is still work to be done.

Because of New Guinea and Australia's common tectonic underpinning, and their periodic dryland connection, the two landmasses share most families and genera of freshwater fishes. Importantly, the rainbowfishes (Melanotaeniidae) and the related blue-eyes (Pseudomugilidae) are endemic to Australia–New Guinea. The Australia–New Guinea ichthyofauna is very different from that of Southeast Asia, Africa, and South America. The latter areas tend to be dominated by cichlids, carps, barbs, loaches, characins, and catfishes. Virtually all the fishes of the Australia–New Guinea region were derived from marine ancestors. This is believed to be a product of the region's 30-plus million years of absolute geological isolation from other continental areas—the period after the breakup of Gondwanaland, as the Australian continent drifted relentlessly north toward the equator.

The Dutch ichthyologist Max Carl Wilhelm Weber delineated an important zoological boundary in 1919—known as Weber's Line—lying just to the west of the Moluccan island of Halmahera and well to the east of the more famous Wallace's Line. It marks an important faunal break between the fishes of New Guinea and those of island Southeast Asia. Weber envisioned this break as a line of "faunal balance" between the Oriental and Australian faunal regions.

We have no evolutionary details of the present New Guinean freshwater fish fauna. No fossils have been found. As many as seven species of lungfishes once inhabited northern Australia, and the extant *Neoceratodus forsteri* (the Australian Lungfish) of eastern Australia has remained virtually unchanged for 100 million years. However, lungfishes did not survive in New Guinea. Perhaps the most ancient fish still found in New Guinea is the Saratoga, a member of the primitive bony tongue family, Osteoglossidae. The family apparently evolved in fresh waters of the Southern Hemisphere, and although it is probably considerably older, its fossil records date back as much as 50 million years. That family is also represented today in Southeast Asia, South America, and Africa.

The core of New Guinea's fish fauna comprises the catfishes, atherinoids (including rainbowfishes, blue-eyes, and hardyheads), gudgeons, and gobies—all of marine origin. Presumably these groups arrived in New Guinea as it rafted northward from Antarctica and closer to Wallacea. Today, the freshwater fishes of New Guinea can be partitioned into northern and southern faunas—the latter being, by far, the richer of the two—a result of its age, affiliation with the Australian craton, and its long, stable history. The northern fauna is of more recent origin, a product of the plate collision and complex arc accretion. This impoverished northern fish fauna apparently evolved from the richer southern fauna and was isolated by the uplift of the central cordillera that took place over the past 10 million years.

The uplands of the central cordillera are largely free of native fishes. No indigenous species have been recorded above 2,000 meters elevation. Most native fishes in the mountains are restricted to the waters of flat basin bottoms of interior valleys. The only exceptions are a few gudgeons and freshwater eels, which penetrate fast-flowing torrential streams. Endemic species are found in various lowland regions: the NW Islands, the Bird's

Above: Threadfin Rainbowfish (*Iriatherina werneri*), from the Trans-Fly. Photo: Gerald Allen

Left: Ichthyologist Gerald Allen photographs a recently-captured fish in a jungle camp, watched by local naturalists. Photo courtesy: Gerald Allen

Red-striped Rainbowfish (*Melanotaenia rubrostriata*) male, from the Southern Lowlands. The most abundant rainbowfish in the Fly system, particularly in the middle and upper portions of the catchment, it is also found at Daru Island near the Torres Strait. Photo: Gerald Allen

Banded Mogurnda (*Mogurnda cingulata*), from the upper Fly watershed. Photo: Gerald Allen

Head, the NW Lowlands, the Sepik-Ramu, the northern lowlands and the southern lowlands of the SE Peninsula, the Southern Lowlands, and the Aru Islands. Lake Kutubu (in the southwestern sector of the Eastern Ranges) is home to 13 native species, 11 of which are endemic. The Aru Islands are also remarkable for their seven endemic rainbowfish species.

Fish Environments Lowland rivers are probably the most important freshwater fish habitat in New Guinea. Their waters are typically turbid, and the bottoms silty. Aquatic

Obbes's Tandan (*Porochilus obbesi*), from the rivers of the Southern Lowlands. Photo: Gerald Allen

Tiger Goby (*Pseudogobiopsis tigrellus*), from the middle portion of the Mamberamo River system of the NW Lowlands. Photo: Gerald Allen

vegetation is generally poorly developed. Ariid catfish (family Ariidae) are common, as are a number of vagrants from the marine realm—croakers, silver biddies, ponyfishes, and juvenile trevallies. Coastal streams are an important habitat with good water clarity, generally flowing through coastal rainforest. Blackwater streams are abundant as rainforest tributaries of larger river systems. These clear-water streams can support substantial fish faunas—ariid catfishes, rainbowfishes, gobies, garfishes, glassfishes, and gudgeons. Blackwater streams close to the coast may host a range of marine or estuarine species. Swamps, backwaters, and floodplain lakes in the lowlands are rich in fishes, especially in the south. Prominent examples include Lake Murray (in the Fly watershed), Chambri Lakes (in the Sepik), and Lake Rombebai (in the Mamberamo). In these environments, the water tends to be clear, and growth of aquatic vegetation is substantial. Such places support species of rainbowfishes, gobies, gudgeons, and ariid catfishes. Hill forest tributaries of major lowland rivers generally host 6–12 species: eel-tailed catfishes, rainbowfishes, hardyheads, grunters, gudgeons, and gobies. Highland rivers in general are very species-poor. Upland lakes are commonplace but also tend to be species-poor, especially at higher elevations. Many of these have received donations of non-native carp and trout from well-meaning expatriate residents with a bent for fishing or with the intent of creating new protein sources for local villages. Trout inhabit Lake Aunde on Mount Wilhelm, at 3,400 meters elevation. The highest-dwelling native species is the Paniai Gudgeon, which inhabits one of the Paniai Lakes at 1,750 meters above sea level. Many species of rainbowfish are endemic to single lakes or sections of waterway.

A tourist boat cruises along the Sepik River. The river is home to a number of exotic fish species that may be impacting the health of the native fish fauna. Photo: Gerald Allen

Some lake habitats and their fish faunas are vulnerable to threats. For instance, Lake Sentani, in northeastern WNG, adjacent to the capital city of Jayapura, is the type locality (the place where a novel species was collected the very first time) for four endemic fish species. Today the burgeoning human populations of Sentani and Abepura have produced serious lake pollution as well as the introduction of various exotic invasive fish species such as walking catfish. Fish farming of non-native species is widespread in Lake Sentani. Overharvesting of the lake's native fishes may also pose a threat to its four endemics (two rainbowfishes, one gudgeon, and one goby). Thirty-four fish species have been recorded from the lake, of which 13 are resident natives, 8 anadromous, and 13 introduced. A population of sawfish, which grew to a length of 3 meters, was well known in the lake until the 1970s but now appears to have been extirpated.

Lake Kutubu, with its 11 endemic fish species, is one of ENG's rainforest jewels, situated in hilly country at 800 meters above sea level in the drainage of the Kikori River, long isolated in New Guinea's rugged interior. Over the last three decades, Western development has arrived in a big way. First came a massive Chevron-led oil project that led to the creation of a major petroleum facility just west of the lake, in a place called Moro. This has been followed by an Exxon-led liquid natural gas project upstream and the construction of a pipeline right-of-way to the coast, used by both projects. How will these giant industrial operations impact the lake and its fishes? This is currently under study by staff of the Australian National University.

The Fly River is New Guinea's largest river as measured by flow. This great river and its tributaries are home to 103 species of fishes, 17 of which are endemic to the Fly basin. At the headwaters of the Fly lies the giant Ok Tedi open pit mine, which has been harvesting copper and gold from the Mount Fubilan lode since 1984. Since the mine did not construct a tailings dam, much of the toxic residue of the mine waste (lead, arsenic, mercury, and cadmium) has washed downstream into the middle reaches of the Fly. How have these toxins affected the Fly fishery?

IMPORTANT NATIVE FISH GROUPS

Fifty-two of the more than 425 families of fishes are represented in the freshwaters of New Guinea. We briefly review them below.

Sharks are represented by three species—the Bull Shark and two little-known species, the Speartooth Shark and the Northern River Shark. The globally widespread Bull Shark commonly invades estuaries and freshwater habitats far from the coast. The **sawfishes** are represented by a single species in New Guinea. This marine species invades interior waters, including the Digul, middle Fly, Sepik, and Ramu Rivers; formerly, it was also known from Lake Sentani. It prefers turbid channels with mud bottoms. Two species of **whiptail stingrays** are known from New Guinea's fresh waters.

The **bony tongues** are primitive bony fishes mainly inhabiting the Southern Hemisphere. A single species, the carnivorous Saratoga, inhabits the southern bulge of New Guinea (the Trans-Fly), as well as Australia, and grows to 90 centimeters long. In this species, the female broods her young in her mouth. The **tenpounders** are represented in New Guinea by the Giant Herring, which grows to 70 centimeters in length. The Oxeye Herring, which grows to more than 100 centimeters, is a New Guinea member of the **tarpons**, sport fishes found mainly in tropical waters.

Five species of **freshwater eels** are found in New Guinea. The largest individuals, growing to well over a meter in length, are popular food fish for villagers in the lowlands of southern New Guinea. A single species of **moray eel** can be found in fresh water in New Guinea. **Snake eels** are known in New Guinea from a single species that grows to 40 centimeters.

The **herrings** are a globally important commercial fish family; five species occur in fresh water in New Guinea. These silvery schooling fish can grow to 23 centimeters long. The **anchovies** have a global distribution and are represented in New Guinea by two species in the Southern Lowlands. The Freshwater Anchovy grows to 38 centimeters. The **milkfishes** include a single species that can grow to 180 centimeters.

The **fork-tailed catfishes** are wide-ranging and include 21 species in New Guinea. The largest species grow to 115 centimeters. The **eel-tailed catfishes** inhabit the Indo-Pacific in both marine and fresh waters. Fourteen species inhabit New Guinea; the Papuan Tandan, the largest species, may grow to a meter or more. A single species of **frogfish** has been found in New Guinea, as have nine species of the worldwide **garfish** family. A single **longtom** or needlefish, growing to 60 centimeters, is recorded from the island.

The **rainbowfishes** (family Melanotaeniidae), whose members are restricted to New Guinea and Australia, is New Guinea's most famous freshwater family. These are very popular aquarium fish. Recent genetic studies reveal there are far more species than previously believed. The ca. 99 New Guinean species are all less than 15 centimeters in length. They are shiny-scaled, and many have variations of colored striping and/or one or more black longitudinal stripes. These schooling fish inhabit streams, lakes, and swamps. Many of the New Guinean species, recently described, have tiny known distributions.

The **blue-eyes** (family Pseudomugilidae) are similar to but mostly smaller than the rainbowfishes and exhibit a similar geographic distribution, restricted to the Australia–New Guinea region. Eighteen species inhabit New Guinea, the largest growing to 25 centimeters. These too are popular aquarium fish, and some of the species are quite handsome, with ornamental fins.

A single **tailfin silverside** is known from New Guinea. The **hardyheads** are small silver-sided schooling fish sometimes know as Old World silversides. New Guinea hosts eight species, the largest growing to 10 centimeters, and all with some longitudinal striping. The **pipefishes** mainly inhabit tropical and temperate seas, but in the New Guinean Region 12 species are restricted to fresh water. This family also encompasses the seahorses, which are marine dwelling.

The **swamp eels** have a single species, the One-gilled Eel, in New Guinea. It grows to 55 centimeters. One **waspfish** is recorded from New Guinea. The **giant perches** include the famous sport and food fish the Barramundi, which is the only member of this family found in New Guinea. This widespread species can grow to weigh 60 kilograms. The New Guinean population is found only in the Southern Lowlands and the Trans-Fly.

The **glass perchlets** are large-eyed, silver-sided small fish; 15 species are known from the fresh waters of New Guinea. The **grunters** are small or medium-size, perch-like fish that inhabit the Indo-Pacific region. The largest species of this group of 18 species reaches 46 centimeters. Two species of **flagtails** inhabit New Guinea's fresh waters. Eleven species from the **mouth-almighty** family are recorded from the island's fresh waters. These large-mouthed species are predators of other fishes and crustaceans. The family also includes the marine-dwelling cardinalfishes. One **smelt-whiting** has been recorded from New Guinea.

The **trevallies** or jacks are widespread marine fishes that favor tropical reefs; the Bigeye Trevally and the Brassy Trevally enter fresh water when young. The **ponyfishes** are known from New Guinea by a single species (Common Ponyfish) that is primarily marine. The **snappers** are mainly marine fishes of the tropics and subtropics. Some species are in high demand for the dinner plate. Four species are found in the fresh waters of New Guinea; one, the Mangrove Jack, grows to 16 kilograms.

Tigerperches are a small family of Southeast Asia and New Guinea. Campbell's Tigerfish, growing to 30 centimeters, is endemic to southern New Guinea and the Trans-

The Spotted Scat (*Scatophagus argus*), widespread in coastal streams, penetrates freshwater sporadically from mangrove habitats. Photo: Gerald Allen

Fly. The **silver biddies** are a tropical, mainly marine family with a single species in New Guinea's fresh waters. The **croakers** are a large family of marine and estuarine species; a single species that reaches 64 centimeters in length dwells in the fresh waters of New Guinea. The **grunts**, **porgies**, and **silver moonfish** are each known from a single species in the region, while the **scats**, which are similar to butterflyfishes, are known from two species.

The Indo-Pacific **archerfishes** are famous for their ability to squirt a jet of water from their mouth to knock insect prey out of overhanging vegetation; three species occur in New Guinea. The **damselfishes** are a large family of primarily tropical reef fishes; New Guinea's fresh waters host three species.

The **mullets** are a well-known temperate and tropical fish family with 70 species. Twelve species inhabit New Guinea, the largest reaching 60 centimeters. These are popular food fishes for New Guinean coastal villagers. The **blennies** are small colorful tropical fishes with three freshwater species in New Guinea. The best known, the Threadless Blenny, grows to 8 centimeters. The single New Guinean species of **loach goby** grows to 25 centimeters.

The **gudgeons** comprise 170 species with a worldwide range. New Guinea boasts 66 species. The largest grows to 40 centimeters. The **gobies**, with ca. 2,000 species, constitute the largest family of marine fishes. Members of the family also inhabit estuarine and freshwater habitats, and it is also the largest family of freshwater fishes in New Guinea, with at least 100 species. Most are dull-colored with dark spotting, but some are colorful.

The Golden-red Cling Goby (*Stiphodon rutilaureus*) ranges from Bali to New Caledonia. In New Guinea it is known from only a few records. Photo: Gerald Allen

They are bottom dwellers that feed on crustaceans, worms, small fish, and mollusks. The worm-gobies are now treated as members of the true gobies.

Nurseryfishes are small and strange-looking, known from New Guinea by a single species that grows to 50 centimeters. The **tongue soles** are known by a single estuarine and freshwater species in New Guinea. The **true soles** have eight species in the region. And the **toadfishes** (also known as puffers) are represented in New Guinea's freshwater habitats by three species.

DANGEROUS FISHES

Many people know about the death of Australian TV personality Steve Irwin from the sting of a large ray in coastal waters off Queensland, Australia. Like Australia, New Guinea hosts some fishes that readers should be wary of. The Bull Shark inhabits estuaries, rivers, and even lakes, often far upstream from the coast. The species has been reported from Lake Yamur, on the Bird's Neck, 130 kilometers from the sea. Large specimens are known to attack swimmers and waders in murky waters.

Many fishes exhibit spines, and in some species, these spines can exude a venom. Species of eel-tailed and fork-tailed catfishes exhibit a venomous spine at the front of the first dorsal fin and the pectoral fins that can inflict a painful puncture wound. Care is needed when handling these venomous species. Soaking the wound in very hot water denatures the protein toxin and provides relief, but serious wounds should receive medical attention. The only fishes that cannot be eaten, because of the toxicity of some internal organs, are the pufferfishes, although other species (e.g., the morays) may cause ciguatera poisoning.

FRESHWATER FISHERIES

The freshwater fishery in New Guinea is limited and certainly most prominent in WNG, because fish is such an important component of the diet in Indonesia. That said, in WNG, most fish sold in open-air markets is of saltwater species. In ENG, Barramundi is caught for the restaurant trade but generally is not available in supermarkets. Most fish captured for consumption goes to address subsistence needs in lowland village communities. The fish are captured by net, by spear, and by hook, and most harvest is carried out by women and children. The economic importance has been little studied to date, but it is likely that freshwater fish provide an important protein source for communities of the interior lowlands.

THE PROBLEM OF EXOTIC SPECIES

Gerald Allen reports 21 exotic fish species that have been deliberately introduced into the fresh waters of New Guinea since 1949. It is expected that more have been introduced of late. In one instance, a multiyear United Nations Development Programme project was established to deliberately introduce edible exotic fish species into the watershed of the Sepik River with the intention of aiding local communities. Such a project today would be unthinkable.

Most introductions have had a negative impact on the fisheries of New Guinea. That said, the African Tilapia is now an important food fish for villagers in many places across the island. The expert opinion is that virtually any introduction of exotic fishes into freshwater habitats that support native fish populations will potentially harm the native fish populations. These introductions are uncontrolled experiments in interspecies competition that tend to end badly for the less competitive native forms.

Here is a list of those species introduced and established in New Guinean fresh waters: Goldfish, Common Carp, Silver Barb, Copper Mahseer, Golden Mahseer, Snowtrout, Pacu, Curimatã, Walking Catfish, Rainbow Trout, Mosquitofish, Guppy, Swordtail, tilapia (2 species), Climbing Perch, Snakeskin Gourami, Threespot Gourami, Giant Gourami, Striped Snakehead, and Blue Panchax. The Common Carp is common in the Baliem River, Lake Kopiago, and the Sepik; it is expected to have a negative influence because of its foraging habits and tendency to greatly disturb silty bottoms and create water turbidity. Mosquitofish are now widespread in ENG and probably compete with rainbowfishes. Tilapia are now widespread in ENG and presumed to harm habitat for native species and compete for food. The Striped Snakehead is a voracious predator of fishes, crustaceans, frogs, snakes, and insects. Its presence on the Bird's Head of WNG is bad news for local fish species and other aquatic wildlife. ■

9 Herpetology

Snakes, Lizards, Turtles, and Frogs

THE NEW GUINEAN REGION is home to pythons, death adders, taipans, sea snakes, crocodiles, sea turtles, side-necked and softshell turtles, skinks, monitors, legless lizards, and frogs. New Guinea's herpetofauna totals ca. 815 species—5 percent of the global total. Some groups (sea turtles, crocodiles) are well known and admired or feared, whereas others (frogs) are poorly known and infrequently seen. In this chapter we take a look at the composition of the herpetofauna, its endemism, its major groups, its most remarkable species, and its relationship to humankind.*

New Guinea has long been considered by outsiders to be a dangerous place, not least because of the presence of the Estuarine Crocodile and at least 38 species of front-fanged venomous snakes (including sea kraits and sea snakes). Adventurous individuals who choose to swim in the island's lowland waterholes or wander barefoot in its forest certainly tempt fate. No doubt scores of New Guinean villagers, possibly more, die annually from snakebite, and probably dozens are killed by crocodile attack. This knowledge adds a certain frisson to the experience of Western fieldworkers or ecotourists camping in the rainforest far from a hospital.

Exploration and Discovery The first wave of naturalists who collected the wildlife of New Guinea—people such as Alfred Russel Wallace—focused the majority of their efforts on butterflies, beetles, and birds. None of these are venomous, and many are colorful and beautiful. The snakes, frogs, and lizards were, in the main, left to be collected in later decades by naturalists with broader and more esoteric tastes. Thus the collection,

Preceding pages: Green Tree Python (*Morelia viridis*), in a typical hunting pose at night, waiting for small mammal prey.

Opposite: A Rainbow Treefrog in the lower montane rainforest of Crater Mountain, ENG.

* Sources for this chapter include Allison (2007a, 2007b), Philipp and Philipp (2007), and additional publications that appear in references section.

A New Guinea Tree Boa (*Candoia aspera*), from the lowland forest of Oransbari on the Bird's Head, WNG.

naming, and enumeration of New Guinea's herpetofauna has lagged behind that of the more popular groups.

The major natural history expeditions to the region are discussed in chapter 2. Expeditions and fieldwork particularly important to the herpetofauna are discussed here. R. P. Lesson collected the first specimens of the herpetofauna from New Guinea in 1824, while he was based on the French vessel *Coquille*. Naturalists on the French and Dutch ships of exploration that followed made small collections of amphibians and reptiles. In 1826, Lesson described a number of species from the *Coquille* voyage. French zoologists A. M. C. Duméril and G. Bibron described others in their review of the world's herpetofauna (1836–39).

Wallace and A. B. Meyer collected a few herps from the Bird's Head and farther east in the mid-1800s. In 1872–73, D'Albertis and Beccari ascended into the Arfak Mountains and collected birds and herps in the lands of the Hattam people. In the ensuing years, collections were made in association with colonial and mission-based stations in New Guinea. G. Boulenger described a large number of novel herp species in the late 1800s and early 1900s from collections made across New Guinea. The great expeditions of the early 20th century (described in chapter 2) collected herps, doubling the number of species known from New Guinea. The famous third Archbold expedition made substantial herpetological collections across WNG from north to south and from low to high. Working with these and

A crocodile skink species (*Tribolonotus gracilis*) from the Torricelli Range, ENG. Photo: Jean-Paul Ferrero/ Minden Pictures

other collections, R. G. Zweifel spent six decades at the American Museum of Natural History working mainly on the frogs of New Guinea and elsewhere in the Pacific. He and collaborators described more than 70 species new to science. Herpetologist L. D. Brongersma in the 1960s organized a large expedition that collected from the Digul River lowlands high into the Star Mountains of WNG. More recently, the work of James Menzies, at the University of Papua New Guinea, and Allen Allison, based out of the Wau Ecology Institute and Bishop Museum, studied and described skinks and frogs from many localities in ENG. Rainer Günther of the Berlin Museum carried out herpetological fieldwork in WNG in the 1990s, leading to the description of many new species. Finally, Conservation International mounted nearly a dozen field surveys to little-known sites across New Guinea, discovering scores of new species of frogs and lizards. This work was led mainly by herpetologist Stephen J. Richards but also included other herpetologists on specific field trips in the region. Since the turn of the 21st century, Allison and Richards have led herpetological field studies in both ENG and WNG.

In spite of the efforts cited above, the herpetofauna remains imperfectly known, and in many localities there are species waiting to be described and named by museum scientists. Allison noted that New Guinea's current list of 442 species of frogs is only an approximation of the frog fauna, as at least 100 additional novel species are already in collections and awaiting description. There have been estimates that New Guinea's frog

A New Guinea Forest Dragon (*Hypsilurus* species) from the foothill forest near Kwerba, in the NW Lowlands. Photo: Ulla Lohmann

fauna may grow to include more than 600 species. This is a wake-up call for young herpetologists in New Guinea and elsewhere to get out into the field and continue the effort to fully delineate this very poorly known group.

The Herpetofauna New Guinea is home to 2 species of crocodiles, 19 species of turtle, 442 described species of frogs, 223 lizards, and 132 snakes. Neither caecilians nor salamanders have been recorded east of Wallace's Line.

The frog fauna includes the following families: Bufonidae, Hylidae, Myobatrachidae, Microhylidae, Ceratobatrachidae, and Ranidae. The two species in the Bufonidae (the toads) are non-native and have been introduced: the invasive Cane Toad from South America and the Asian Common Toad from Southeast Asia. The native frog families include water-dwelling lineages as well as species inhabiting leaf litter, moss, and arboreal epiphytes. Many of these are very small, some tiny. The Myobatrachidae, with 7 species in New Guinea, is of Gondwanan origin, and the lineage is more species-rich in Australia. It is the only frog family endemic to Australia–New Guinea. The Hylidae is represented in New Guinea by 87 species in two genera—*Litoria* and *Nyctimystes*. Inhabiting Australia and New Guinea, the Hylidae may also have a Gondwanan origin. The nearly cosmopolitan Microhylidae includes 19 genera in New Guinea and more than 100 species. The Ranidae has a nearly worldwide distribution and includes lineages that will be familiar to most readers (e.g., the North American species

This large monitor lizard, *Varanus salvadorii*, is common and widespread in New Guinea. Photo: Allen Allison of bullfrog or green frog). Fourteen species of this family inhabit New Guinea. Finally, the Ceratobatrachidae, all now in the genus *Cornufer*, includes 9 species in New Guinea.

New Guinea's crocodiles are part of an ancient lineage dating back more than 200 million years. The group includes the New Guinea [Freshwater] Crocodile and the Estuarine Crocodile. The Estuarine Crocodile ranges from Australia west to southeastern India and is known to disperse across salt water. The New Guinea Crocodile is endemic to New Guinea. Allison has noted that this lineage may, in fact, comprise two sibling species, one from the southern watershed and one from the northern watershed. Molecular studies should be able to clarify this issue.

New Guinea's turtles include 6 marine species in two families and 13 freshwater species distributed in three families. The Carettochelyidae includes a single species, the Pig-nosed Turtle, which inhabits New Guinea and Australia. It is a relict form, with fossils tracing back to the Miocene. Another 10 freshwater species are side-necked turtles of the family Chelidae (which includes the snake-necked turtles, genus *Chelodina*). The softshell turtles of the family Trionychidae (2 species in New Guinea) mainly inhabit swamps and lowland rivers of the Southern Lowlands and are probably of Gondwanan origin. The 6 species of sea turtles include 4 species (Green, Hawksbill, Olive Ridley, and Leatherback) that breed on the beaches of the island. All are placed in the Cheloniidae but the Leatherback, which is the sole existing member of the Dermochelyidae. The Leatherback Turtle nests on dark sand beaches of the northern Bird's Head in WNG and also in a few places on the northern beaches of the SE Peninsula of ENG.

New Guinea hosts 223 species of lizards. They are from the families Dibamidae (legless lizards, 1 species), Agamidae (dragons, 20 species), Scincidae (skinks, 134 species),

A *Sphenomorphus* skink from the Foja Mountains (NW Lowlands). Skinks are abundant and widespread throughout New Guinea. Photo: Stephen J. Richards

Bent-toed Gecko (*Cyrtodactylus boreoclivus*), from the Foja Mountains (NW Lowlands, WNG), a new species discovered by Paul Oliver in 2008.

Pygopodidae (snake-lizards, 2 species), Varanidae (monitors, 15 species), and Gekkonidae (geckos, 51 species).

The single dibamid lizard is small and wormlike. This very primitive form lacks external ears, has a scale over each tiny eye, and lacks any forelimbs. The male has vestigial hind limbs used to grip the female during mating. The similar-looking snake-lizards also entirely lack front limbs, and their hind limbs are vestigial; apparently they are related to the geckos. The snake-lizards are capable of producing a very high-pitched squeak. The family is restricted to New Guinea and Australia. The dragons are widespread and iguana-like, readily climbing trees. Many are colorfully patterned and frilled. Some New Guinean species grow to nearly a meter in length and can deliver a nasty bite with their sharp teeth, so they should be handled with caution. The skinks are New Guinea's largest lizard group. Most are small, short-limbed, and long-tailed. The monitors are large or very large lizards. They are handsomely patterned and have rough dorsal skin. The skin is typically used as the tympanic covering at the top of traditional wooden kundu drums. Finally, the geckos are a widespread and species-rich family of small lizards that are most famous for using their specialized feet to scale vertical walls and even walk upside down on ceilings.

There are 132 species of snakes recorded from the region. Most species also occur in Australia. They include species of eight families, all but the first family shared with Australia: Cylindrophiidae (pipe snakes, 1 species in the New Guinean Region); Typhlopidae (burrowing snakes, 11 species); Gerrhopilidae (Indomalayan blind snakes, 9 species); Pythonidae (pythons, 13 species); Boidae (boas, 3 species); Acrochordidae (file snakes, 2 species); Colubridae

A *Lechriodus platyceps* frog from the Foja Mountains hunts on the forest floor.

(colubrids, 28 species); Homalopsidae (mudsnakes or bockadams, 10 species); Elapidae (front-fanged snakes, 55 species, 26 of which are sea snakes or sea kraits).

The pipe snakes are handsomely banded small snakes with minute eyes that live in leaf litter and in the ground. The burrowing snakes and Indomalayan blind snakes are small and wormlike and rarely encountered. The pythons are of Australian origin, and a few New Guinean species are shared with Australia. This family includes large or very large constricting species (discussed below). The boas are small to medium-size in New Guinea and are docile and ground dwelling. Boas also inhabit North and South America and Madagascar, and one species is widespread in the Pacific region. The file snakes are primitive aquatic snakes that inhabit swamps, estuaries, and coastal habitats. Individual file snakes, distinctive because of their baggy and wrinkled skin, can grow to more than 2 meters in length. The colubrids are the largest snake family and are widespread. Most are harmless, though some, such as the Brown Tree Snake, are rear-fanged and mildly venomous. The mudsnakes or bockadams are stout-bodied water snakes that are mildly venomous. The elapid front-fanged snakes include terrestrial venomous snakes as well as the sea kraits and sea snakes. All the truly venomous snakes of New Guinea occur in this last family. They are discussed in a later section, "Venomous Snakes."

Introduced Species The toxic Cane Toad was introduced to islands in the Pacific from South America as a biological control agent for arthropod pests of Sugarcane. It was introduced to ENG to control the Sweet Potato Moth. The toad has prospered in New Guinea but has failed to control the insect pest of concern. The Asian Common Toad was






Some of the frog species captured for study
during a field expedition to the Foja Mountains.
From top, left to right, the species are:
Tree frog (*Nyctimistes* cf. *fluviatilis*)
Frog (*Papurana* species)
Tree frog (*Nyctimystes humeralis*)
Frog (*Cornufer papuensis*)
Frog (*Sphenophryne cornuta*)
Tree frog (*Litoria* species)
Tree frog (*Litoria* cf. *arfakiana*)
Frog (*Oreophryne* species)
Frog (*Papurana aurata*)
Frog (*Choerophryne pipiens*)
Frog (*Lechriodus melanopyga*)

introduced to the Bird's Head of WNG and has spread widely. According to P. P. van Dijk it now inhabits ENG. With similar toxicity to the Cane Toad, this species is unwelcome in new habitats and may pose a threat to native species of snakes and mammals.

Endemism More than 90 percent of New Guinea's frogs are endemic, and about half of these are known from only a single locality. This latter point is, in part, a reflection of the inadequate level of survey but also may be because many species exhibit geographically restricted ranges. It seems some montane lineages are represented by species with ranges confined to single mountaintops. Three of New Guinea's freshwater turtles are endemic to the region. Some 60 percent of New Guinea's lizards are endemic to the island, and ca. 49 percent of New Guinea's snake species are endemic. By contrast 47 percent of the amphibian and reptile genera that occur in New Guinea also occur in Australia.

Comparison with Other Tropical Islands The following species counts compare the herp faunas of the islands of New Guinea and Borneo: frogs, 442 species versus 150 species; turtles, 19 versus 13; snakes, 132 versus 155; lizards, 223 versus 113. Combining all of these, New Guinea hosts 816 species, and Borneo 438 species. Comparing numbers of families on the two islands, New Guinea tops Borneo in every instance except for the snakes. New Guinea probably hosts more species of frogs because of the abundant and diverse humid forest habitats. Borneo probably supports more snakes because it hosts more open and savanna habitats. Borneo has no significant barriers to dispersal, hence has less restricted-range endemism than New Guinea; also, Borneo was formerly connected by land to the rest of Southeast Asia, so many widespread lineages are present (this also explains why bird endemism is relatively low in Borneo compared to New Guinea). In another comparison, New Guinea hosts 442 amphibians and 374 reptiles (not counting the crocodiles), and Madagascar hosts 228 amphibians and 381 reptiles. It appears that New Guinea is the amphibian island, whereas Madagascar is the reptile island. This may be related to the greater abundance of open, dry, and grassy habitats in Madagascar.

Remarkable Species New Guinea has its fair share of remarkable snakes, frogs, and lizards. **Boelen's Python** is a handsomely patterned black-and-yellow/white montane snake that grows to a length of 3 meters. It is much desired by snake fanciers around the world but is very rare in collections and is protected in both WNG and ENG. The **Papuan Python** grows to 4.8 meters and is uncommon in lowland to mid-montane forest throughout New Guinea. It forages mainly for mammals and other snakes. The **Amethystine Python**, known from New Guinea, Australia, and the Moluccas, is the region's largest snake, reportedly growing to 7 meters and weighing up to 90 kilograms. That said, most specimens encountered are considerably smaller.

The **Papuan Monitor**, largely confined to the lowlands of southern New Guinea, is said to be the longest lizard on Earth, reportedly reaching up to 4 meters in length. The largest museum specimen, however, is a mere 2.65 meters long. The **blue-tongued skinks** include several species, at least one occurring in New Guinea. These are the largest skinks and have a prominent blue tongue, which is displayed in a defensive posture.

The **Estuarine Crocodile**, otherwise known as the Saltwater Crocodile or "Saltie," is one of the most fearsome of reptiles, responsible annually for the deaths of humans in Australia and New Guinea. It is the largest living reptile on Earth today. Specimens have been reported to reach a length of 7 meters and a weight of 1,500 kilograms. On average, this crocodile kills two humans per year in Australia and, presumably, many more in WNG and ENG. Even if the data were available, it is likely that human death by crocodile is substantially underreported in both western and eastern New Guinea.

The **Pinocchio Frog** (also known as the Spike-nosed Treefrog) was discovered in the Foja Mountains of WNG in 2008 by herpetologist Paul Oliver. This new species has a snout that stands erect and elongates when the male calls. In 2013, scientists discovered what appears to be the world's smallest frog. In fact, at 7 millimeters long, *Paedophryne amauensis* may be the world's smallest vertebrate. It was collected in 2009 in the hill forests of Central Province, PNG, and is common in Varirata National Park, near Port Moresby.

Venomous Snakes New Guinea is home to 55 species of front-fanged venomous snakes, but many of these are the relatively harmless and docile sea kraits and sea snakes (26 species). The terrestrial venomous species of concern include 2 species of death adders as well as the Small-eyed Snake, Papuan Black Snake, Papuan Taipan, Eastern Brown Snake,

An Estuarine Crocodile (*Crocodylus porosus*), the largest and most deadly of the crocodiles. This is a species to be feared in New Guinea and Australia. Photo: Trevor Beck Frost

A Green Turtle hunts over a reef wall. This is a common reef visitor in New Guinea.

Black Whipsnake, Brown-headed Snake, Crowned Snake, and 15 worm-eating snakes of the genus *Toxicocalamus*.

First-time visitors to New Guinea often worry about venomous snakes, but most will see few snakes and probably encounter not a single venomous one. In general, to non-herpetologists, snakes are hard to find in New Guinea, as they tend to stay out of sight. One of the most common snakes in New Guinea is the Brown Tree Snake, also informally known as "the snake that ate Guam." This New Guinean native was inadvertently introduced to Guam and killed off much of the native avifauna there. In New Guinea this is a nocturnal hunter of birds and bird nests. It is a good climber, and because of this it often shows up in homes. It is a rear-fanged colubrid and is quite docile, slim, and handsome-looking.

The venomous snake that harms the most people is the **Smooth-scaled Death Adder**. It is widespread and common in lowland forest and edge and thus is commonly encountered by villagers when they are out and about. It is a small sit-and-wait predator and is often tread upon by barefoot villagers. A bite from this snake can kill if its victim has no access to emergency medical care or antivenin. Those wearing rubber roots are usually safe from snakebite.

Perhaps the most fearsome venomous snakes are three savanna lovers. The first is the **Papuan Taipan**, known from the dry-zone grasslands of the SE Peninsula and the Trans-Fly. This shy snake grows to 2 meters in length. If harassed it defends itself aggressively and may strike multiple times, in some cases hitting a person in the calf or even above the knee. Venom delivery is substantial, and the victim requires immediate hospitalization. The **Eastern Brown Snake** inhabits grasslands of the SE Peninsula and also should be avoided. When it feels threatened it assumes a characteristic defensive stance by lifting the front third of its body off the ground in a rigid S shape and hissing violently with a wide-open mouth. The snake will make repeated lunges at an antagonist and may strike several times. Finally, the **Papuan Black Snake** is another large and dangerous venomous snake found in swamps and other lowland habitats in southern New Guinea. The population of this frog-eating specialist has apparently been much reduced by the now widespread presence of the toxic Cane Toad, and the snake is now rarely encountered.

Snakes and People Across most of the world, people fear and dislike spiders and snakes and often kill them on sight. This is the case in New Guinea, at least for snakes. Perhaps New Guinea is one place where fear of snakes is justified, because some of the more common species, such as the two death adders, pose a mortal threat to local villagers carrying out their daily chores. Individuals tending gardens, working to clear forest for subsistence gardens, or collecting forest products all put themselves at risk when they travel through grasslands and forest without the protection of work boots. Local naturalists and village residents treat all snakes as dangerous, although, in fact, most snakes encountered are nonvenomous species. Naturally, visitors and residents of New Guinea, especially those who are not professional herpetologists, should treat all snakes with respect; always keep a distance, and do not harass or attempt to kill them. One final thought: snakes are our friends and constitute an important component of New Guinea's natural ecosystems. They are important predators and do contribute to the control of populations of rats and other vermin. ■

10 Ornithology

The Birdlife

FOR AMERICAN AND EUROPEAN READERS, it is likely that the birdlife of New Guinea is as exotic and distinctive as any on Earth. Bird families inhabiting New Guinea but not found in the United States and Europe include the cassowaries, megapodes, owlet-nightjars, frogmouths, berrypeckers, honeyeaters, scrubwrens, whistlers, fantails, monarchs, birds of paradise, and bowerbirds. The shared families, by contrast, are few, and include the ospreys, hawks, falcons, nightjars, crows, and, of course, some of the very widespread waterbirds such as the shearwaters, storm-petrels, sandpipers, and plovers.*

New Guinea supports the Pacific's richest and most diverse avifauna. By contrast, Australia hosts the Pacific's richest savanna and dry-zone avifauna. Both landmasses rest atop the Australian continental craton, isolated by deepwater barriers from Southeast Asia to the west and from the Melanesia islands to the northeast and southeast. Quite a few bird groups that evolved on the Australian craton have not been successful in colonizing oceanic island archipelagoes but have done well in New Guinea, which has had periodic land connections to Australia. Whereas the differences between the avifaunas of New Guinea and Australia are mainly a product of the distinct dominant environments in the two regions, the differences distinguishing New Guinea's avifauna from that of Southeast Asia are of historical biogeographic origin. Wallace's Line, an ancient deepwater barrier between Bali and Lombok in Indonesia, marks the eastern limit of many continental Asian bird lineages. In a similar manner, moving from New Guinea eastward into the islands of Melanesia, one suddenly encounters oceanic island avifaunas with few or none of many of the lineages

Preceding pages: A male Twelve-wired Bird of Paradise (*Seleucidis melanoleucus*) displays atop a perch among rattan vines in swamp rainforest.

Opposite: A male Blue Bird of Paradise (*Paradisornis rudolphi*) inverted in its courtship display. This occurs in the forest understory well below its morning song perch high in the canopy.

* Sources for this chapter include Mack and Dumbacher (2007), Pratt and Beehler (2015), Beehler and Pratt (2016), and Beehler (2007b), as well as other publications appearing in references section.

that are widespread in Australia and the New Guinean Region—yet are distinctive in other ways, featuring certain Australo-Papuan lineages that have exploded across the insular geography (e.g., fruit-doves, monarchs, whistlers).

The Australia–New Guinea avifauna constitutes one of the world's great avifaunas, separate in its history and evolution from those of Asia, Africa, and the Americas. The region is famous for being home to a rich and unique humid forest avifauna that includes a number of distinctive nonpasserine groups as well as the passerines. The latter group includes hundreds of small insectivores belonging to numerous families centered on the region and, most renowned of all, the birds of paradise and bowerbirds. There are only seven small bird families unique to New Guinea—the satinbirds, typical berrypeckers, painted berrypeckers, berryhunters, ploughbills, melampittas, and ifrits. These are the few that have not radiated out from New Guinea. Most New Guinean bird families have expanded their ranges outward, for this continent-size island has behaved like a giant heart, pumping a lifeblood of bird lineages into the forests of neighboring Australia, Oceania, and in some instances even insular Southeast Asia.

The 769 bird species of the New Guinean avifauna can be classified into five discrete groups: 625 breeding land and freshwater species, 46 seabirds (resident or visiting), 60 migrants from eastern Asia, 33 austral migrants from Australia and New Zealand, and 5 non-native resident species. By far the richest segment is that comprising breeding land and freshwater birds; these are the resident rainforest, montane, and alpine species, plus species of more specialized habitats such as mangrove and savanna, that provide the New Guinean Region with such an arcane and varied bird fauna. Of these, 365 species (or 58 percent) are endemic to the New Guinean Region.

The current complete bird list for the New Guinean Region comprises 101 families, 330 genera, 769 species, and 1,331 subspecies. The major changes in the list since the publication of Mayr's 1941 New Guinea checklist relate to the substantial reduction of marginally distinct subspecies and the recognition of a number of small but distinctive songbird families that formerly were subsumed in large and poorly delineated "grab-bag" families. In addition, a number of polytypic species have been dissected into pairs of allied species (e.g., Spotted and Thick-billed Berrypeckers).

How does New Guinea stack up against other large tropical islands? Compare New Guinea (769 species) with Borneo (688 species), Sumatra (580 species), Sri Lanka (493 species), and Madagascar (258 species).

GEOGRAPHY

Fundamental to understanding the geography and evolution of New Guinea's birds is the notable faunal break separating the avifauna of Southeast Asia from that of New Guinea and Australia. This major discontinuity includes both Wallace's Line (farther west—separating Borneo from Sulawesi and Bali from Lombok) and Weber's Line of "faunal balance" (farther

An adult Southern Cassowary (*Casuarius casuarius*), one of the important seed dispersers in the lowland forests of New Guinea. In New Guinea, many species of rainforest trees have evolved that produce very large-seeded fruits that are dispersed solely by cassowaries. Photo: Bruce Beehler

east—separating Timor from New Guinea and passing west of Halmahera) and relates to the geologically old deepwater channels separating the islands on the continental shelf of Asia from New Guinea, Australia, and associated islands to the east. These deepwater discontinuities mark the edges of tectonic plates.

The great land-bridge islands of Sumatra, Java, and Borneo, which sit atop the Eurasian Plate, share with mainland Asia the barbets, woodpeckers, trogons, broadbills, fairy-bluebirds, leafbirds, babblers, and bulbuls. All these are absent from New Guinea, presumably because they failed to colonize across the imposing and ancient deepwater barriers. New Guinea is instead home to cassowaries, birds of paradise, bowerbirds, honeyeaters, and numerous smaller Australo-Papuan bird families, which in turn are largely or entirely lacking from the Asian fauna. During the Pleistocene glacial periods, when sea levels were lowered by as much as 130 meters, the large land-bridge islands of Sumatra, Java, and Borneo formed a vast extension of the Asian mainland that is often referred to as Sundaland. In turn, New Guinea and Australia then formed a single landmass, Sahul, a fact reflected in bird distributions today. This separation between the Australo-Papuan and Asian faunas dates back tens of millions of years, enough time to allow for the differentiation of dozens of bird families and hundreds of bird species in Australia and New Guinea.

Lying between the Sundaic and Sahul regions are several archipelagoes surrounded by deep water: Sulawesi, the Moluccas, and the Lesser Sunda Islands. This region, called Wallacea, after the famous naturalist Alfred Russel Wallace, contains a mixture of biota from the Sundaic and Sahul regions. It has served as a gateway for Asian bird species entering the New Guinean Region from the west—but more importantly, it has acted as the avenue

The Orange-footed Scrubfowl (*Megapodius reinwardt*) is one of New Guinea's 11 species of megapodes, terrestrial foragers that build large mounded ground nests in which their huge eggs are laid. The warmth produced by the nest incubates the eggs without the help of the parents. The young hatch, dig out of the nest, and disperse into the forest, never spending any time being cared for or fed by their parents.

for dispersal for the songbird lineage (the passerines), which evolved in Sahul in the early Tertiary and expanded worldwide in the latter half of the Tertiary. This is the most species-rich lineage in the class Aves.

The dry habitats of southern New Guinea and the Aru Islands are floristically similar to those in Australian savannas to the south, and, not surprisingly, the local bird communities inhabiting these woodlands likewise are similar. Such birds as the Bar-shouldered Dove, Blue-winged Kookaburra, Blue-faced Honeyeater, and Magpielark—all widespread in Australia—occur in New Guinea only in a few southern coastal areas of appropriate habitat. The bird communities of these patches of savanna habitat are impoverished in comparison with those in Australia and may be considered a relict fauna that was richer when the Torres Strait was dry.

Many New Guinean birds are largely restricted to lowland forest. The fruit-eating pigeons, the large parrots, kingfishers, pittas, meliphagas, monarchs, and manucodes are among those that are poorly represented in, or absent from, the highlands above 1,500 meters elevation. In general, lowland forest birds show larger geographic ranges than montane species, reflecting greater habitat contiguity in the lowlands. In many cases, however, regional populations of lowland birds have differentiated, the local isolates achieving species status. Such is the case for the brushturkeys, the crowned pigeons, the streaked lories, the large fig-parrots, the pygmy parrots, and the *Paradisaea* birds of paradise. Typically,

populations have differentiated into western, southern, and northern forms centered on the broadest expanses of lowland forest. Thus we find the Black Lory and Western Crowned Pigeon on the Bird's Head, the Yellow-streaked Lory and Southern Crowned Pigeon in the southern watershed, and the Brown Lory and Victoria Crowned Pigeon in the northern lowlands. The three principal geographic regions into which many lowland birds segregate are separated by barriers defined by low rainfall and/or mountains. It appears probable that speciation occurred when dissected populations were confined to regional refuges of humid forest, segregated from other areas by broad belts of inhospitable habitat during periods when rainfall was reduced.

Ornate Fruit-Doves (*Ptilinopus ornatus*) feeding in an *Endospermum* tree. The distinctive maroon-headed population of this fruit-dove inhabits the Bird's Head of WNG.

Differentiation among highland birds is a more complex subject. More than 200 breeding bird species are confined to regions above 500 meters elevation. The central cordillera of New Guinea extends the length of the island without major breaks. Speciation has occurred in many montane taxa, with the result that in typical groups, regional isolates have segregated largely on an east-west basis. For example, three species of Astrapia birds of paradise occupy geographically separate ranges along the central cordillera—the Splendid Astrapia in the western half, the Ribbon-tailed in a central stretch, and Stephanie's in the eastern component. The outlying ranges—"mountain islands"—have fewer montane bird species than the central cordillera, but most support some local specialties. Thus, the mountains of the Bird's Head, which have the most endemic forms of any mountain island, have their own species of forest-rail, two endemic honeyeaters, four birds of paradise (including a recent split of *Lophorina*), and a bowerbird, among others.

Certain patterns of distribution remain enigmatic. Some primarily montane species, such as the Black-eared Catbird and the White-faced Robin, also occur in lowland forest near the mouth of the Fly River. These lowland isolates appear to be relicts of populations whose ranges formerly extended, unbroken, from Australia to New Guinea. Other species have peculiarly "spotty" or "patchy" distributions within what appears to be continuous habitat. Such species as the Broad-billed Fairywren, Yellow-breasted Satinbird, Painted Quail-thrush, Rusty Whistler, Greater Melampitta, White-rumped Robin, and Banded Yellow Robin all have broad geographic ranges but often extremely local distributions—present in one area of forest but absent in another. This phenomenon of extreme patchiness seems most prevalent in hill forest species.

ECOLOGY

In this section we touch on some key features of the ecology of New Guinea birds.

Elevation New Guinea's forest bird communities vary substantially with elevation. First, the lowland and hill forest communities are richest in species, while mountain communities become gradually less species-rich with increasing elevation. Thus, along a sampled transect

A Victoria Crowned Pigeon (*Goura victoria*) searches for grit in streamside gravel. The crowned pigeons are the world's largest members of the family Columbidae and inhabit lowland forests of the New Guinean region. Photo: Bruce Beehler.

in eastern New Guinea, the forest community at 1,500 meters has about 100 species, one at 2,500 meters supports ca. 75 species, and one at 3,350 meters has but 25 species. Explanations for gradual impoverishment increasing with elevation include several factors that are probably interrelated: reduction of available land area, decline in air temperature, increase in daily incidence of cloud cover and fog, and increase in frequency of physical disturbances caused by land slippage. Accompanying these physical changes are unfavorable biotic factors: decline in productivity, decrease in floral species richness, plus lower canopy height and reduced structural diversity of the vegetation.

Second, each species exhibits its own elevational range, and for some species this range can be quite narrow. As one proceeds from the lowlands up into the mountains, individual species drop out and new ones appear, so that by the time the highest summits are reached, an entirely different species community is present. Thus, the species list changes with elevation, and the elevational overlap shared by montane bird species is restricted.

Vegetation Each bird species prefers forest or non-forest habitat, rarely both. Since most of New Guinea is forested, it is not surprising that most bird species are found in forest, and that forest bird communities are the most species-rich. By contrast, non-forest habitats are species-poor. In addition, grasslands, mangroves, and savanna habitats support communities that are relatively small in New Guinea compared with those in regions where such habitats are widespread, such as Australia.

New Guinea's forest birds also sort out within the forest vegetation. Some species, such as the Red-collared Myzomela, Yellow-bellied Gerygone, and New Guinea Thornbill, forage high in the forest canopy. Other species, such as the Dimorphic Fantail, Black Berrypecker, and Yellow-bellied Longbill, forage in the forest understory. Yet other species, such as the Painted Quail-thrush, Spotted Jewel-babbler, and Greater Ground-Robin, forage on the ground itself. In some prominent instances, species within a single genus will sort out by foraging height in the forest. Among the fantails, one finds the Sooty Thicket-Fantail foraging near the ground, the Black Fantail in the understory, and the Chestnut-bellied Fantail in the middle stories of the forest.

Diet New Guinea is unusual in supporting large numbers of fruit eaters and nectar eaters. These include numbers of obligate frugivores, relatively uncommon in other parts of the world. In contrast with a comparable lowland forest community in Peru, the New Guinean fauna has twice as many fruit eaters and nearly twice as many nectar eaters, as measured by proportion of the fauna. Of special interest are the fruit-doves, amazingly diverse and abundant, and the brush-tongued lories and lorikeets, remarkable for their nearly exclusive diet of pollen and nectar. It is not uncommon to find noisy and species-rich assemblages of bird species foraging in fruiting and flowering trees. These feeding assemblages can include 30 or more species, making popular fruiting and flowering trees great places to see species that are otherwise difficult to observe in the forest.

New Guinea's assemblage of ground-feeding forest birds is likewise considerable. With 3 cassowaries, 11 species of mound-building megapodes, 5 large ground-pigeons, plus an array of forest-rails and other smaller species, it appears that a considerable radiation in the terrestrial avifauna has occurred. The ground-feeding passerines in particular include some of the most interesting and unique components of the avifauna, birds such as logrunners, jewel-babblers, mouse-warblers, the Piping Bellbird and Rufous-naped Bellbird, melampittas, and ground-robins.

In spite of its overall richness, gaps do exist in the ecological composition of the New Guinean avifauna. Vultures, a conspicuous element in other tropical faunas, are absent from New Guinea. The woodpecker niche is filled only partly by a few bark-gleaning species of treecreepers, sittellas, and birds of paradise. The remarkable ant-following guild of the Neotropics is absent in New Guinea (as is the army ant phenomenon).

Nonetheless, mixed interspecific flocks are important in New Guinea, not only

Above: This female Lesser Melampitta (*Melampitta lugubris*) is a forest interior ground dweller. The species shows close evolutionary links to the birds of paradise. Photo: Dani López-Velasco

Right: This male Red-collared Myzomela (*Myzomela rosenbergii*) is a diminutive nectar-feeder of the mountains.

because of their ecological significance but also because their presence in the forest offers crucial opportunities for observing many songbird species. Interspecific flocking is most conspicuous in the lowlands but also occurs in montane forest. Walking through a forest, one may encounter practically no birds for an hour and then be overwhelmed by dozens of vocal individuals of many species moving through the vegetation. The forest becomes quiet again after the flock passes. There are two main types of flocks, which usually move separately but occasionally join.

The lowland "brown and black" flock is composed of medium to large omnivorous species whose plumage is predominately brown, rusty, or black. These are led by groups of Papuan Babblers and one or more pitohui species. A key "sentinel" species is the Spangled Drongo, which follows the group, sallies rather than gleans, and steals prey from other species. Other followers include the Black Cicadabird, Tawny Straightbill, a number

of birds of paradise (mainly the brown females or young males), and various less-regular flock associates.

The "warbler-flycatcher" flocks of the mountains are composed of small insectivores. The leaders are usually gerygones or Island Leaf-Warblers; regular followers include monarchs, boatbills, fantails, and whistlers, and occasional followers include white-eyes, shrikethrushes, and bronze cuckoos, among others.

Nesting As in other tropical forest regions, nesting appears to be a risky business for birds in New Guinea. A large proportion of nesting attempts fail owing to depredation of the eggs or young. This generalization probably varies depending on the species and its nest type and placement. Birds are thought to evolve different kinds of nests and nest placement to escape the attention of predators that rob nests. Nesting habits of New Guinean birds are indeed diverse. The scrubfowl along the coast builds a mound of sand and

The Kofiau Paradise-Kingfisher (*Tanysiptera elliot*i) is found only on tiny Kofiau Island, of the Raja Ampat Islands. It is typical of the paradise-kingfishers, foraging in the shaded interior of lowland rainforest.

decaying vegetation and lays its eggs inside, whereas other ground-nesting birds, such as the Pheasant Pigeon, may hide their nest at the base of a tree trunk. Many nonpasserine birds nest in tree cavities, including parrots, owls, owlet-nightjars, and kingfishers, but few songbirds do. The nest of the Buff-faced Pygmy Parrot and some kingfishers is usually a cavity excavated within an active termite nest that has been plastered on the side of a large tree trunk. The frogmouths, treeswifts, cuckooshrikes, peltopses, and flycatchers build such a small and cryptic nest atop a canopy branch that the nest hardly shows beneath the incubating bird. Songbirds excel at building nests, allowing them to hide the egg or place it out of reach. For instance, the Papuan Babbler constructs a pendent, domed nest, 1.5 meters long, suspended from the spiny *Calamus* lawyer vine—an effective defense against potentially marauding snakes and rats. Or consider Blyth's Hornbill, in which the male plasters the female and young into their nest inside a tree hollow.

The median clutch size for New Guinean forest birds is two. Some groups, such as pigeons and birds of paradise, commonly lay only one egg per nest, while few regularly produce three or more. Although active nests can be found in any month, there are apparently optimal nesting seasons for certain groups. Most songbirds breed just prior to the rainy season, whereas many pigeons nest during the rains. These nesting seasons vary regionally. In many areas where the rains come at the end of the year, most nesting occurs between August and December, during the austral spring and early summer.

Opposite: A pair of Black-capped Lories (*Lorius lorius*), one displaying to the other, on the Huon Peninsula.

Below, clockwise: This Painted Tiger-Parrot (*Psittacella picta*) female is feeding on the unripe fruit of a heath of the genus *Diplycosia*. Photo: Carlos Bocos

This Red-breasted Pygmy Parrot (*Micropsitta bruijnii*) adeptly forages head-down on vertical trunks of trees, more like a nuthatch than a parrot. This smallest of the parrots feeds mainly upon materials it scrapes from the bark surface of trees—presumably mainly algae and liverworts. Photo: Carlos Bocos

Yellow-billed Lorikeet (*Neopsittacus musschenbroekii*) peers down from a casuarina tree.

Molt Little is known about patterns of molt (the shedding and replacement of feathers) in New Guinean birds. Perhaps most adult birds molt after successfully nesting, during the austral summer and autumn. For example, in the Wau region of ENG, insectivorous songbirds revealed a molting peak between November and April, with much lower percentages of individuals in molt from May to October. In this area, the songbird nesting season centers on the last months of the year; thus timing of molt seems to follow nesting.

Migration within New Guinea Many New Guinean rainforest birds are sedentary, rarely leaving their established home ranges; however, some species are conspicuous exceptions and travel locally within New Guinea. Not surprisingly, such birds are those feeding on patchy and seasonal resources such as fruits and flowers. The Papuan Mountain-Pigeon is commonly observed in flocks, flying swiftly high in the sky, but little is known about the pattern and seasonality of the species' travels. Lories and lorikeets form conspicuous flocks that wander in search of flowering trees, much like the preceding species. The jewel-like Red-collared Myzomela generally lives at high elevations on Mount Kaindi, above the Wau valley (eastern ENG), but during certain seasons, it descends the mountain to forage in town gardens at 1,000 meters.

Intercontinental Migration New Guinea serves as winter quarters for long-distance migrants from both the Northern and Southern Hemispheres. Birds from the North, the *Palearctic migrants*, move south into the New Guinea Region in August–October, spend their winter season there, and leave in March–May. The largest assortment of Palearctic migrants consists of waders and seabirds, which either settle in the region to overwinter or pass

A Western Crested Berrypecker (*Paramythia olivacea*) forages at the fruit of a *Schefflera* vine in the high mountains of WNG.

through on their way farther south to Australia (waders) or to temperate seas (seabirds). Most of the waders winter along coastal locations. Only a few species of northern land-bird migrants reach New Guinea, among them the Brown Shrike, Gray's Grasshopper-Warbler, Grey-streaked Flycatcher, Oriental Cuckoo, Grey Wagtail, and Eastern Yellow Wagtail. These move southward and eastward from mainland Asia and the Indonesian islands to arrive in the New Guinean Region, touching down mainly in the western reaches of WNG.

The greatest volume of land-bird migration occurs between Australia and New Guinea. A number of Australian breeding land-bird species spend the nonbreeding season during the austral winter (March–October) in New Guinea, but how many birds migrate and when they arrive each year depend on both the timing of the winter season and unpredictable drought conditions in Australia. Some, like the Rainbow Bee-eater and Sacred Kingfisher, are among New Guinea's best-known garden birds. Most of these migrants occupy non-forest or forest-edge habitats in New Guinea. Such zones may offer the benefit of reduced competition from resident New Guinean species. Some migrants do winter in the forest proper: Buff-breasted Paradise-Kingfisher, Noisy Pitta, Black-faced Monarch, and Rufous Fantail. The nature of their interactions with their resident relatives is not known.

A remarkable interchange of waterbirds occurs between the open but well-watered country of the Trans-Fly and Australia. Tens of thousands of Australian waterfowl, ibises, egrets, pelicans, and others spend the austral winter in this southern bulge of New Guinea.

There are also great migrations of southern seabirds. Most abundant are the *trans-equatorial migrants*, for example the Short-tailed Shearwater and Wilson's Storm-Petrel, which breed in the southern oceans during the austral summer and afterward escape winter by passing through the New Guinean Region in autumn to spend their winter season feeding in the waters of the North Pacific and Indian Oceans during the northern summer. A few northern seabirds do just the reverse; for example, jaegers breed in the Arctic and winter in southern oceans, including the waters around New Guinea.

Historical Changes Although the tropics have been considered a zone of great stability, change is very much a part of the New Guinean Region's history. As recently as 10,000 years ago, most of the higher mountaintops were encrusted with glacial ice, and forest zonation must have been considerably depressed compared to the pattern we see today. As the snowcaps continue to recede today, it is clear that climatic and other environmental changes are occurring. Bird populations inevitably are responding to these fluctuations, but it is difficult to monitor changes in a region with few long-term observers.

The most rapid shifts we see are in relation to humankind's transformation of local habitats. Coinciding with continued clearing of forest in mid-mountain valleys are major changes in local bird faunas. The new clearings are prime targets for opportunistic avian colonists, either from the lowlands or from other open habitats. The Grey Shrikethrush, known primarily along the southern coastal lowlands, recently has invaded the Eastern Ranges to elevations of 1,500 meters. Documenting similar changes in the forest fauna is difficult, and more study of this phenomenon would be useful.

THE BIRDS OF PARADISE

New Guinea is famous for its 39 species of birds of paradise. The family Paradisaeidae ranges from Halmahera island east through New Guinea to the Milne Bay Islands and then south into the humid forests of eastern Australia, totaling 43 species. Only four members of this family do not occur in the New Guinean Region, so the family is strongly allied to this great tropical island. It is likely that the lineage evolved along with the uplift of New Guinea's central cordillera, as this is where virtually all the genera can be found, though perhaps some of the species have arisen in association with the rise of ancillary ranges or nearby islands. Eight genera are mountain dwelling and eight are largely lowland dwelling or are lowland–hill forest dwelling. The paradisaeid lineage has been dated back an estimated 18 million years, when it split from the basal corvoid lineage. This aligns well with the initial uplift of proto–New Guinea. Recent molecular genomic studies show that the birds of paradise cluster weakly with the ifrits, melampittas, monarchs, and Australian mudnesters. Presumably the birds of paradise evolved along with the mountainous island of New Guinea.

Birds of paradise are sturdy forest-dwelling songbirds with strong beaks, legs, and claws, all useful to their foraging specializations. They range from small (King Bird of Paradise, 35 grams) to very large (Curl-crested Manucode, 256 grams). Some are short-tailed and others exhibit very long tails. They include short-billed and long-billed forms and exemplify a striking adaptive radiation that allows them to take advantage of a range of ecological roles in the New Guinean rainforest. Most are vocal, the males producing loud and far-carrying sounds.

Sexual dimorphism is strong in most lineages. All of the sexually dichromatic genera are known or are presumed to be polygamous and promiscuous, with court-style mating systems in which males occupy fixed courts in order to attract females for mating. In the polygamous forms, the females tend to be brown with ventral barring, and the males are mainly black or multicolor, with various erectile display plumes on the head and/or pectoral regions. The few monogamous species, in the genera *Lycocorax* (not present in New Guinea), *Phonygammus*, and *Manucodia*, are sexually monochromatic, all-black, and unadorned with display plumes. That said, males of the manucode species exhibit an extremely elongated trachea for producing specialized far-carrying courtship sounds.

The monogamous species of birds of paradise establish pair bonds, and both sexes help at the nest. In the polygamous species, males and females interact only to mate, and the female alone builds the nest and raises the offspring. The males in these species establish display courts through the forest. The parotias and the Magnificent and Wilson's Birds of Paradise construct courts on or near the ground in forest tangles and display on the ground (parotia) or on the vertical stems of small saplings near the ground (Magnificent, Wilson's). The riflebirds and Superb Bird of Paradise (now being split into three species) display atop a fallen log or dead tree stub. The *Paradisaea* birds of paradise display in a group on limbs high in the canopy of the forest.

Opposite: A male Lesser Bird of Paradise (*Paradisaea minor*) displays in a lowland rainforest near Oransbari, WNG. This species typically displays in a communal lek of two or more males in the upper canopy.

In many polygamous birds of paradise, the males establish solitary display courts. In the remainder, males cluster their display courts into what is termed a *lek*. For instance, in the King Bird of Paradise, the males form display pairs, typically spaced about 70 meters apart but in close vocal contact. Raggiana Birds of Paradise cluster into a single canopy tree, and as many as 15 males use the lek space for calling and display. This is true lek behavior, and it is remarkable to behold in an early morning in the forest. The males arrive in the lek tree and begin calling before dawn. Then the dominant males take their perches in the center of the lek and begin displaying to one another and to visiting females. The females sneak into the lek, mate, and then depart. The males leave the lek only to forage in nearby fruit trees. The males attend the lek for as many as six months a year.

The lek systems seen in the *Paradisaea* birds of paradise are much like those of the Guianan Cock-of-the-Rock of northern South America or the Greater Sage-Grouse of western North America. Males compete to dominate the lek and capture the majority of the mating rights with the females. Because of the longevity of these birds and the strong competition, plumage maturation among the males is delayed, and in the *Paradisaea* birds of paradise, the staged acquisition of adult plumage may take as many as six or seven years. The dominant male in a very popular lek may be up to 10 years old. He may mate with dozens or scores of females in a season, hence dominating the gene pool of the next generation. It is this highly channelized mating that leads to the extreme plumage adornments in these and similar lek-breeding birds such as the cotingas and manakins (a process called "runaway selection").

Opposite: Male Red Bird of Paradise (*Paradisaea rubra*) performs an inverted display on bare branches emerging from the canopy. This species is endemic to the Raja Ampat Islands in WNG.

Above: Two Emperor Birds of Paradise (*Paradisaea guilielmi*) display in synchrony at their tree-top lek, hanging below the branch with plumes fanned. Huon Peninsula, ENG.

One of the finest ornithological experiences on Earth is to spend a morning watching the activities in the lek of a Raggiana or Greater or Lesser Bird of Paradise. In contrast to the hidden lives of many birds, here all the behavior—male versus male and male with female—is on display. The males are sexy and active and showy; the females are demure and cagey and shy. The displays produced by the males are jaw dropping. The occasional physical altercations between males may lead to two birds, claws locked, dropping 30 meters to the forest floor—serious conflict. Once a female chooses a male in a big lek there is usually an orderly and perfunctory series of steps leading to copulation. The female crouches beside the male. The male pummels the female with rhythmic beats of his wings and the stropping of his beak across the back of her neck. This seemingly abusive behavior is followed by a hasty mounting, copulation, and the departure of the female from the lek—all while the other, competing males stand by, passive observers.

Male Wahnes's Parotia (*Parotia wahnesi*) at his understory display court, beginning to spread his skirt-like feathers for the "ballerina dance" phase of his display. An endemic species to the Huon Peninsula, ENG.

The major mystery group of the birds of paradise lineage is the genus *Paradigalla*. In its two species, the males and females are alike and slightly ornamented. Fieldworkers have not determined whether they are monogamous or polygamous. Vocal behavior of the males and nesting behavior of the females suggest the species is polygamous, but this requires confirmation by additional field study. Here is a ready-made field project for a young researcher!

Although the mating systems of birds of paradise have been attracting the attention of evolutionary biologists since Darwin, the dietary ecology of the family is also of interest for its impact on the forests of New Guinea. Birds of paradise consume a mix of arthropods and fruits. The morphological adaptations for insect foraging have given the birds special skills in harvesting difficult-to-harvest fruit. These distinctive foraging styles differentiate birds of paradise from classic New Guinean frugivores, such obligate fruit eaters as the fruit-doves and imperial pigeons. Studies by T.K. Pratt and the author have shown that birds of paradise are superior seed dispersers and have established close relationships with several families of forest trees that produce large-seeded and highly nutritious capsular fruits.

Certain mahoganies and nutmegs produce fruits that are protected by woody capsules that crack open slightly, giving a glimpse of a specialized arillate seed with a bright red or orange aril, or covering. The aril is the edible portion, which in these examples is rich in protein and lipid. Most of New Guinea's typical fruits, such as figs, are small-seeded and offer edible rewards that are mainly water, pulp, and sugar. The fruit-doves and imperial pigeons mainly subsist on the low-nutrition fruits that are easy to harvest and are produced in huge quantities that ripen all at once. The pigeons sit for long hours in the fruiting trees, defecating most of the seeds right under the parent tree, offering little dispersal assistance.

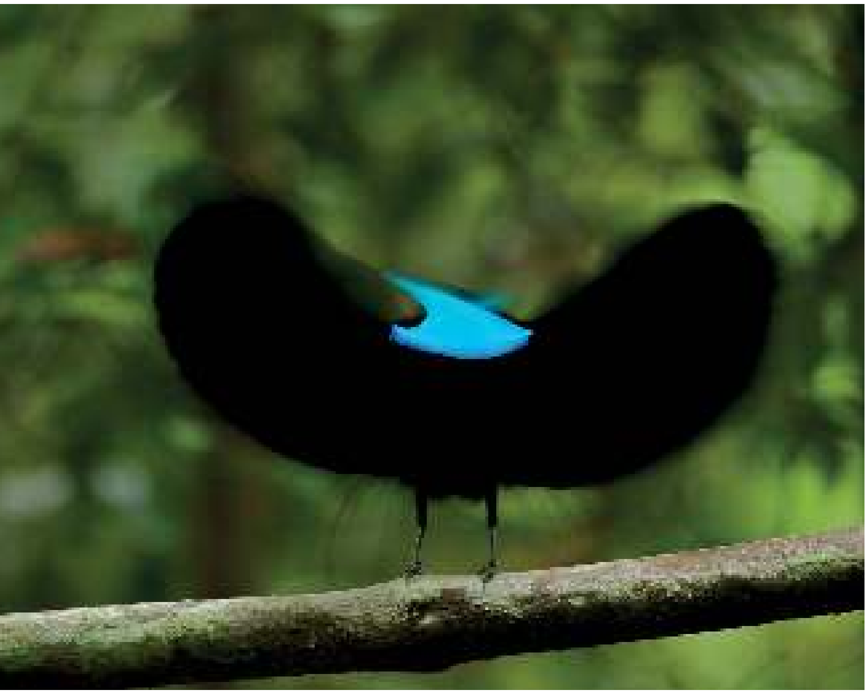
Male Western Parotia (*Parotia sefilata*) performs his ballerina dance in the Arfak Mountains, WNG. The six species of Parotia range widely across New Guinea's mountain landscape.

With the birds of paradise, the situation is different. When foraging on the specialized mahoganies and nutmegs, the birds of paradise enter the tree, spend a minute or two, consume only one or two fruits (with their large seeds) and then move on. These specialized fruit trees produce small crops that ripen over a long season. The foraging birds do not linger in the tree, because of fear of predation and also because the tree offers only a few ripe fruits on any particular day. They then regurgitate or defecate the seeds away from the parent plant, providing a high-quality "seed rain"—which ensures the best dispersal of the large seeds.

Here's the main point of this story: If one watches a ripe fig tree, one sees as many as 40 species of birds coming in and feeding, including many fruit-doves. If one stands under a specialized mahogany or nutmeg, one sees very few species foraging in the trees—some

Male Vogelkop Superb Bird of Paradise (*Lophorina superba*) on his display log in the Arfak Mountains, WNG, with his cape fully raised. Note the false eyes created by iridescent feathers on the crown.

Male Magnificent Riflebird (*Ptiloris magnificus*) singing and displaying to a female by snapping his head from side to side, hiding it behind his wing. Lowland rainforest near Oransbari, WNG.



Male King Bird of Paradise (*Cicinnurus regius*) display postures include spreading a breast fan and erecting tail feathers (top), and a spread-wing display (bottom). Lowland rainforest of WNG.

times only species of birds of paradise. Fieldwork has shown that the most specialized fruiting trees may attract six or seven species of birds of paradise but no other fruit eaters. The protected fruits make it difficult for other foragers to extract the large arillate seeds, but the birds of paradise, because of their powerful and nimble beaks and legs, are skilled at getting them. It appears that certain food trees and certain birds of paradise have formed evolutionary alliances. The trees provide specialized nutritional rewards. And the birds provide excellent dispersal of the large seeds through the forest. Thus birds of paradise are not just beautiful and behaviorally interesting. They are also critical to the rejuvenation of the forest with a diversity of specialized rainforest trees.

The reader may worry about the yearly harvest of bird of paradise skins across the island for informal trade and sale. Are the birds of paradise seriously threatened by this harvest? No. The reason for this is because only the old males, with their abundant plumes, are harvested, leaving a large majority of the birds (including numbers of less well-plumed males) to carry on in the forest. It so happens that the subadult males are sexually mature and perfectly capable of fertilizing eggs. In addition, recall that a few males can provide fertilization services to many females. So birds of paradise remain common in New Guinea's forests in spite of the annual harvest. Even during the early 1900s, when the international plume trade was peaking, the birds were not threatened by the take of adult males, which represent just a small proportion of the adult population.

THE BOWERBIRDS

The bowerbird family (Ptilonorhynchidae) encompasses ca. 22 species; the familial range is confined to New Guinea and Australia. Whereas the birds of paradise are strict forest dwellers, the bowerbirds have both a forest-dwelling lineage and a lineage that inhabits dry woodland and savanna. For many decades, the bowerbirds were thought to be a sister group to the birds of paradise. Recent molecular systematic research has demonstrated that bowerbirds are not closely related to the birds of paradise but instead lie within a clade that includes the Australian treecreepers. The bowerbird-treecreeper clade is sister to a large clade that includes the fairywrens, honeyeaters, and scrubwrens.

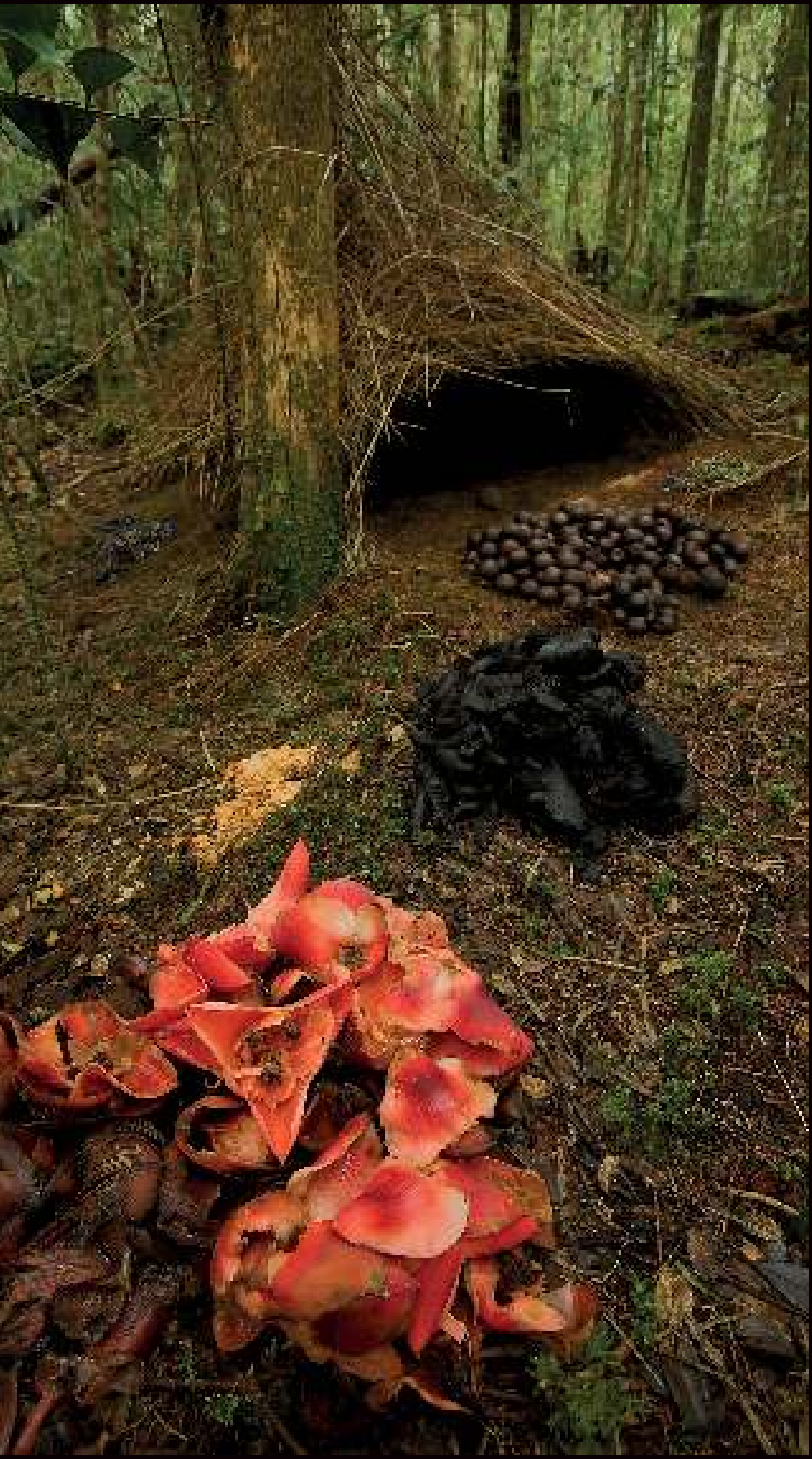
Bowerbirds are sturdy songbirds, like the birds of paradise, but they are large-headed and blunt-billed. In flight, bowerbirds are very distinctive, with a conspicuous head-up look—lacking the graceful, undulating flap-and-swoop patterns of the birds of paradise. The bowerbirds are medium to medium-large songbirds with powerful claws and a strong and deep beak. The family includes monogamous as well as polygamous court-displaying species (yet another reason this family was thought to be related to the birds of paradise).

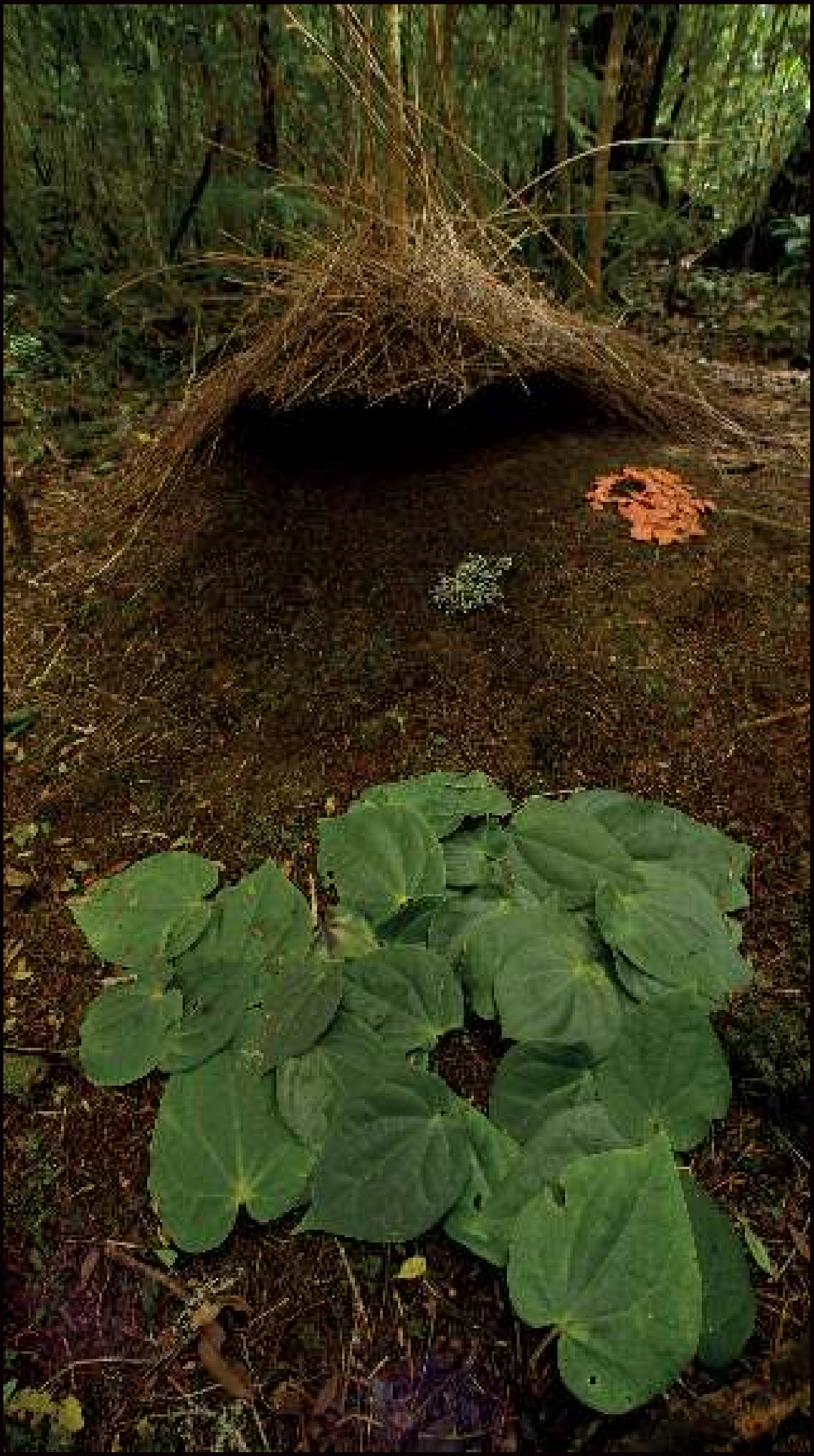
Bowerbirds are most famous for the stick bowers the males construct and maintain, which they use as display courts for polygamous mating with the females. The large tepee-style bower of the Vogelkop Bowerbird of the Bird's Head of WNG is perhaps the most elaborate (non-nest) construction manufactured by an animal other than a human. In each polygamous species of bowerbird, the male constructs a stick bower and decorates it with a variety of found items. Each bower construction is specific to each species, though some individuals develop their own personal styles of decoration. The monogamous bowerbirds—the catbirds—do not construct bowers but behave like ordinary songbirds. These latter species are sexually monomorphic, and the males exhibit none of the specialized adornments found in some of the polygamous bowerbirds.

An interesting evolutionary aspect of the polygamous bowerbirds concerns the relationship between the plumage ornamentation of the male and the ornateness of the bower he builds. The bowerbird species with the most beautiful and colorful males (in the genus *Sericulus*) construct the smallest and least-ornamented bowers. And the bowerbird species with the plainest male plumages build the grandest bowers. The ornithologist E. Thomas Gilliard called this the "transferral effect," which postulates that evolution has transferred the focus of sexual selection from the plumage of the male to the bower that the male builds. And it is presumed that, by having an ornamented bower instead of ornamented plumage, the males reduce the threat of predation, being less gaudy and obvious to predators.

The mating behavior of the polygamous bowerbirds is strikingly similar to that of the birds of paradise, with one exception. In the bowerbirds, the court dispersion of males of

A male Golden-fronted Bowerbird (*Amblyornis flavifrons*) displaying at its bower, a tiny blue fruit in its beak. The female (not shown) is watching from an adjacent low perch. The larger pale blue fruits scattered around the base of the bower have been placed there to make the scene more attractive to visiting females and to demonstrate the male's artistic sense of design. The fruits are not for eating. This species inhabits the upland forests of the isolated Foja Mountains (NW Lowlands). Photo: Bruce Beehler





Four bowers of the Vogelkop Bowerbirds, all located on the same mountainside in the Arfak Mountains, show the variation of bower decoration by individual bowerbirds.

most species is solitary and widely spaced rather than clustered into leks. This is probably because the bower is vulnerable to raiding and destruction by adjacent rival males; thus distance from rival bowers will guarantee added protection from raiding and lower energetic costs of defending the bower.

The bowers come in two basic forms, relating to the two polygamous lineages of bowerbirds: avenue type—with two parallel walls of sticks, and maypole-type, more or less circular and built upward upon the infrastructure of a single tall sapling. The avenue bowers are built by species in the genera *Chlamydera*, *Ptilonorhynchus*, and *Sericulus*. The maypole bowers are constructed by species in the genera *Amblyornis* and *Prionodura* (the latter represented by one Australian species). The single species in the genus *Archboldia* builds a fern platform that fits into neither category (even though *Archboldia* is closely related to the maypole builders).

The least imposing bowers are constructed by the four species in the genus *Sericulus*—the golden bowerbirds. These are beautiful birds that build rudimentary bowers forming two parallel walls of sticks about 25 centimeters tall. The two New Guinean species of *Chlamydera* bowerbirds build either a large avenue bower sitting atop a platform of sticks ornamented with green fruit (Fawn-breasted Bowerbird) or a four-walled avenue bower ornamented with pebbles and dull blue berries (Yellow-breasted Bowerbird). Archbold's Bowerbird (*Archboldia*) constructs a large, rectangular fern mat that it decorates with beetle elytra. MacGregor's Bowerbird (*Amblyornis*) constructs a simple maypole bower. Its court encompasses a large circular base of moss enclosed in a mossy circular perimeter wall. In the middle of this dance ground stands a vertical sapling, which supports a tall stack of sticks, looking like a prickly tower. At the base is mounded a small circle of moss. Various natural items collected from the forest are hung from twigs near the bower and on the moss base of the bower: insect frass, beetle elytra, charcoal, fungi, small fruits, lichens, and more.

Most fantastic of all is the bower of the Vogelkop Bowerbird. This is a tepee of sticks about 1.5 meters tall and about 2 meters in diameter, with a single low front opening that gives out onto a flat platform of moss. The platform is typically adorned with a pile of large red or blue fruits, charcoal, mushrooms, rhododendron flowers, and any other interesting artifacts the male can collect (including all manner of human-manufactured things such as mint wrappers, empty small red mackerel tins, and more). The male often hangs out inside the hut and vocalizes to attract females. Mating takes place inside the bower. This is the largest and most elaborately decorated bower, and the male is entirely dull and looks exactly like the female.

The catbirds (genus *Ailuroedus*) include two (or possibly several) species of monogamous green-backed bowerbirds that are fig specialists. Note that the fig-specialist manucode birds of paradise are also monogamous.

Bowerbirds are famous for their ventriloquial vocalizations. Males of *Amblyornis* species imitate the voices of many other birds in the forest as well as other forest sounds. They also make additional weird vocalizations that are either unidentifiable or resemble sounds from civilization that the bird could never have experienced (e.g., a Golden-fronted Bowerbird in the Foja Mountains made sounds that were likened to a dump truck dumping gravel).

HONEYEATERS

Whereas the bowerbirds and birds of paradise are the most glamorous bird families in New Guinea, the honeyeater family (Meliphagidae) is probably the most substantial and perhaps ecologically the most important. The family includes 178 species and ranges from Australia and New Guinea through the South Pacific north to the Marianas, west to Bali, and east as far as Tahiti. The 65 species in New Guinea make it the most species-rich bird family on the island.

A Wattled Smoky Honeyeater (*Melipotes carolae*) forages at the fruit of a vining *Schefflera* in the Foja Mountains of WNG.

The honeyeaters are passerines that lie in a clade that includes the pardalotes, the scrubwrens, and the Goldenface (*Pachycare flavogriseum*). Thus they are not closely related to the bowerbirds or the birds of paradise, even though they are ubiquitous in every habitat that supports species of those two families.

New Guinea's honeyeaters range in size from very small (like a sunbird), to medium-size (like a thrush), to large (like a smallish crow). Most are rather dull-plumaged (black, olive, gray, brown, and in some instances streaked). Many exhibit bare skin around the eye or a pale ear patch. Quite a few have complex facial markings and plumes of white, yellow, and black, making them distinctive and handsome. Some have throat or facial wattles of bare, colored skin. The prettiest are the diminutive *Myzomela* honeyeaters, nectar feeders with slim decurved beaks and either very plain brownish plumage or colorful plumage marked with red, black, white, and olive. Whereas the plumages of the sexes tend to differ strongly in myzomelas, in most other honeyeater genera the sexes are alike.

Many genera of New Guinean honeyeaters are pugnacious, chasing other foraging bird species from feeding perches in flowering and fruiting trees. In fact, the place to focus on honeyeaters is at fruiting and flowering trees, where they seem always to be present, often mixing with fruit-doves, lorikeets, and other songbirds. At these feeding trees, honeyeaters seem to dominate the scene—vocalizing, chasing, and threatening when not actually foraging. At certain flowering trees one might encounter 10 or more species of honeyeaters in a day, from myzomelas to the very large friarbirds. The interactions between honeyeaters and lorikeets can be chaotic, and one can hear the action from quite a distance in the forest. Some rare species can essentially be found only at a flowering tree—species such as the Plain Honeyeater or the Yellow-gaped Meliphaga.

In the higher mountains and subalpine shrublands, honeyeaters predominate. The Common Smoky Honeyeater forages quietly for small fruits; the Red-collared Myzomela forages at tiny flowering shrubs; and the Sooty Honeyeater and Belford's Melidectes forage at the red tubular flowers of various endemic species of rhododendrons. Given the amount of time honeyeaters spend foraging for fruit and nectar, there is no doubt that this family serves important pollination and seed-dispersal functions in the forests of New Guinea.

STORY OF THE PITOHUI

In late September 1975, I set up a field camp in the mountains of the upper Watut River, in northeastern Papua New Guinea. This was my very first time camping out in the rainforest of New Guinea without Western counterparts. I was accompanied, instead, by local Morobe Province naturalists Amat Titi and Timis Surrey. I was based at the Wau Ecology Institute, serving out my Watson Fellowship one-year grant studying tropical forest birds. For my first four months in ENG, I focused my efforts on the mid-montane forest and its birdlife near the summit of Mount Kaindi. I now wanted to expand my horizons and get to know the hill forest bird fauna, downslope from my base in Wau. So I set up a camp for a week in the forest at about 750 meters elevation, and with Titi and Timis, I netted birds and bats.

I caught lots of birds that were novel to me. Some were difficult to identify; others were surprises. The Hooded Pitohui was a common forest bird here, and I knew this species already from my work around Wau. The pitohui looks a bit like a slightly oversize Orchard Oriole, with a black head, wings, and tail, and a chestnut-brown body. It is not uncommon to see small parties of Hooded Pitohuis skulking through the upper stories of the forest. They were always shy but vocal, giving their distinctive *Koo-Koo-Oh!* notes and pleasant piping songs from some hidden perch. I watched pitohuis hunt for good-size insects on branches and larger limbs and also visit trees carrying small fruits, especially figs.

We netted a Hooded Pitohui on our fifth day in the camp, and it elicited an interesting response from the men, for a specific reason linked to their relationship with all birds. Titi and Timis disliked having to release the birds after capturing, measuring, and banding them. Papua New Guineans consider birds and all other small vertebrates as "game" and found it unnatural not to consume all that we captured. But when I pulled the pitohui out of the cloth holding bag after weighing it, Titi looked at it and grimaced. He said this was a bird that tasted bad—and thus was one of the few animals not regularly consumed by his clan. He called it a "rubbish bird." At the time I thought this was mildly interesting, and I noted it in my field book, but I never pursued the issue.

More than a decade later, Jack Dumbacher, a research student working with me at Varirata National Park in the hills behind Port Moresby, discovered the secret of the Hooded Pitohui. Dumbacher, with assistance from scientists at the US National Institutes of Health, was able to show that the pitohui's feathers and skin contain a potent neurotoxic alkaloid called homobatrachotoxin—a molecule identical to that in the skin of one of the poison-dart

A Hooded Pitohui (*Pitohui dichrous*) forages in the canopy of a fig tree. This bird was discovered by Jack Dumbacher to be chemically defended with a neurotoxic alkaloid called homobatrachotoxin—known to be the chief toxin in the deadly Neotropical poison-dart frog *Phyllobates terribilis*.

frogs of South America. This was the first chemically defended bird to be discovered by Western scientists. Of course, Titi and his village knew all along the bird was poisonous, as did most hill communities in New Guinea that were familiar with the bird.

A key difference between Jack's experience with pitohuis and mine was that he had been poisoned by them and I never was. After handling several pitohuis, Jack had touched his hand to his mouth, and before long his tongue and lips began to tingle and become numb. That clue set Jack on the road to discovery. I had handled dozens and dozens of pitohuis over more than a decade but never was "zapped" by their toxin, so Titi's warning never tweaked my scientific interest. The rest is history. In 2004, Jack showed that the Hooded Pitohui consumes a tiny melyrid beetle that carries this toxin. Presumably the bird sequesters the beetle's toxin for its own chemical defense. Jack has postulated that the toxic defense of the pitohui is to protect it from predation by bird-eating snakes. The next step in the pitohui story will be to locate the ultimate source of the toxin (called a "steroidal alkaloid") that presumably feeds the beetle that feeds the bird. I think it is a plant or a fungus. Finding and identifying this "source" life-form will presumably also tell us the source of the poison-dart frog's poison in South America. Many plants and fungi are ancient lineages that evolved before the breakup of Gondwana, the ancient southern supercontinent (South America + Antarctica + Australia–New Guinea). Thus we presume that the same lineage of toxic plants or fungi would be living now in South America and New Guinea. In this way the frog (known only from South America) and the bird (known only from New Guinea) are biologically linked by an ancient plant that has a now-disjunct widespread "Gondwanan" distribution. At least that is the current thinking about this persistent mystery. ■

11 Mammalogy

Monotremes, Marsupials, and Placental Mammals

Preceding pages: A mother Huon Tree Kangaroo (*Dendrolagus matschiei*) and her young peer down from a mossy limb in mountain forest of the YUS Conservation Area on the Huon Peninsula of ENG, where this species is endemic.

Opposite: A Common Spotted Cuscus (*Spilocuscus maculatus*) slowly moves through some vines in a lowland rainforest. This species ranges throughout New Guinea's lowlands. Its slow movements make it seem sloth-like. The species forages on leaves, fruits, and seeds.

THE MAMMAL FAUNA of New Guinea is fantastic and yet cryptic. Visitors to New Guinea and non-mammalogists doing fieldwork in New Guinea's rainforests rarely see wild native mammals, and those seen are mainly rather small and obscure—mice, marsupial mice, nocturnal micro-bats, fruit bats. In fact, the only mammals commonly seen in New Guinea are the commonplace, small micro-bats seen foraging at dusk or the flying foxes of the genus *Pteropus*, which often nest colonially in protected locations in urban areas. Of course, this scarcity is because most mammals are nocturnal or have evolved nocturnality because of relentless daytime hunting by local residents—hunting that local residents have been pursuing for 47,000 years. Thus, most or all of the larger mammal species tend to be uncommon or rare or at least elusive. It is not unlikely that traditional subsistence hunting in New Guinea has brought about the extinction of a number of mammals, mostly the larger and less elusive species, just as has happened in North American and apparently in Australia, where the fossil and subfossil record is considerably more complete, because dry environmental conditions lead to better preservation of fossil and subfossil material for study. There are quite a few described species of extinct mammals known from New Guinea that are larger than current relatives, and it is suspected that these larger forms were targeted as game by New Guinean hunters (see chapter 13). That said, distinguishing human-caused extinctions from those brought about by climate change is very difficult.*

* Sources for this chapter include Helgen (2007), Allison (2007b), Flannery (1995a, 1995b), and other publications in references section.

The Eastern Long-beaked Echidna (*Zaglossus bartoni*) is one of the rarest mammals in New Guinea, surviving only in isolated forests with minimal hunting pressure. It forages for ants and earthworms by drilling into the soft ground with its long "snout" (actually its jaw). This species (or a very close relative) also inhabited Australia until the 19th century.

A total of 293 species of terrestrial mammals are known from the New Guinean Region. This number comprises 4 echidnas; 17 quolls and small dasyurids; 12 tree kangaroos; 12 wallabies; 8 striped possums (5 trioks, 3 gliders); 1 pygmy-possum; 1 feather-tailed possum; 12 cuscuses (possums); 10 ringtails; 12 bandicoots; 110 rodents; 29 fruit bats (flying foxes); and 57 micro-bats. Only in New Guinea and Australia do all three major clades of living mammals coexist—the monotremes, the marsupials, and the placentals. And nowhere else are the marsupials so diverse in evolutionary lineages, morphology, and ecology. And in no other continental fauna are the placental mammal lineages so poorly represented. By contrast, nearby Southeast Asia is home to the primates, elephants, rhinos, deer, civets, cats, canids, squirrels, and tree shrews. Welcome to the very strange world of native New Guinean mammals!

To an ornithologist working in the field in New Guinea, it is almost as if native mammals do not exist. Because of overhunting in most accessible locations, the possums, tree kangaroos, and other edible game animals are very shy and reclusive. Western visitors typically see living mammals in New Guinea only when local hunters bring them in for sale, held in a sturdy copra bag.

In this chapter we will review the mammal groups of New Guinea, make comparisons with Australia, and also discuss the effects of traditional hunting on New Guinea's mammals and on past and possible future extinctions of certain species and lineages.

TAXONOMIC REVIEW OF THE NATIVE SPECIES

The **echidnas** are represented in New Guinea by two genera: *Tachyglossus*, with 1 species (also widespread in Australia); and *Zaglossus*, with 3 species. These are egg-laying monotremes—the most bizarre of all mammals and perhaps the most primitive of living mammal groups. Echidnas look like a cross between a hedgehog and a porcupine, but with a long naked proboscis/jaw, no teeth, a long and extensible tongue, and shovel-like clawed feet for digging. The males develop a spur on the foot, which during the breeding season exudes a milky substance produced by the crural gland in the thigh. The exudate does not appear to be toxic as it is in the platypus. The nature and purpose of this exudate is not known. These terrestrial burrowing mammals forage in the ground for earthworms, ants, and termites, which they harvest with their sticky and spiny tongue.

The quolls and **small dasyurids** are small to medium-size marsupial predators grouped in the family Dasyuridae. Seventeen species inhabit New Guinea: 7 dasyures, 2 quolls, 5 murexias, 1 planigale, and 2 dunnarts. They are superficially rodent-like, either

Left: The Long-tailed Pygmy-Possum (*Cercartetus caudatus*) inhabits New Guinea's upland forests and is also found in North Queensland, Australia. It preys primarily upon arthropods.

Above: This small wallaby (*Dorcopsulus* species) was photographed in the uplands of the Foja Mountains. It may constitute a distinct endemic species. New Guinea is home to no fewer than 12 species of wallaby.

blackish with white spots, or varying shades of brown, or dark brown dorsally and paler ventrally. All have a pointed snout and a long tail. The smallest are mouse-like. They feed on insects and small vertebrates, including birds.

The **bandicoots** (marsupials in the family Peramelidae) are represented in New Guinea by 12 species in four genera. The New Guinean species are small or medium-large, ratlike, mainly brown-furred, with rodent-like ears, a long, pointed snout, and a long hairless or slightly hairy tail. In some, the fur is spiny. The bandicoots are omnivorous and both diurnal and nocturnal, depending on threats of predation. They are burrow dwelling. The Giant Bandicoot of the SE Peninsula is classified as endangered on the IUCN Red List.

This arboreal woolly rat of the genus *Mallomys* was photographed in the Foja Mountains using a camera trap. This is apparently a local montane endemic, not yet described.

The **pygmy-possums** include a single species from New Guinea—the Long-tailed Pygmy-Possum. This small marsupial is mouse-like and confiding, with large black eyes, unmarked brown dorsal pelage, and a long tail. The species subsists on insects and plant exudates.

The 12 New Guinean species of **cuscuses** are large possums with short and woolly pelage and a partially naked prehensile tail. This marsupial group includes some of New Guinea's more common mammals—the Ground Cuscus, Northern Common Cuscus, and Common Spotted Cuscus. These are slow-moving and seemingly dull-witted house-cat-size mammals that forage mainly in forest trees for fruit and leaves. They have small ears, a rounded head, and large, rounded catlike eyes. Their distally naked curled tail is distinctive. The largest New Guinean individuals of the Common Spotted Cuscus weigh in excess of 6 kilograms. Naturally, these slow-moving creatures are favored targets for traditional hunters throughout New Guinea.

The 10 species of New Guinean **ringtails** include two genera of small to medium-size possums with small heads and mainly furred prehensile tails. Smaller than the typical cuscuses, these nocturnal arboreal marsupials forage mainly on leaves but also consume bark, fungi, lichens, ferns, fruits, leaf buds, and pollen.

The **striped possums** are represented by 8 species in New Guinea—5 trioks of the genus *Dactylopsila* and 3 gliders of the genus *Petaurus*. The trioks are black-striped, handsome, and gracile, living a largely arboreal life in forest, foraging primarily for bark-dwelling arthropods in dead wood. The gliders are tree-living marsupial versions of flying squirrels. They have long furred tails. The gliders appear to subsist on fruit, arthropods, and plant sap.

The adorably stripe-faced **Feather-tailed Possum** (*Distoechurus pennatus*) is the single species of its genus. This primarily nocturnal marsupial is widespread through lowland and upland forests to an elevation of 2,600 meters elevation. It is not known what the species consumes in nature.

The **tree kangaroos** are a distinct marsupial lineage within the Macropodidae (kangaroo family), with 12 species known from New Guinea, 3 of which have been scientifically described since 1990. These are tree-dwelling kangaroos that roost and forage in the forest canopy, feeding primarily on foliage and epiphytes, though they will visit the ground to forage at times. New Guinea today is the home of most of the tree kangaroos, and only 2 species inhabit Australia. Two species, Mrs. Scott's Tree Kangaroo (also called the Tenkile) and the Golden-mantled Tree Kangaroo, are critically endangered, with tiny, fragmented ranges along New Guinea's north coastal mountains.

This diminutive moss mouse (*Pogonomys*) was photographed in the Foja Mountains.

The **wallabies** are represented by 12 species in New Guinea. Most are terrestrial forest-dwelling marsupials, but 3 species are savanna dwellers that inhabit open habitats of the Trans-Fly and the Port Moresby rain-shadow woodlands. These terrestrial foragers consume leaves, fruits, flowers, and fungi. The savanna species specialize on grasses, forbs, and shrubs. Wallabies are nothing more than undersize kangaroos. The Agile Wallaby, which inhabits the Trans-Fly of New Guinea as well as northern Australia, is New Guinea's largest native mammal, with large individuals reaching 25 kilograms.

The **rodents** are placental mammals represented in New Guinea by 110 native species of murid rats and mice in 26 genera. There are 13 species of the genus *Melomys*, 7 species of the genus *Rattus*, and 5 species of the genus *Stenomys*. Many are small rainforest-dwelling crea-

Opposite: A Spectacled Flying Fox (*Pteropus conspicillatus*) hangs in a roost tree, gripping a large fruit. Large communal roosts of this flying fox can be found in the city of Madang (ENG).

Right: The Common Blossom Bat (*Syconycteris australis*) is one of the most widespread and abundant species of pteropodid fruit bat in New Guinea. It subsists on pollen and nectar harvested from rainforest trees and vines.

Below: The Little Bentwing Bat (*Miniopterus australis*) is widespread and common through New Guinea and parts of Australia. This photo shows a parasitic (wingless) bat fly behind the bat's left ear. Photo: © Pavel German

tures. Several are giant rats that weigh as much as 3 kilograms. These large rats are popular prey of the New Guinea Harpy-Eagle, which captures them on the ground in the forest interior. A web-footed rat is a mountain stream specialist.

Twenty-nine species of **fruit bats** (flying foxes) of the family Pteropodidae are known from the New Guinean Region. This is a lineage of small and large non-echolocating fruit- and nectar-feeding bats that exhibit doglike faces and large eyes. They are evolutionarily distinct from the microchiropteran (micro-) bats. The group includes *Pteropus neohibernicus*, the largest of the fruit bats by wingspan—which reaches nearly 2 meters. The species of fruit bats are important seed dispersers in New Guinea's forests. *Pteropus conspicillatus* forms large tree roosts of hundreds in the canopies of protected trees in urban areas, and these can be observed flying out in the early evening to nearby rainforests to forage. The flying foxes of the genus *Pteropus* are perhaps the most commonly observed native mammal in New Guinea. They mainly inhabit the lowlands and coastal areas.

The micro-bats (suborder Microchiroptera) are represented in New Guinea by 57 species of 11 genera. Many roost in caves and forage at night for flying insects, which they find through echolocation. Most species in this lineage are small and have very small eyes. Large ears and weird facial morphologies apparently assist with their echolocating ability. This assemblage of small insect-feeding bats is especially poorly

known in New Guinea and merits targeted field research across the island using the latest electronic technology (these creatures are best detected by the high-pitched sounds they make when in flight).

This overview of New Guinean mammals is undoubtedly incomplete. Experts suspect that a considerable portion of the species inhabiting the island have yet to be discovered or described to science, and yet other groups have been inadequately studied and classified (meaning that cryptic species have been lumped in with widespread species, leading to undercounting). The mammals of New Guinea need much additional field and museum study.

EXOTIC SPECIES

Most exotic mammals introduced to New Guinea are human commensals. Neither the dog nor the pig has a long history in New Guinea: the former was introduced at least 2,000 years ago, and the latter either before or after the dog (its time of arrival subject to scientific disagreement). By comparison, the Dingo has been present in Australia for at least 3,500 years. Both the dog and the pig presumably have had a serious detrimental effect on the local mammalian fauna of New Guinea, undoubtedly leading to extinctions of local native species. The disappearance of the thylacine (marsupial wolf) from New Guinea (as well as mainland Australia) can probably be blamed on the arrival of the dog/Dingo. Some researchers consider the subalpine populations of the dog in the high peaks of the SE Peninsula and Border Ranges evolutionarily distinct and have named it the New Guinea Singing Dog. Looking much like small Dingos, these creatures are notable howlers and do not bark. That said, they are still best treated as not distinguishable from the Dingo of Australia, and their presence in New Guinea is certainly a result of human translocation.

The other typical commensals are here as well—the House Mouse, Black Rat, Norway Rat, and House Cat, and most of these are found mainly in close association with human settlements or urban areas. Four additional exotic rat species are also known from the island. The House Shrew is known from a record from the Aru Islands as well as a questionable record from the Bird's Head. Three exotic deer species have been introduced: Fallow and Axis Deer were introduced to the Madang area of northern ENG. Their current status is unknown. The Rusa Deer was introduced by the Dutch to the Merauke area and now is widespread in the southern bulge of New Guinea (mainly the Trans-Fly). Another population of Rusa Deer is known from the forests of the northern Bird's Head, and the animal is quite abundant in some places. Finally, a small population of Crab-eating Macaques exists in the Abepura suburbs of Jayapura, in northeastern WNG. Attempts to remove this population have not been successful, and some biologists are concerned that if the species becomes acclimated to the forests of New Guinea it could potentially decimate native bird populations.

The Agile Wallaby (*Macropus agilis*) is New Guinea's largest native land mammal, inhabiting grasslands in the Trans-Fly and the southern dry zone of the SE Peninsula. Photo: Roland Seitre/naturepl

TRADITIONAL HUNTING

Mammals, of course, are high on the list of priority bushmeat harvested by traditional village hunters. The ongoing modernization of life in New Guinea has led to a reduction in the prevalence of regular bushmeat hunting, and yet the more rural villages, especially those with no road connection to cities, still depend on traditional hunting to secure protein for the table, especially to celebrate annual holidays and special occasions. The impacts of traditional hunting often lead to the local extirpation of populations of favored game mammals within a day's walk of the village. Although firearms are no longer widely available in all parts of New Guinea, men hunting with talented hunting dogs can decimate a local bushmeat fauna.

Andrew Mack and Paige West conducted interview-based research on the harvest of wild bushmeat in the Eastern Ranges. They found wild-hunted protein served as an important part of the rural villager's diet. A few prime species are targeted (wild pigs, cassowaries, wallabies, tree kangaroos, cuscuses, ringtails, megapodes, echidnas, and bandicoots), but many other species are taken adventitiously. The researchers estimated that in ENG, hundreds of thousands of people consume millions of vertebrate animals each year, amounting to tens of thousands of tons of wild meat annually. They posited that loss of this subsistence food resource would create a substantial economic burden in the parts of ENG where people have the least nutritious diets and the poorest health care. They recommended that traditional hunting be managed actively across ENG to achieve a sustainable harvest. Naturally, these recommendations would also apply to WNG.

The Northern Brown Bandicoot (*Isoodon macrourus*) inhabits the Trans-Fly and the SE Peninsula of New Guinea, as well as northern and eastern Australia. The bandicoots form a distinct lineage of small to medium-size terrestrial omnivores, feeding largely on arthropods. Photo: Martin Willis

EXTINCTIONS

To obtain a better understanding of extinction of mammals in precontact New Guinea, we must look to adjacent Australia, where knowledge of the fossil fauna is far superior to that of New Guinea. All the largest Australian marsupials and monotremes have been extirpated, and some of those that lived into the Pleistocene possibly were wiped out by human hunters. These include the large (30-kilogram) "*Zaglossus*" *hacketti* as well as *Zaglossus bartoni*, the Eastern Long-beaked Echidna, which still survives in the central cordillera of New Guinea but is endangered there. Australia also lost a 200-kilogram wombat, a large koala, a marsupial tapir, and the largest marupsial known, *Diprotodon optatum*, which may have topped 2,700 kilograms. Other large extinct marsupial forms included animals that resembled hippos, ground sloths, camels, and a lion. There is some evidence that this last may have survived in Australia to the time of European settlement. C. Lumholtz reported searching for this 120-kilogram predator, though without success. A very large kangaroo, *Procoptodon goliath*, which may have weighed more than 200 kilograms, became extinct during the most recent glacial cycle. Some 20 species of Australian wallabies and kangaroos disappeared by the end of the Pleistocene. Finally, it is worth mentioning the apparently carnivorous macropodid (wallaby or kangaroo) named *Propleopus oscillans*, which may have weighed 50 kilograms. The work of C. Johnson supports the notion that this assemblage of large marsupials was exterminated shortly after the arrival of humans on the Australian continent, but recent research asserts that the extinction of much of the Australian megafauna cannot be proved to have been caused by human hunting.

New Guinea's extirpated large Pleistocene marsupials include 12 species of large herbivores, among them large diprotodontids (members of the Diprotodontidae, an extinct family of large marsupial browsers), such as *Hulitherium thomasetti*, *Nototherium* (now *Kolopsis*) *watutense*, and *Maokopia ronaldi*, as well as large kangaroos or wallabies such as *Protemnodon tumbana*, *P. nombe*, and *P. hopei*. A tree kangaroo larger than any living species, *Dendrolagus noibano*, and an apparently distinct species of thylacine also are known from subfossil remains. Two small wallabies (*Thylogale christenseni* and an unnamed *Thylogale*) known from the Western Ranges of WNG are now apparently gone. And a large bandicoot is known from subfossil remains from the Aru Islands.

The thylacine, of course, is one of Australia's most famous marsupial extinctions. The Australian species or a close relative inhabited New Guinea, known from subfossil remains from the Kiowa rock shelter in Chimbu Province, PNG. Reports of sightings of the thylacine continue to be made in Australia and New Guinea, though none of these have been confirmed by reviewable evidence.

FUTURE THREATS

So, what does the future hold for the native mammal species of New Guinea? For some seriously threatened species, such as Mrs. Scott's Tree Kangaroo (the Tenkile), the Golden-mantled Tree Kangaroo, and the three species of long-beaked echidnas, continued traditional harvest by village hunters with dogs might lead to additional extirpation of local populations or even extinction of these species, unless there is additional creation of strict no-hunting zones where these threatened species still survive. Other species with tiny ranges may be threatened by extensive logging or plantation development. There is little doubt that additional undescribed species of mammals, already rare, remain hidden in New Guinea's forests. These need to be sought out, described, and conserved along with the rest of the mammalian fauna. Neither the government of PNG nor of Indonesia shows the necessary capacity or commitment to actively conserve mammal species and their critical habitat. This situation must change. Governments and politicians need to recognize that wild nature, especially in its most charismatic forms, offers long-term economic potential that far exceeds the takings of extractive enterprises. The gold, gas, and oil will be gone in decades. The forests and wildlife can provide tourism resources that can generate substantial cash flow forever, if these resources are properly managed. ■

12 Paleontology

Ancient Life

THE HISTORY OF PAST LIFE on Earth is recorded as fossils deposited into sediments laid down over many millenia. These fossils end up deep under the seafloor or in stream or lake sediments and then after millions of years of burial are exposed by erosion following exhumation that typically results from mountain uplift brought on by the slow collision between tectonic plates. In this chapter we examine the fossil record for New Guinea, recognizing that through most of the fossil record on Earth (Silurian to early Tertiary) New Guinea was nothing more than the stable northern margin of the Australian craton. Only recent plate collision and tectonic mountain-building created the separate entity now known as New Guinea. It is important to keep this in mind, for the mountainous New Guinea distinct from Australia that we know today is a recent phenomenon—something less than 10 million years old (mid-Miocene). The mass extinction of the dinosaurs took place 66 million years ago—56 million years before New Guinea was New Guinea. Only the land-based life recorded in sediments from the mid-Miocene and thereafter refers to the former terrestrial life that actually inhabited New Guinea as we know it today.*

Preceding pages: Impressions of fossil ammonites of the genus *Dactyliceras* from the Jurassic of WNG.

Opposite: Paleontologist Ken Aplin examines a bone mass extracted from a cave in the Muller Range of ENG. Photo: Stephen J. Richards

PALEOZOIC LIFE (541–240 MILLION YEARS AGO)

The oldest life forms known that have been collected from sediments found in today's New Guinea are Ordovician marine cephalopods (ca. 450 million years old) from the southern watershed of the Border Ranges of WNG. Silurian graptolites (tiny fossils of

* Sources for this chapter include Hope and Aplin (2007), Long et al. (2001), Flannery (1994), and additional publications appearing in references section.

weird extinct marine organisms) are known from the Bird's Head, and Silurian tabulate corals are known from the southern watershed of the Border Ranges as well (ca. 420 million years old). Silurian conodonts and agnathan marine chordates (as weird and little known as graptolites) were collected from the Lorentz River of southeastern WNG.

The oldest terrestrial fossils are leaf impressions of plants from the early Permian (ca. 270 million years old), exposed in the southern foothills of the Western Ranges of the central cordillera from south of Puncak Jaya west to the Weyland Mountains. W. Jongmans and J. F. Rigby (cited in Hope and Aplin 2007) reported ferns of the family Osmundaceae (relatives of the modern Interrupted Fern of the eastern United States), *Glossopteris* (famous for its southern/Gondwanan associations), and other seed ferns and gymnosperms, which exemplify a flora with both Gondwanan and East Asian elements, suggesting former biotic connections both north and south. Of course, during this time, Australia–New Guinea remained firmly attached to Antarctica, and all the continental landmasses on Earth were linked as Pangaea, though the ancient Tethys Sea separated Australia from the nearest parts of Laurasia.

Impressions of brachiopods (marine shelled invertebrates) have been found in Permian rocks (ca. 260 million years old). Brachiopods, mollusk-like creatures that first appeared in the Cambrian (543–490 mya) and continue to persist today in cold-water marine environments, exhibit affinities to northern taxa as well as southern, in biotic agreement with the plant fossils. By the way, in the early Permian, the South Pole stood at the present location of South Australia, and the sea where modern New Guinea would form had a paleolatitude of ca. 55° south.

Miocene dugong (sea cow) fossil vertebrae from the Selminum Tem cave in the Hindenburg Mountains of the Border Ranges of ENG. Photo: Erich M. G. Fitzgerald.

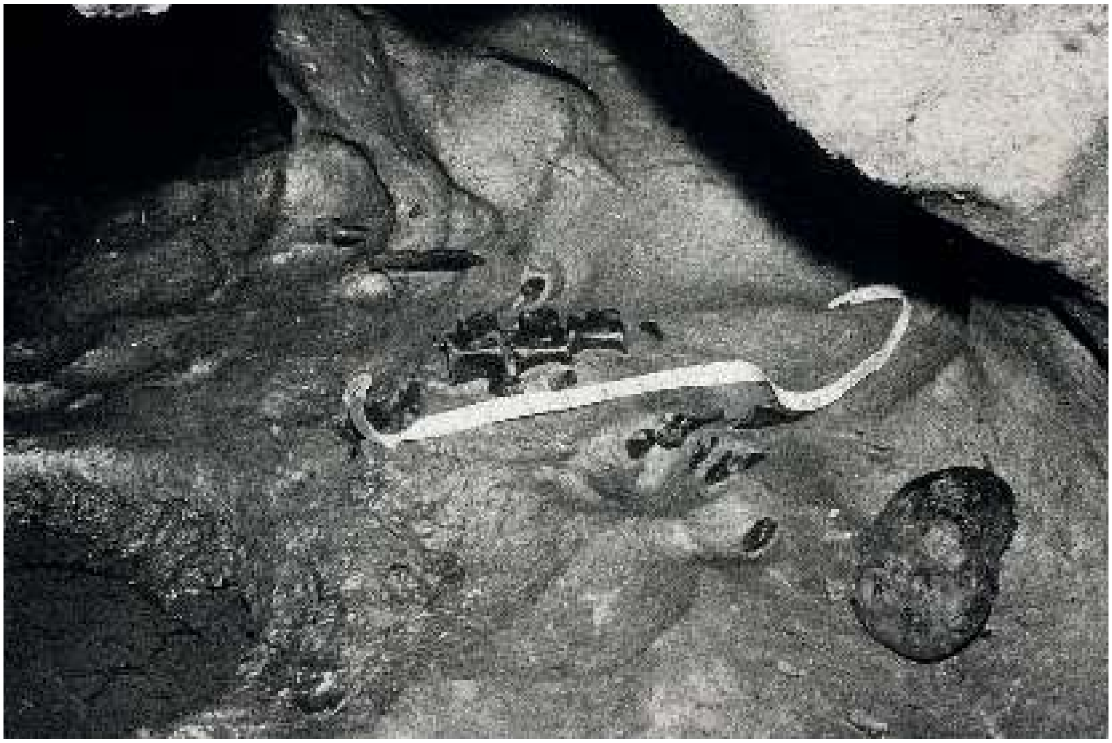
MESOZOIC LIFE (240–66 MILLION YEARS AGO)

In the mid-Jurassic (ca. 160 mya), some land surfaces of presumed island arcs existed north of Gondwana; today they are represented by deposits in central ENG and the Bird's Head of WNG. Apparently these rocks are not fossil-bearing. G. E. G. Westermann reported mollusks, including ammonites, an extinct group of cephalopods resembling the modern-day nautilus, from Jurassic sediments of ancient reef ecosystems now exposed as rock of the northern foothills of the central cordillera. Formed from mid-Tertiary limestones, the central cordillera has eroded to expose these older Mesozoic rocks, and ammonites occur from many locations in this area.

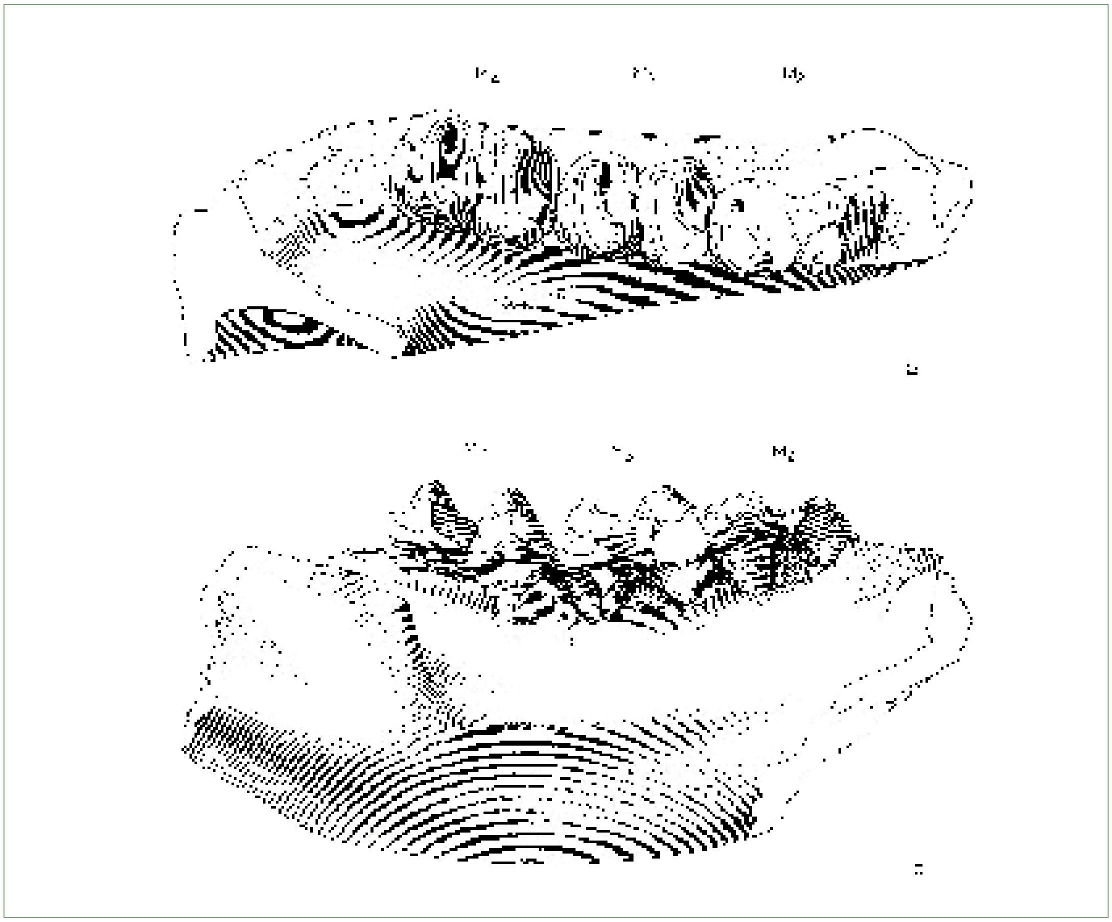
CENOZOIC LIFE (66 MILLION YEARS AGO–PRESENT)

Marine carbonate-rock facies of Tertiary age are widespread in New Guinea and consist of reef systems, oolites, and deepwater sediments, according to G. S. Hope and K. P. Aplin. Hence, limestones and related sedimentary rocks are widespread, and these now cap the highest peaks along the western sector of the central cordillera. They contain fossil mollusks, crinoids (sea lilies), bryozoans (small colonial organisms), and corals. Parts of modern New Guinea emerged from the sea in the Oligocene (ca. 35 mya), but most of these lands were resubmerged in the early Miocene (ca. 20 mya), perhaps with some remnant exposures.

Plant fossils, mainly pollen and spores, have been recovered from oil exploration



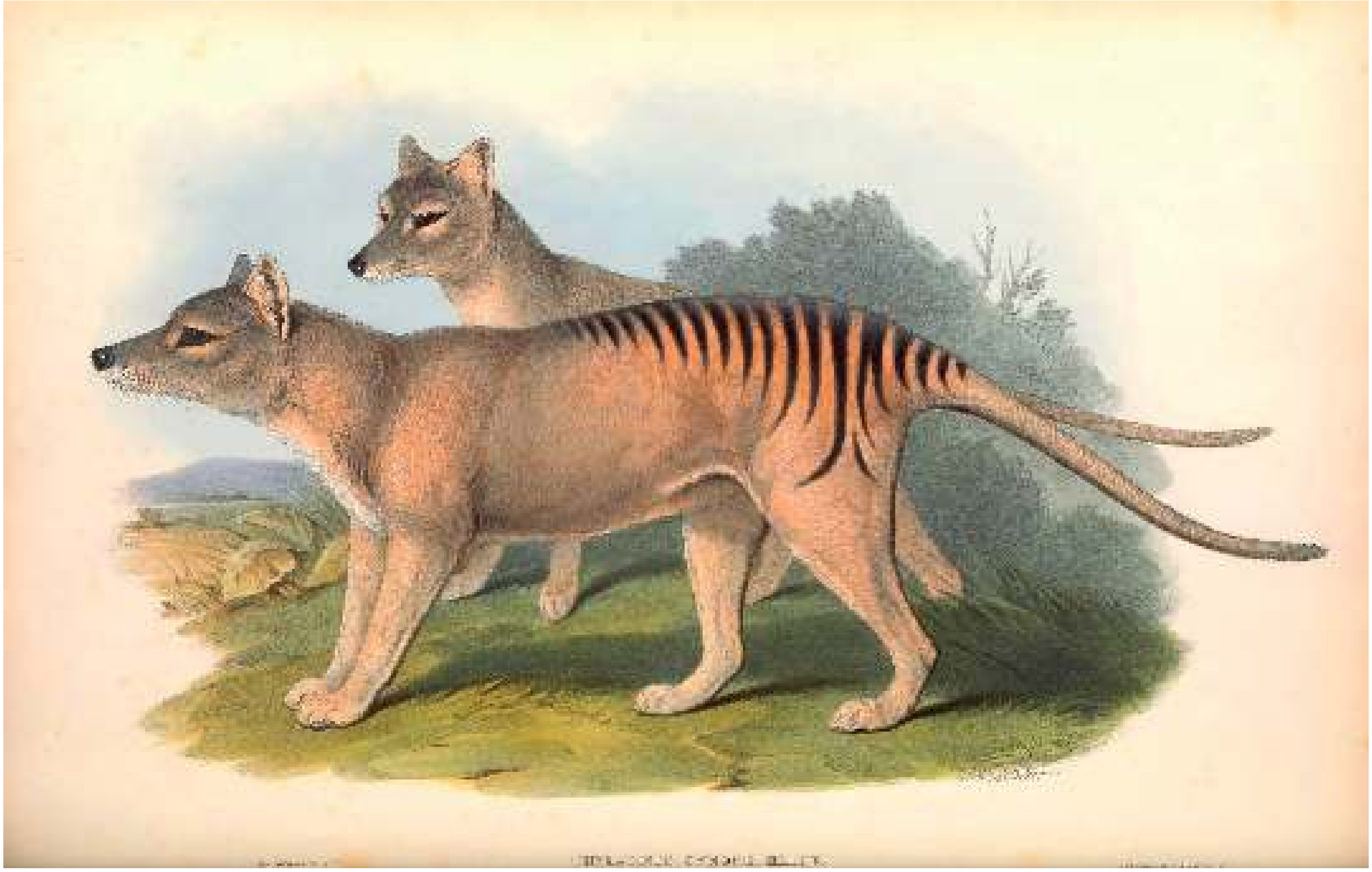
Miocene dugong (sea cow) fossil in situ in the Selminum Tem cave in the Hindenburg Mountains, when collected in 1975 by Rod Wells. The cave was flooding when the fossil was being collected. Photo: Rod Wells, Flinders University.



Journal illustration of the fossil jaw of the diprotodontid *Nototherium* (now *Kolopsis*) *watutense*, from Plane (1967). This large marsupial may have weighed as much as 400 kilograms. It is known from Pliocene fossils from the Bulolo-Wau valley (ENG) and from Pleistocene material from the lowlands west of Jayapura (WNG). Courtesy: Geosciences Australia/Bulletin of the Bureau of Mineral Resources, Geology, and Geophysics, Australia

boreholes. Identification of well-known and widespread taxa with fixed paleo-ages have been used to determine the ages of certain strata. R. J. Morley described Eocene pollen from the Waripi Formation on the Bird's Head peninsula that included Australian plant groups such as Casuarina, Myrtaceae, and Euphorbiaceae and no obvious Asian taxa, suggesting that a distributional barrier still separated New Guinea and proto-Asia at that time (ca. 50 mya). The flora and the encompassing rock facies suggest a dry and seasonal climate. At the time, these fossil-bearing sites may have been 20 degrees farther south than at present.

The first New Guinean *Nothofagus* (now *Trisyngyne*) pollen is reported from the Eocene Waripi Formation. The genus is better represented in pollen cores in the mid-Miocene, in accord with its appearance in New Guinea. *Nothofagus* originated in southern Australia and Antarctica. The *brassospora* group of this lineage was dominant across Australia in the Eocene. Its expansion into New Guinea during the Miocene may reflect conditions in New Guinea cooler than at present that allowed the genus to occupy lowland sites. The *brassospora* group became extinct in Australia in the late Pleistocene, but 5 species still remain in New Caledonia and 14 species currently inhabit the mountains of New Guinea. The New Guinean species occur in cool and wet upland forest habitats. The genus thus heralds the presence of these cool and humid climates in NG from the late Cenozoic. There is no evidence—fossil or otherwise—of *Nothofagus* west of Weber's Line, even though old Gondwanan gymnosperms



such as *Agathis*, *Phyllocladus*, and *Dacrycarpus* are present today in the Moluccas.

In the late Cenozoic, New Guinea was a series of low tropical islands with possible intermittent connections to one another and to Australia. These island masses, according to Hope and Aplin, were a destination for migrant Asian plants and animals able to cross narrowed water gaps. Although paleontologists have described a diverse rainforest fauna in northern Australia through the Miocene, there is no evidence that this rich fauna inhabited New Guinea. The oldest mammal fossil from New Guinea is a small sea cow from the early–middle Miocene (ca. 11.8 mya), collected from the Darai limestone from the Selminum Cave in the Hindenburg Mountains of western ENG. The bulk of our knowledge of the Tertiary in New Guinea is dependent on a collection of vertebrate fossils (the Awe fauna) from the Otibanda Formation near Bulolo, ENG, most of them collected from alluvial mining sites from river cuts of the upper Watut and Bulolo Rivers. The Otibanda fossils are late Pliocene in age, about 2.5–3.1 million years old, and the paleo-environment is thought to be lake-bed deposits in rainforest near sea level.

The Awe fauna includes large marsupials, a few small marsupials, and one murid rodent. Taxa include a species of thylacine (marsupial wolf), a smallish dasyure (*Myoictis* species), three kangaroos (or wallabies), three members of the marsupial Diprotodontidae, a small cassowary, a boa, and two crocodiles. Of greatest interest are the kangaroos and the diprotodontids. The

Lithograph of the Thylacine (marsupial wolf) from John Gould's *Mammals of Australia* (1863). A single tooth of a species of thylacine has been recovered from Pliocene alluvial deposits near Bulolo. In addition, remains have been recovered from the Nombe and Kiowa Rockshelters in ENG. A thylacine apparently inhabited New Guinea until into the Holocene. Photo courtesy of Biodiversity Heritage Library and Smithsonian Institution.

kangaroos, of the genus *Protemnodon*, were larger than any living kangaroos, and the members of the genus were formerly widespread across Australia and New Guinea. They apparently ranged from lowlands to highlands and even into alpine shrublands/grasslands.

The New Guinean diprotodontids range from large to very large browsing quadrupeds and perhaps are analogues to the South American ground sloths. One species, *Kolopsoides cultridens*, is known only from the ENG Pliocene and could perhaps represent a distinct New Guinean lineage. *Kolopsis watutense* may have weighed as much as 400 kilograms and thus would be one of the largest mammals ever known from New Guinea. More material is needed to confirm this. Overall, the Pliocene vertebrate fauna appears to have associations with northern Australia. Hope and Aplin postulated two waves of migration by this time period from Australia and one from Asia, as evidenced by the presence of murine rodents.

Pleistocene (2.6 Million–11,700 Years Ago) Glacial periods during the Pleistocene led to several global sea-level oscillations. The low sea-level stands were opportunities for Australian species to migrate north into New Guinea. That said, the fossil record for the Pleistocene in New Guinea is poor. Many vertebrate families prominent in Australia during this time are not yet known from the New Guinea fossil record. A fragment of a fossil jaw of a large diprotodontid named *Zygmaturus nimborensia* has been recovered from some lowland karst west of Lake Sentani, in WNG. This fossil, in fact, apparently refers to the species *Kolopsis watutense*, known from the Otibanda Formation of ENG. This would be the only fossil mammal in New Guinea represented in both the Pliocene and Pleistocene.

Type locality (where novel species were collected the very first time) of the Pliocene Awe fauna, Watut River, ENG. The Awe fauna includes a cassowary, several diprotodontids, and a number of other mammals. Courtesy: Geosciences Australia/Bulletin of the Bureau of Mineral Resources, Geology, and Geophysics, Australia

The Pureni montane wetlands near Tari (ENG) have produced a diprotodontid named *Hulitherium thomasetti*, a large kangaroo (*Protemnodon*), a small cassowary, and a crocodile. *Hulitherium* was quite large and may have weighed as much as 440 kilograms. The Pureni site lies at 1,500 meters above sea level, considerably higher than any other known crocodile record. The fossils are estimated to be 80,000 years old. More recent Pleistocene cave deposits near Chuave (ENG) have produced two large extinct kangaroo species (*Protemnodon*). Another montane site in the West Baliem valley of WNG is the source of fossils of a 100-kilogram diprotodontid named *Maokopia ronaldi* and a sturdy kangaroo named *Protemnodon hopei*. Located at 2,900 meters, ca. 40,000 years ago, during a glacial period, these extinct mammals inhabited chilly alpine shrublands or grasslands adjacent to glacial ice. Of these forms, *Hulitherium thomasetti* is represented by abundant fossil material and was a dominant member of this peri-glacial fauna.

A Pleistocene fossil very similar to today's Doria's Tree Kangaroo was found in the Nombe rock shelter in the Eastern Ranges. Dated to ca. 20,000 years ago, it was named *Dendrolagus noibano*. It was larger than any modern member of the lineage, and Doria's Tree Kangaroo might be its dwarfed descendant.

A late Pleistocene fossil deposit on the Ayamaru Plateau of the Bird's Head of WNG contained an undescribed ringtail and a very small striped possum. Finally, a fossil site in the Aru Islands contained an undescribed species of bandicoot of late Pleistocene age. At this time the Aru Islands were connected to New Guinea because of lowered sea level.

Michael D. Plane (left) examining a fossil mammal skull with Professor R.A. Stirton (sitting). Plane completed his master's degree at Berkeley studying under Stirton, writing up the results of the material collected by various fieldworkers (including Plane). Photo: *The Examiner*, Launceston, Tasmania

Holocene (11,700 Years Ago–Present) Holocene fossils and subfossils have mainly been collected in caves and rock shelters in association with archaeological deposits. Subfossil-bearing human rock shelters in the uplands of New Guinea have been discovered in both the east and the west. These provide evidence for the interaction between human populations and now extinct species of vertebrates that disappeared before modern times. J. I. Menzies described a fossil fruit bat (*Aproteles bulmerae*) from sediments of the Kiowa rock shelter in ENG, dated to ca. 10,000 years ago. This species has subsequently been found to be extant, today inhabiting caves in western ENG. It is apparently very rare and is considered critically endangered. The species, described from a fossil, may soon be extinct if actions are not taken to ensure its survival. The rock shelters have also been the source of skeletal material identified as a species of thylacine and two species of wallaby, all three now presumed extinct. According to Tim Flannery, it is possible all three of these extinctions may have coincided with the introduction to New Guinea of the dog.

NEW GUINEAN VERSUS AUSTRALIAN PALEOBIOTAS

Even though the biota of Sahul (Australia–New Guinea) is indeed a single biota resting atop the Australian tectonic plate, the environmental histories of Australia and New Guinea have been distinct, and this environmental distinction has probably been the main reason that the New Guinean Tertiary and Quaternary faunas were different from those in Australia. Australia supported a very rich fauna from this period that included more than a half dozen families not yet recorded from the fossil faunas of New Guinea.

New Guinea's rising central cordillera attracted rainfall that fostered cool and humid forest environments, something often lacking in Australia's expansive low interior regions. As has been stressed in earlier chapters, major environmental differences between New Guinea and Australia can explain much of the distinction between the biotas of the two regions sharing a single tectonic plate. New Guinea was montane and wet, whereas Australia was low and dry.

A main take-home point of this chapter is that New Guinea's paleontology is fragmentary at best and strongly merits much additional investigation, especially of the terrestrial biota that prospered after the full elevation of today's New Guinea from the seas in the late Tertiary. Most of the story of the evolution of New Guinea's flora and fauna remains to be told. That will require major new collections, their analysis, their synthesis, and their integration with the better-known Australian paleobiota. ■

13 Paleoanthropology

Human Colonization of New Guinea

THE NATURAL HISTORY OF NEW GUINEA very much includes the remarkable story of human colonization of the Sahul region (Australia–New Guinea) no less than 47,000 years ago. Recall that in the late Pleistocene, because of low sea-level stands, Australia and New Guinea formed one large continental mass offering a large target for human colonists dispersing southeastward from mainland Asia and Sundaland. At this time, sea levels were between 55 and 130 meters lower than they are today. Thus, there can be no real distinction between first arrival in Australia and first arrival in New Guinea—they were one and the same landmass.*

Compare the estimated human arrival time in Sahul, 47,000–65,000 years ago, with that in North America, ca. 14,000 years ago. Humans were in Sahul as much as 33,000–51,000 years earlier than they were in North America. Based on the most reliable field evidence, New Guinea has been occupied and has been impacted by human populations and hunters for no less than 47 millennia. This time span is long, very long, but cannot compete with that of Africa (and possibly Europe), where modern humans evolved by ca. 300,000 years ago. Modern humans filtered out of Africa starting either ca. 200,000 years ago or ca. 90,000 years ago, depending on what authority one finds most convincing. If one accepts the old date, this probably happened in several waves, which apparently led to the colonization of Asia and then Sahul. All these latter dates remain controversial, as with just about every aspect of the evolution of modern humankind.

Preceding pages: Trench excavation in search of artifacts at the ancient human-occupation site near Kosipe, ENG. Photo: Glenn Summerhayes

Opposite: Partial grano-diorite pestle pommel in the form of a bird. Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco

* Main sources for this chapter are O'Connell et mult. (2018), Clarkson et mult. (2017), Summerhayes et al. (2016), Pasveer (2007), Pawley et al. (2005), Flannery (1994), Swadling (1981) and others cited in references section.

The oldest well-defined evidence of human occupation known from New Guinea proper is the mountain site of Kosipe (Ivane River valley), which dates to ca. 47,000 years ago. This date may, in fact, be a reflection of the sparse sampling of New Guinea as well as a product of a tropical humid climate that poorly preserves archaeological remains. A 65,000-year-old record from the Madjedbebe rock shelter in northern Australia is geographically close to southern New Guinea and lies in what is today Arnhem Land in Northern Territory. If there were humans in Arnhem Land at this time, then it is likely there were humans in New Guinea, which was then connected by a broad land bridge across the Arafura Sea. That said, competing authorities dismiss the 65,000-year figure and suggest the oldest Australian occupation dates do not exceed 50,000 years.

We must deduce the conditions for New Guinea's first humans based on what has been found contemporaneously in better-studied northern Australia. The oldest living situation in the Madjedbebe rock shelter of Arnhem Land includes a hearth and a collection of stone artifacts of mainly quartzite, silcrete, mudstone, and dolerite. The assemblage includes points, flakes, faceted cores, grinding stones, edge-ground hatchets, ground ochers, and fragments of sheet mica. The living site includes fuel wood and various plant foods (seeds, tubers, Pandanus nuts). More than 10,000 artifacts were recovered from the oldest zone of occupation in the Madjedbebe rock shelter. This living site was dated using carbon 14 and single-grain optically stimulated luminescence methods. The latter provides a date that individual grains of quartz were last exposed to sunlight.

This possibly 65,000-year-old site establishes an earliest date for colonization of Sahul. Artifacts in Niah Cave in Borneo were recently dated to 74,000 years, which indicates potential colonists were established in Sundaland, west of New Guinea, well before the Arnhem Land dates. The Arnhem Land colonists arrived when Australia was cool and relatively wet. These occupants employed elaborate stone-working technology, the sophisticated use of ocher for adornment, and examples of seed grinding and pigment processing, as well as the world's oldest-known edge-ground hatchets.

We know little about the early inhabitants of New Guinea, and our knowledge is based on a few dozen archaeological sites scattered across the island, from the coast to the central highlands. Not surprisingly, most records are of relatively recent habitation. New Guinea's is not an environment that favors long-term preservation of organic remains. That said, well-preserved pollen cores in bogs and swamps provide indirect evidence of human occupation through abrupt changes in floral dominance of non-forest species that cannot be tied to climate shifts. These pollen-flora changes can provide strong evidence of human impact on local floras.

The ca. 47,000-year-old site (the range of estimates is 44,000–49,000 years) in the Ivane valley, near Kosipe in the uplands of the SE Peninsula, provides the best evidence of early occupation of interior New Guinea. This site is 10 days' walk from the south coast, and any access from the north would require surmounting a high pass of the central cordillera exceeding 3,500 meters. The implication is that predecessors to these upland colonists must have been established along the south coast well before these dates. Thus a 50,000-year date would be a conservative estimate of the first colonists' arrival in New Guinea.

The evidence from the Kosipe site indicates the inhabitants subsisted largely on pandanus nuts that grew wild in the uplands, hunted and cooked local forest game, and also transported yams collected from lowland sites (as the yams could not grow at this elevation). The presence of charcoal in soil layers and waisted stone implements (with a narrow "waist" where the tool would have been affixed to a handle) probably indicate clearing of forest using tools and fire.

Molecular Genetics of Ancient Lineages The most remarkable recent paleo-anthropological discovery related to the region is that today's inhabitants of Sahul harbor Denisovan DNA in their genomes. The Denisovans are an ancient and little-known hominin lineage first discovered in Denisova Cave in the Altai Mountains of Siberia (in today's Russia). Samples from this cave have been dated to 125,000 years ago. Today, among current human lineages around the world, the highest proportion of Denisovan DNA (6 percent) is found in inhabitants of New Guinea. Evidence is that the Denisovans shared a common ancestor with the Neanderthals and that they interbred with lineages of modern humans. Molecular evidence suggests that the Denisovans split from the modern human lineage ca. 1 million years ago and from Neanderthals ca. 0.6 million years ago.

Additional molecular systematic studies of modern New Guinean populations suggest that colonists may have arrived prior to 70,000 years ago, consistent with the dating evidence from Madjedbebe rock shelter. Mitochondrial DNA samples exhibit high genetic diversity. New Guinean and Australian sequences are more similar to each other than to Asian samples, suggesting possible joint colonization, which makes sense, given that early colonists arrived on Sahul, a single landmass. Differences in diversity of mitochondrial versus T-chromosome data for New Guinea indicate the possibility of multiple pulses of migration. The mitochondrial DNA samples from New Guinea and Australia are distinct, arguing for separate colonization or post-colonization histories. The New Guinean coastal populations are unrelated to those from the New Guinea highlands and indicate a recent colonization

Field delineation of a plot from the 47,000-year-old human-occupation site near Kosipe, in the Ivane valley, in the central sector of the SE Peninsula. Photo: Glenn Summerhayes

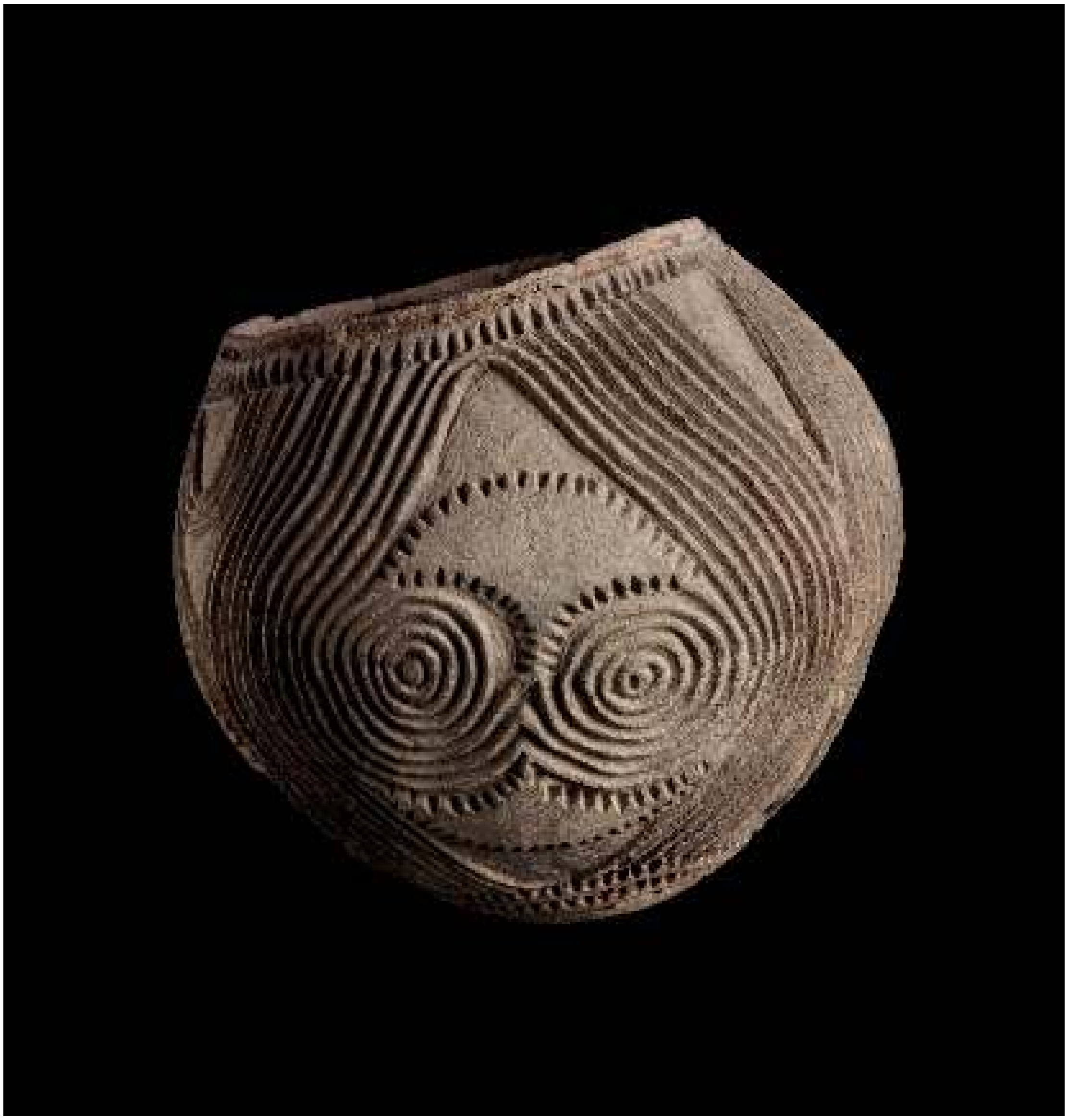
by the prehistoric Pacific Lapita culture to the coastal lowlands. These coastal samples cluster with Polynesian samples, as expected.

Colonization of Sahul Given the isolation of Sahul from mainland and island Southeast Asia during the Pleistocene, one of the great questions facing paleoanthropologists is the timing, geographic route, and pattern of colonization of Sahul. And the fact that modern New Guinean populations share DNA with both Denisovan and Neanderthal lineages is evidence that the colonization process was complex and certainly a series of invasions over time.

Wallace's and Weber's Lines mark the presence of ancient deepwater barriers separating Sundaland from Sahul. Even during periods of low sea level (ca. 50,000 years ago), deepwater barriers challenged colonists attempting to disperse eastward from Sundaland. The crossing would have required one sea voyage of 65 kilometers and three of more than 30 kilometers over open sea. Multiple, purposeful, successful colonization attempts would

Opposite, left: Prehistoric obsidian blade from Biak Island, WNG. This looks to have been fashioned as a hatchet blade to be fixed to a wooden shaft. Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco

Opposite, right: Adze of wood, stone, and woven orchid fiber made by the Dani people of the Baliem valley (WNG). Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco



Left: Low-fired clay food pot from the Abelam people, Prince Alexander Mountains (Sepik-Ramu, ENG). Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco

have been needed to effectively settle Sahul. Colonists must have had substantial sailing capacity and boat technology, and probably moved back and forth across each major water passage in the colonization process. By 35,000 years ago, colonists had settled New Hanover Island in the Bismarck group north of New Guinea. This required a sailing voyage of more than 200 kilometers—a true open ocean voyage where neither the departed island nor the targeted island is in view for long periods of travel.

We now know that the first colonists arrived on Sahul prior to ca. 50,000 years ago and perhaps prior to 65,000 years ago. What was their route, and how did they accomplish this technological feat? In terms of routes, both the Lesser Sundas (southern) and Moluccas (northern) routes appear feasible. In all likelihood, different groups of colonists probably used both routes. The southern route would have led colonists to northern Australia and the northern route to the Bird's Head of New Guinea. We have records of activity in Golo

Cave on Halmahera dating to 35,000 years ago (northern route), in Lene Hara on Timor dated to 42,000 years ago (southern route), and Lemdubu Cave on the Aru Islands dating to 28,000 years ago (southern route).

Certainly, many of the oldest occupation sites must have been coastal, but given that these were coastal during low sea-level stands, they would have been inundated by the rising sea and are no longer available for study. Today, there are more than 70 archaeological sites from the Sahul dated older than 20,000 years ago.

One study, using class I human leucocyte antigen obtained through direct DNA typing, identified three groups of people who migrated to New Guinea. Highland groups were apparently the first wave of migrants, followed by populations in the highlands' fringe foothills, and finally, north coastal groups, which apparently arrived last in this process. The assumption is that colonists traveled eastward in waves across Wallace's Line from the time of the initial colonization to recent times, in search of resources and opportunities. This happens even today, when the Bugis people from western Sulawesi, traveling in small boats, arrive in the Raja Ampat Islands in search of marine products and shark fin.

Occupation Kria and Toé Caves near the Ayamaru Lakes of the Bird's Head give evidence of occupation of sites in interior New Guinea from 26,000 years ago to the early Holocene. Kria Cave contained more than 2 meters of undisturbed sediment with an intact stratigraphy exhibiting five occupation units. The four lowest units are similar in containing mainly stone and bone artifacts, many remains of a forest wallaby species (*Dorcopsis muelleri*), and small amounts of mollusk shell, eggshell, ocher, charcoal, and botanical trace remains. In the 1980s, researchers Robert Bailey and Thomas Headland argued that hunter-gatherer societies were unable to inhabit rainforest habitats without access to agricultural products from sedentary agriculturalists. The data from the Ayamaru Lakes as well as from Kosipe indicate that their hypothesis was probably not correct.

Tool Use and Habitat Modification The fact that the earliest colonists to Sahul must have arrived via boat demonstrates that they were capable of sophisticated tool use. Construction of a seaworthy vessel for an oceanic voyage is no easy task. So it is clear that the first New Guineans were capable modern humans. It is thus not surprising that the earliest known residents of Sahul possessed the sort of tools (stone hatchets) that would be required to fashion a dugout canoe or some sort of sturdier sailing vessel.

There is evidence that early colonists to New Guinea deployed fire to modify habitat. This is, of course, a practice that continues today in rural New Guinea during the dry season. Fire can be used to prepare ground for planting and as an aid to hunting game in grassland areas. The combination of fire with hatchet use is twinned in the preparation of subsistence gardens today. Presumably this one-two punch allowed humans to successfully occupy all of New Guinea over the first several millennia of occupation.

Diet and Arboriculture The Kosipe site, ca. 47,000 years old, at 1,980 meters elevation, provides evidence for human use of *Pandanus* nuts, a species of yam, and wild-hunted mammalian game. At that time, apparently, the yams were harvested at lower

Opposite: Red-clay traditional art on coastal walls of a small islet southeast of Misool Island (Raja Ampat Islands).

elevations and brought to this higher site. The presence of waisted stone tools (e.g., ax heads) also indicates that human settlers cleared forest to foster growth of food plants. The availability of Taro and banana agriculture and fashioned stone tools may have made it possible for New Guinean colonists to settle interior upland forests in a manner more permanent and substantial than original colonists with their limited domesticated resources.

Rather than agriculture, what we are probably seeing at the Kosipe site (and all very old sites) is mainly arboriculture, in which families managed wild fruit and nut trees in the forest, planted them around their homes, and harvested other food plants (e.g., native yam species) adventitiously. The fruiting trees of interest included various pandanus, Breadfruit, species of galip nut (*Canarium*) and okari nut (*Terminalia*), *Cordyline fruticosa*, *Pometia pinnata*, *Dracontomelon*, *Inocarpus*, *Spondias*, *Burckella*, *Lithocarpus*, and others. By 9,000 years ago agriculture was in play in highland valleys (e.g., Kuk) where presumably Taro and bananas were cultivated. By 6,000 years ago, intensive cultivation was in play, and the rest is history. The ditching and mounding at Kuk exemplifies substantial investment in crops of favored food plants. Much the same process took place in WNG in the Baliem valley starting around 7,000 years ago. This sort of agriculture may not have appeared in the lowlands until recently, although work by G. S. Hope at Lake Hordorli in the lower Cyclops Mountains near Sentani supports the presence of shifting agricultures in the lowlands by 11,000 years ago. Even today, quite a few rural societies depend primarily on harvest of sago, and for all groups, hunting and gathering continue to offer important foods for the table.

Faunal Extinction and Humans During the 1990s a series of publications pushed the notion of a mass extinction of some 88 species of large mammals, reptiles, and birds of the Sahul shortly after the arrival of humans in the later Pleistocene. This hypothesis was tied to similar events in North America and elsewhere—landmasses where a naive megafauna was decimated by a rapidly colonizing human population. Australia and New Guinea in the early Pleistocene did indeed support a remarkable fauna of large vertebrates (see chapters 11 and 12), but the most recent scholarly work dismisses the notion that humans brought about a rapid mass extinction on Sahul. Many of the largest extinct vertebrates are shown to have either disappeared prior to the arrival of humankind in Sahul or continued to persist well after human arrival and settlement. The major weakness of the mass-extinction hypothesis was any direct evidence that humans hunted and killed these oversize vertebrates. Such a thing, of course, is well documented for the Māori decimation of the giant moa species of New Zealand—a relatively recent event. The conclusion is that climate change impacts may have contributed as much or more than human hunting in the majority of extinctions of the Sahul megafauna.

Climate and Occupation If, indeed, the first colonists arrived by 65,000 years ago, that would align with a globally cool period with ice-cap expansion and an allied low sea level. The other major peak in cool climate and ice-cap expansion was at the Last Glacial Maximum (LGM), ca. 24,500 years ago. A high sea stand at 7,000 years ago had sea levels substantially higher than at present, drowning current coastlines and creating an inland sea in the lower Sepik and perhaps also in the Lakeplain of the Tariku and Taritatu Rivers. Thus, any coastal habitation at 65,000 or 24,500 years ago would be beneath the sea today, and the coastal communities from 7,000 years ago would be distant from today's coast, at a higher elevation.

Lapita Culture Identified by their distinctive dentate-stamped pottery, the people of the Lapita culture invaded the northern Sahul around 3,600 years ago and were predominate in the islands north and east of New Guinea until about 1,500 years ago. These were seafaring island people who arose in Taiwan or southern China, spoke an Austronesian language, and were expert seafarers, with substantial outrigger canoes and the ability to navigate across

Prehistoric stone mortar, possibly in shape of a stylized Wattled Brushturkey. Stone is possibly weathered andesite. From Kainantu subdistrict (ENG). Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco

the sea out of sight of land. Their descendants are today's Polynesians, who completed the colonization of the tropical Pacific to Hawaii, Easter Island, and New Zealand. There is no evidence that the Lapita people colonized the interior of New Guinea, which was already occupied by earlier unrelated colonists who spoke non-Austronesian languages. The Lapita pottery has been found from the Bismarck Archipelago east to Tonga, Samoa, Fiji, and New Caledonia. Most of the villages of the Lapita people were placed on small offshore islands, though they harvested and traded obsidian from the interior of New Britain. They carried with them dogs, pigs, chickens, Taro, a yam species, coconuts, and Breadfruit. Aside from the distinctive pottery, they were known for their ground-stone adzes, shell artifacts, and flaked obsidian tools. DNA extracted from burial sites has shown genetic linkages to the people of East Asia. The Lapita people presumably brought with them to the New Guinean Region various Asian food crops, pigs, dogs, and unique cultural knowledge.

Languages The assumption is that the capability and expertise needed to sail from insular Southeast Asia across Wallace's Line to New Guinea required the first colonists to have a language. Thus languages have been present and evolving in New Guinea for more than 50,000 years—and this long tenure on New Guinea helps explain the variety and complexity of New Guinea's linguistic culture of two major language phyla (Papuan/Non-Austronesian, and Oceanic and Non-Oceanic Austronesian) and more than 1,000 distinct living languages—nearly 20 percent of the world's total. New Guinea is home to 17 language families—six times more than those found in pre-Columbian Europe. And this does not include the additional 9 languages so distinct that they cannot be included in any of the existing 17 families.

Two areas of New Guinea show remarkable linguistic diversity—northern New Guinea from the Bird's Head east to the Sepik-Ramu, and the Southern Lowlands between the Digul and Purari Rivers. Linguists think that many of the older language families in New Guinea trace back a minimum of 8,000 years. By contrast, Indo-European and Austronesian are thought to be ca. 5,000 years old. Today, of course, typical New Guinean languages have a few hundred to a few thousand speakers, and many of them are threatened with extinction. Presumably many scores of languages have gone extinct over the past thousand years.

Paleoanthropologists excavating an ancient human-occupation site near Kosipe, ENG. Photo: Glenn Summerhayes

Pigs and Sweet Potato Pigs and the Sweet Potato are so essential to the welfare of village-living rural New Guineans today that their history in the region is very important to the understanding of New Guinea's prehistory. Their arrival in the interior of New Guinea spelled a cultural and agricultural revolution and led to a substantial expansion of New Guinea's human population. Today's dense populations in the interior upland valleys of the highlands of WNG and ENG are a product of the economic and nutritional value and adaptability of these two domesticates.

The pig most likely arrived in New Guinea with the Lapita people around 3,500 years ago. It is genetically unrelated to the Sulawesi Wild Boar and instead shows close affinities to the pig populations of Polynesia, Melanesia, and Halmahera (the "Pacific clade"). Earlier evidence of the pig in interior New Guinea by 10,000 years ago remains unproven by subsequent research. The cultural and nutritional importance of the pig in New Guinea today is not tied to a postulated long history on the island.

The same can be said for the Sweet Potato. This staple was apparently domesticated in Peru by at least 8,000 years ago—making it one of the earliest domesticated food plants. European explorers carried the Sweet Potato to Europe in the 15th century and from there it was carried east and southeast into the Pacific. It may also have spread from northern South America to eastern Polynesia by 1,600 years ago. Jack Golson has suggested that the Sweet Potato may have arrived in the highlands of New Guinea as much as 1,200 years ago. Several thousand cultivars have been developed under the isolation of the New Guinean highlands—another line of evidence for the older rather than younger dating of the Sweet Potato's arrival in New Guinea. That said, most estimates place the Sweet Potato in New Guinea no earlier than 400 years ago. When the Sweet Potato did indeed arrive, it led to a major agricultural shift in the interior highlands—from Taro culture in valley-bottom swamps to Sweet Potato culture across the hilly valley uplands. The dynamic appearance of *Casuarina* ca. 1,200 years ago into the interior upland valleys had an important silvicultural impact, because of the ability of this shade tree to fix nitrogen. The widespread planting of this tree and the Sweet Potato may have led to the evolution of densely populated communities in the interior valleys of the Baliem and Wahgi Rivers.

Finally, the arrival of the dog in New Guinea, some time more than 2,000 years ago, created a revolution in hunting of wild game, because of the ability of dogs to locate New Guinea's mammals by scent. This probably led to expansion of human populations in the interior as well as the serious reduction in many game species, leading in some cases to widespread local extirpations or species extinctions. ■

14 People

Cultural and Linguistic Diversity

THERE ARE MORE LANGUAGES and more traditional cultures in New Guinea than in any other comparable area on Earth. Given that humans arrived and colonized Sahul at least 47,000 years ago (and possibly as early as ca. 65,000 years ago), it is perhaps no surprise that New Guinea is home to an estimated 1,100 languages in at least 17 language families. This family count does not include a collection of at least 9 very isolated languages with no known affiliation, standing on their own as deeply distinct. The combination of the passage of many millennia, the rugged topography, the myriad torrential rivers, plus the warlike nature of most precontact ethnic groups has generated cultural and linguistic diversity on an extreme scale. There is also considerable physical diversity among the traditional inhabitants of New Guinea, indicating long periods of genetic isolation and differentiation, as well as probably multiple invasions of distinct human lineages from the west over this long period.*

New Guinea is a part of Melanesia—"the island lands where dark-skinned people live" (a term coined by French explorer Jules Dumont d'Urville, *Melanesia* means, literally, "black islands"). Its name distinguishes Melanesia from Indonesia (Indian islands) to the west, Micronesia (tiny islands) to the north, and Polynesia (many islands) to the east. No doubt, Melanesia is the leader in ethnic and linguistic diversity among these four Indo-Pacific island groupings, even though there seems to be little correlation between these four regional categories and the language families that inhabit them. Melanesia includes New Guinea, the Torres Strait Islands (of Australia), the Bismarck Archipelago (New Britain, New Ireland, Manus), the Solomon Islands, Vanuatu, Fiji, and New Caledonia.

Preceding pages: Huli wigmen with their fantastic feathers are a feature of highlands shows in PNG.

Opposite: "Sing-sing" scene, with Western Highlands man leading a dance in Payakona village, Eastern Ranges, ENG. His headdress decoration includes 24 wire-like pale whitish-blue head plumes from the King of Saxony Bird of Paradise, two Papuan Lorikeets, and flank plumages of the Blue Bird of Paradise. Notice also the painted kina-shell breastplate, and adornments of orchid fronds and ferns, as well as two large pale leaves of a laurel tree.

* This chapter is based on the following main references: Chowning (1982), Mansoben (2007), Pawley et al. (2005), Hodgins et al. (2005), and Friede et al. (2017).

The cultures of the many peoples of Melanesia share practices with other Pacific peoples. Ones that most readily come to mind are the wantok system of communal sharing of wealth (wantok is pidgin for "one talk" and refers to one's relatives); the payback system of violent retribution that traditionally led to long-term emnities between adjacent communities; the elaborate compensation ceremonies that can resolve injustices in the manner of a village court; the system of indebtedness created through the sharing of pigs; and the widespread swidden agricultural practices of the region. We discuss all these and more in the pages to follow.

LANGUAGES

New Guinea is home to various Non-Austronesian (Papuan) language families. Also, the Austronesian language family is widespread in coastal and island locations that extend from Madagascar east across the Indian Ocean and the tropical Pacific to Easter Island and

A line of Bena Bena women dancers at a highlands sing-sing. The dancer in the middle of the frame is wearing a cuscus-fur vest, a nose ornament of a King of Saxony Bird of Paradise head plume, a headband of contour feathers of the New Guinea Vulturine Parrot, and a top headdress that includes red New Guinea Vulturine Parrot feathers, Lesser Bird of Paradise flank plumes, and yellow orchid vines.

from Taiwan south to New Zealand. The 1,200 plus languages in the Austronesian family can be divided into an Oceanic group to the north and east of New Guinea and a Non-Oceanic grouping to the west of the Bird's Neck. Historically, the Proto-Oceanic language group is affiliated with the Lapita culture and has been influenced by a period of interaction with the Papuan languages along the north coast of New Guinea. The Lapita culture appeared suddenly in the Bismarck Archipelago around 3,500 years ago and within two to three centuries had been carried east through the distant islands of Polynesia. The Non-Austronesian (Papuan) languages dominate in New Guinea's interior and uplands, but also can be found in Timor and the Aru Islands. It is accepted that the Austronesian family of languages is a recent arrival in the region through a pulse of seafaring colonization of islands, whereas the various Non-Austronesian language families are ancient and endemic, based on the much earlier bouts of colonization and penetration of interior and upland regions of the great island. One assumes many of the languages of this Non-Austronesian assemblage arrived prior to 20,000 years ago.

A dancer celebrating the formal declaration of the creation of the YUS Conservation Area at a village in the interior uplands of the Huon Peninsula. The man wears a headdress of cassowary feathers, a headband with dog teeth, necklaces with pig tusks, and an array of plants, including gingers and cordyline leaves, among others. Photo: Bruce Beehler


WOMEN

Preceding pages: Chimbu women dancing at an annual highlands show in ENG.

The Ethnologue website is perhaps the most authoritative source for the world's languages. Its database includes ca. 800 languages for ENG and 260 languages for WNG, totaling 1,060 languages for the island. Nearly 80 percent of the languages in New Guinea are Non-Austronesian; the remainder are Austronesian.

To give an initial sense of New Guinea's language richness, we can compare New Guinea (ca. 1,100 traditional languages) with various other parts of the world. Counts of traditional languages for other areas follow: India, 447; China, 299; Brazil, 210; Peru, 150; Vanuatu, 138; Borneo, 90; Madagascar, 1; and New Zealand, 1. This is only partly indicative of New Guinea's uniqueness, linguistically. The deep diversity of New Guinea's language diversity outstrips that of the whole of Africa. And compare New Guinea's 17 language families with Europe's 3 families. Just the Trans–New Guinea family, boasting 400 languages, is the world's third most diverse language family on Earth.

MAJOR TRADITIONAL CULTURAL GROUPS

We here assume that a group speaking a unique language has a unique culture. This would be especially so in the collection of languages from the Papuan families found in the interior of New Guinea. Most cultural groups on the island of New Guinea are small (fewer than 3,000 speakers). Ethnologue lists 124 New Guinean language groups that are on the wane. Because of colonial tribal pacification, improving transportation, migration, and intermarriage, the small cultural groups tend to be subsumed (mainly through marriage) into the larger, more successful, or more aggressive groups. In the following section we discuss some of the more dominant and well-known cultural groups in New Guinea. Most are distinguished by their language. We review a selection of groups from west to east.

The **Arfak/Sougb** people inhabit the uplands of the Arfak Mountains of the eastern Bird's Head of WNG. These highland people build distinctively shaped bark-sided houses and are great hunters of birds and other wildlife. This area is home to the twin Anggi Lakes, two of the (very few) large upland lakes in New Guinea. The Arfaks offer excellent bush walking for adventurous tourists, as well as superb birding opportunities.

The **Me** or **Kapauku** people inhabit the highland valleys in the vicinity of the Paniai Lakes of the western end of the central cordillera. The group subsists primarily on garden crops, dominated by Sweet Potato, as well as pig husbandry. Like the Dani man (discussed below), the traditional Me man sports a penis gourd as a main unit of body ornamentation. Wearing of penis gourds extends from the Western Ranges to the Border Ranges.

The **Kamoro** people inhabit the coastal lowland forests of the western terminus of the Southern Lowlands of WNG, downstream from Timika and the Freeport mine. They have traditionally been seminomadic, moving to harvest sago and mangrove and stream fishes. Culturally, they are known for their seasonal "renewal of life" festival, in which they construct a special memorial house to hold the bones of their dead. The Kamoro are also recognized for their distinctive carvings of ornamented canoes and ornate spirit poles.

The **Asmat** are easterly neighbors of the Kamoro, living in the waterlogged lowlands of the Casuarina Coast (in the west-central Southern Lowlands). In 1770, Captain James Cook lost 20 crew members who landed on the coast to gather fresh water for the ship—from a surprise attack by the Asmat. The tribe was infamous for its warriors' ferocity. Today, the Asmat are known for their expert wood carving, especially of ornamental war shields and ancestral poles.

The **Marind-Anim** people inhabit alluvial lowlands southeast of the Asmat and west of the PNG border. Historically, this group has been infamous for the habits of its wide-ranging headhunting war parties, which struck terror in the hearts of their less pugnacious neighbors.

The **Dani** are populous (250,000) and live in the Baliem valley, a popular tourist destination. They are well known for their distinctive traditional dress, their famously warlike habits, and the attention they have received from overseas anthropologists (e.g., Robert Gardner, in his film entitled *Dead Birds*). The Dani are perhaps most famous for the men's main traditional item of dress: a hollowed and dried gourd that encompasses the penis, held erect by a string fastened around the hips.

The **Mountain Ok** (or Min people; 30,000-plus) inhabit the highland forests of the Border Ranges on either side of the border that separates WNG from ENG. Their tradi-

Asmat men's house with wood-carver in action. The Asmat, famous warriors and wood-carvers, inhabit the swampy lowlands of the west-central sector of the Southern Lowlands (WNG).

tional dress also includes the penis gourd. They garden, growing Taro and Sweet Potato, and keep pigs.

The **Huli** people inhabit the highlands in and around the Tari valley of Hela Province of western PNG (in the southern watershed of the western sector of the Eastern Ranges). Famously warlike, the Huli are remarkable for their ornate headdresses of plumes of birds of paradise, their elaborately shaped human-hair wigs, worn by certain select men in each clan, as well as their intricately painted faces.

The **Enga** people inhabit the highlands north and east of the Huli, in Enga Province of west-central PNG. These warlike and fractious people attempt to settle disputes through material compensation mediated by a ritual pig exchange, known as a ti. The Enga people are physically robust, and in traditional ceremonies the men wear a long, woven cloth skirt and a round human-hair wig topped with plumes of birds of paradise.

The **Melpa** people inhabit the Western Highlands Province of PNG, centered on the Wahgi valley and the town of Mount Hagen. These are famous Sweet Potato horticulturalists and are warlike even today, much like their neighbors to the west, the Enga and the Huli. Very entrepreneurial, the Melpa have traditionally conducted ritual exchange ceremonies known as moka. By creating indebtedness among allies, big men gained strength and stature in the community. The Melpa and the Chimbu (discussed next) are famous for their highland coffee farming, which is carried out as well by the Angan/Kapau farther to the southeast.

The **Chimbu-Wahgi** people, of Chimbu Province in central PNG, are famous for their pig-killing exchange ceremonies and their populous interior upland valleys where Sweet Potato is the dominant crop. Today, Chimbu communities can be found in all the larger cities of ENG. Tourists to Chimbu often make the backcountry trek to climb ENG's highest summit, Mount Wilhelm.

The **Kainantu-Goroka** people (400,000-plus) inhabit the Eastern Highlands Province of PNG, in two principal towns, Goroka and Kainantu. This territory includes the Asaro valley, famous now for its highlands coffee locally grown by communities there. The rural communities cultivate Sweet Potato and care for pigs.

The **Finisterre-Huon** people inhabit rugged interior upland valleys of the Finisterre and Saruwaged Ranges, north and northwest of Lae, the Morobe Province capital (PNG). The people are gardeners and subsist on a wide variety of plant crops. Today communities manage small shade-grown plantations of coffee and cacao, the products of which are sold to coastal wholesalers. Traditional decoration included donning of red-furred pelts of the Huon Tree Kangaroo.

The **Angan/Kapau** (**Kukukuku**) people of Morobe Province, PNG, live in the mountains between Marawaka, Aseki, Menyamya, and Kaintiba, south of the Markham valley. These diminutive people traditionally were famous for their ferocity as tribal fighters, but today they are known for their industriousness and their ability to carry on a peaceful Western lifestyle of productive work and home life. As with the Mountain Ok, these people are very short of stature.

Opposite: Wig and headdress, Mendi, Southern Highlands Province (ENG), with various natural components. From top to bottom: blackish cassowary feathers, two tones of green parrot feathers, whole bodies of Papuan Lorikeets (green, yellow, red), kingfisher feathers (bright blue), New Guinea Vulturine Parrot feathers (red), orange cuscus-fur band, white bailer shell, green elytra of cetoniine flower chafer beetles, and dark brown wig. Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco

The **Mekeo** people (20,000), Austronesian-speaking agriculturalists, inhabit the southern coastal lowlands of the northern portion of the SE Peninsula, north of Port Moresby (PNG), northwestward to the Lakekamu basin. The Mekeo are most famous for their stunning traditional face painting and feathered headdresses displayed in traditional ceremonies, worn by both men and women. The combination of the brightly painted face and a halo-like array of colored feathers is perhaps the most beautiful traditional costume known on Earth, which is saying a lot, considering the stunning outfits worn by the Huli and Engan wig men.

The **Binandere** people inhabit the lowlands and hills of Oro Province (PNG), from north of the town of Popondetta and the slopes of Mount Lamington to the Morobe Province boundary. Before Western contact, the Binandere were a warlike group that battled neighboring groups and expanded their territorial claims to include the Eia, Mamba, Kumusi, and Gira watersheds. They are related to the **Orokaiva** people, another important lowland group inhabiting Oro Province of southeastern PNG. In traditional celebrations, these groups wear costumes featuring headdresses of colorful lorikeet tail feathers and aprons of geometrically decorated tapa (bark) cloth.

AGRICULTURE

The New Guinean Region is one of the original centers of agriculture and plant domestication. New Guinea's oldest settlement site (Ivane valley; see chapter 13), estimated to be ca. 47,000 years old, exhibits evidence of plant husbandry. The Kuk site in the Wahgi valley of ENG provides evidence of 9,000-year-old Taro fields with constructed drainage ditches. There is evidence that New Guinea was the first region where bananas, Sugarcane, Taro, and the Greater Yam (*Dioscorea alata*) were domesticated.

CULTURAL ARTIFACTS

New Guinea is famous for its diverse cultural life and the remarkable and in many cases bizarrely beautiful artifacts produced by its traditional village societies. Most relate to either ornamentation of items used in daily life, celebration of periodic festivals, or communion with the spirit world. Many items were single-use, to be made and used and then discarded. This aligns to the temporary nature of many or most traditional villages in New Guinea. Because of their regular seasonal or periodic movement, communities did not wish to be weighted down with an abundance of material goods.

Most of the more remarkable artifacts are no longer manufactured for customary use (because of the advent of Christianity or arrival of plastic and metal trade goods) but are reproduced only for sale to tourists. We provide a concise review of the most remarkable of these artifacts and housewares (mainly of precontact provenience) below.

Decorative Stone Implements Stone tools are rarely seen today in rural New Guinean societies (even though tourism brochures continue to mention "Stone Age New Guinea").

These were more common prior to Western contact. Finely crafted decorative stone mortars and pestles are among the most attractive and mysterious of New Guinea's domestic housewares (because of their current rarity). Today, mortars and pestles are typically made of a hardwood and are employed in the making of ceremonial puddings of Taro and coconut. Most stonework is of prehistorical provenience and has been found in villages where Taro was or is the main staple food. The mortars are handsome, and the pestle often features a bird or human form. These artifacts, fashioned from basalt, volcanic tufa, or serpentine, apparently date mainly between 8,000 and 3,000 years ago, and most have been found in

Dani battle scene, Baliem valley, 1961. Photo: Karl G. Heider. © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM2006.17.1.89.2

the highlands of ENG and the Sepik-Ramu area just to the north, implying a cultural connection between the interior uplands and interior lowlands in central-northern ENG.

Prior to the arrival of Western explorers, village New Guineans sought hard yet workable stone to craft stone axes, to be both worn ceremonially and employed for daily use in clearing of forest for gardens. Greenstone was treasured for the more elaborate ceremonial pieces. Many of these were made of serpentinite, quarried from ophiolite zones on the northern scarp of the Western Ranges, the Eastern Ranges, and the SE Peninsula.

In the Angan territory of the northernmost SE Peninsula, doughnut-shaped, incised stone heads were fitted to a stout handle to be used to strike enemies in warfare. The stone heads are often well carved and handsome and have become popular collectibles.

In addition, obsidian was much sought after for the preparation of arrow points and waisted blades. Obsidian does not occur on the mainland of New Guinea and thus has been traded far and wide from three source locations (islets off Manus Island, at Talasea in West New Britain, and from Fergusson Island in the SE Islands).

Pottery The famous and beautifully incised Lapita pottery was produced mainly in the islands of the Bismarck Archipelago north of New Guinea, but a fragment has been found along the north coast (near Aitape) and on the SE Peninsula. This pottery disappeared from use around 2,000 years ago. Other pottery has been manufactured by some New Guinean communities, mainly in the lowlands of the Sepik-Ramu region. Pots with stylized facial designs were traditionally made in the Chambri Lakes in the middle Sepik, and conical sago food bowls with ornate incised patterns were produced in the middle Sepik as well. Overall, pottery making was not commonplace in the New Guinean Region and is rarely practiced now that store-bought aluminum cooking pots are readily available.

Drums Two basic types of carved wooden drums are common in New Guinean cultures. Best known is the *kundu*, a handheld tubular drum with a lizard-skin affixed to the top for striking with the hand. This type of drum remains in widespread use through New Guinea. Another type of drum is the *garamut*, which is a large wooden vessel with a slit

Spirit house in the Sepik River basin (ENG). Photo: Bruce Beehler

opening at the top that is struck rapidly with a stick. The garamut is fashioned by hollowing out a large hardwood log. These often exhibit patterned designs incised on the sides of the drum and ornately carved figures projecting from each end of the drum. The large drums created a percussive signal that would carry a considerable distance.

Masks Wooden, painted woven fiber, and clay masks are well known across New Guinea from a variety of groups, especially in the Sepik, the Asmat, and several other lowland regions. Many were for display—not for wearing—perhaps offering spiritual protection to men's houses or other structures. In the Ramu River area they were suspended from a sacred flute to embody the voice of the spirit that emanated from it. Yam masks of woven basketry were produced in the eastern Sepik (ENG).

Decorative Canoe Prows and Paddles These handsome, decorative carved wooden artifacts are best known from the Sepik and the Asmat. They often display a crocodile motif.

Headdresses Most traditional New Guinean societies even today produce headdresses for ceremonial occasions. There is a wide range of styles, some colorful and elaborate, others quite mundane. The most remarkable are those of the Mekeo, Binandere, Huli, and Melpa, all from ENG. These are best seen at local annual festivals organized by local governments (Mount Hagen Show, Goroka Show, Hiri Moale Festival). Many smaller festi-

A vista of a traditional rural upland hamlet, in the Baliem valley, WNG, surrounded by shade-tree plantings and expanses of Sweet Potato gardens.

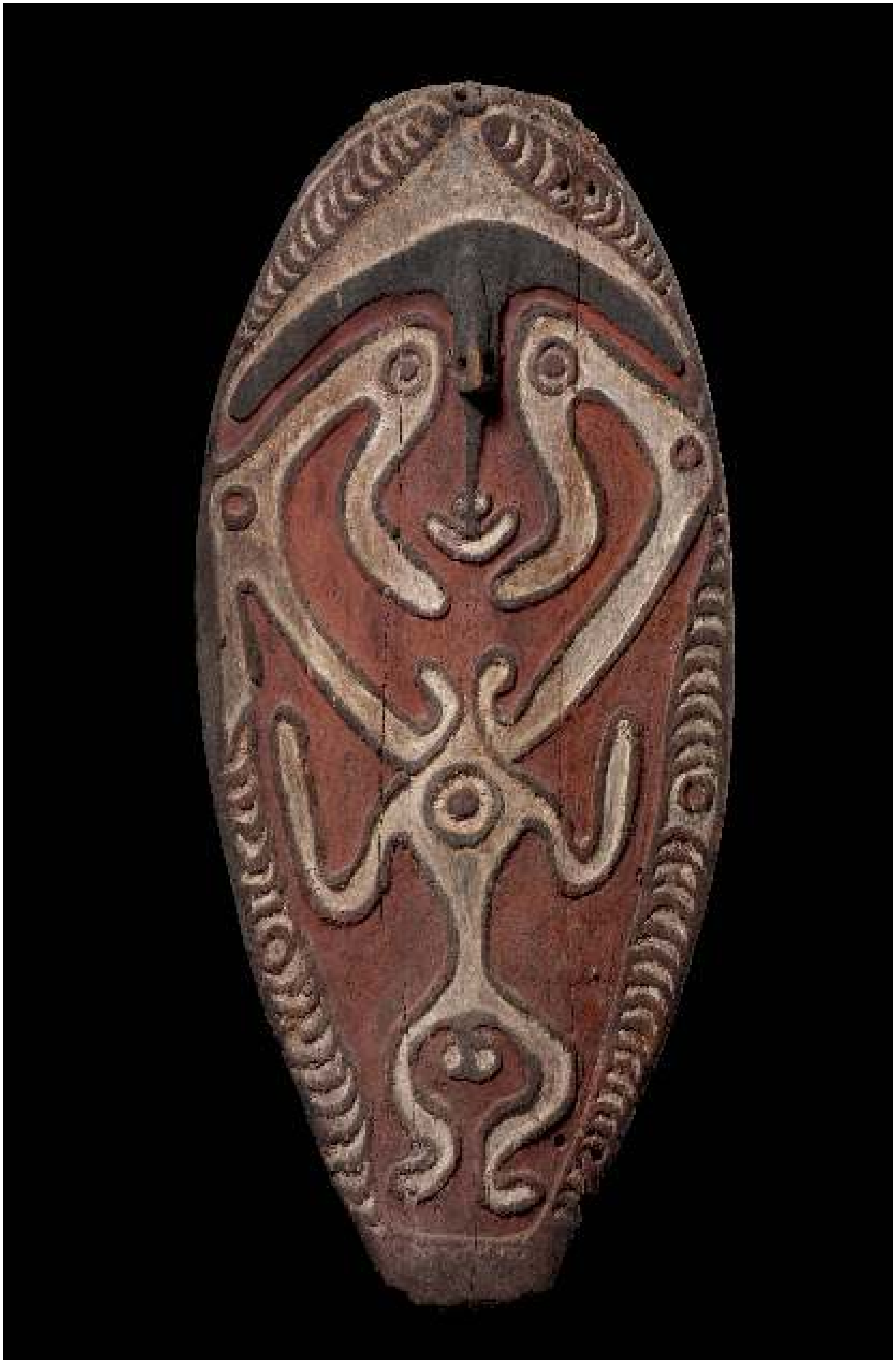
Headdress with plumes and flowers, from Margarima area, South Highlands Province, PNG. Vertical dark-banded feather: Ring-necked Pheasant; tall bushy brown vertical feathers: cassowary; whitish plumes: Lesser Bird of Paradise; patch of red feathers: New Guinea Vulturine Parrot; iridescent blue feathers and velvety black plumes: Superb Bird of Paradise; dried yellow daisies; woven headband. Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco

vals are held each year as well, and, ritual "sing-sings" can take place to celebrate all sorts of festive occasions.

Shields Adorned with various incised and painted designs, shields were commonplace prior to Western contact in many societies, mainly because of the constant state of ritual war between ethnic groups living on adjacent territories. Distinctive wooden shields are known from the Sepik-Ramu, the Eastern Ranges, the SE Peninsula, and from the Trobriand Islands.

Ancestor Figures Typically, these were carved wooden figurines—highly stylized—that were stored in traditional men's houses. Other figures depicted the female form.

Spirit Houses (Haus Tambaran) Tall, decorated structures built by riverine societies in the Sepik-Ramu region, these were places where men gathered to commune with local spirits of ancestors to gain strength and prowess to lead their communities. They were manufactured with timber and palm thatch and decorated and designed. Many had a distinctive high-peaked roof. A few of these structures remain to be seen in some villages along the main stem of the Sepik River, but the widespread adoption of Christianity has led to the abandonment of most customary spiritual practices associated with spirit houses.



Spirit board (*gope*) from the Era River delta, Gulf Province, PNG. Photo courtesy of John and Marcia Friede, the Jolika Collection, de Young Museum, Fine Arts Museums of San Francisco

Yam Storehouses They look a bit like miniature spirit houses, but yam storehouses are found in the Trobriand Islands, off the north coast of the SE Peninsula, where an annual yam festival is held. The storehouse for the year's yam crop also held spiritual significance. Yam exchange and the annual yam festival and its relation to local sexual practices was written about by anthropologist Bronislaw Malinowski.

Carved Ceremonial Daggers Fashioned from the leg bone of a cassowary, daggers were carried by men in many parts of New Guinea. Old daggers were ornately carved with intricate designs and animate patterns.

Spirit Boards Also called *gope*, these decoratively carved and painted boards adorned the entrance and interior of men's houses in the Southern Lowlands of ENG in coastal areas facing the Gulf of Papua, west of Kerema. Typically featuring a stylized geometric design, they resemble a small and handsomely patterned wooden shield, sometimes with a stylized human depiction. They offered spiritual protection and provided a linkage to the spirit world.

Trophy Heads Certain lowland groups prepared, ornamented, and displayed decorated and over-modeled (clay-covered) human skulls, either of enemies killed in battle or of revered ancestors.

CULTURAL PRACTICES

Here we review some of the characteristic cultural practices that are widespread in New Guinea. This is a eclectic list and reflects the bias of the author's personal field experience.

Both *patrilineal and matrilineal* societies are found in New Guinea. These determine the manner in which land and resources are passed down from one generation to the next, as well as the pattern of movement of husbands and wives after marriage (either to the wife's village or to the husband's village). Some New Guinean societies are not unilineal; they have territorial groups made up of kin from both father's and mother's side.

The *wantok system* is a communal sharing of resources among those of a clan, which has arisen to ensure all relatives are properly cared for in a rural society. Here is an example of how it works in the village: If a man goes hunting in the forest and kills a large cassowary, he will carefully plan the sharing of the meat from this trophy among his village relatives, with the expectation that his relatives will share with him in the future when they procure wild game. This ensures the well-being of all relatives in the community.

The *payback system*, a precontact practice that echoes the Old Testament "eye for an eye," holds sway in most New Guinean traditional societies. Any injury or insult is expected to result in a counterpart response by the lineage of the injured. This can lead to a Hatfield-versus-McCoy-type feud between rival clans, which can continue until mediated compensation of the last-injured party is carried out.

A *compensation ceremony* formalizes the transfer of material compensation (pigs, money) to the family of an injured party to ensure there is no further payback violence carried out by the family of the injured party.

Bride-price is traditional in some ENG highland societies. A marriage is formalized with the purchase of the wife by the husband's family. Traditionally, the payment was in the form of live pigs and cassowaries and plumes of birds of paradise. Today the payment is often a combination of cash, pigs, and cassowaries.

Polygamy is commonplace in a number of traditional societies in New Guinea. The most powerful and wealthy men may have a number of wives. This practice is widespread in Enga Province (PNG) today.

A traditional *pig exchange*, or *moka*, was an important social tradition in the highlands of ENG, especially in the Wahgi valley near Mount Hagen. In this ceremony, a powerful community member would publicly and formally distribute pigs to all his closest associates, thereby creating indebtedness and consolidating recognized power (to the giver of pigs) in the community. Periodically, this ceremony was carried out by other big men, thereby showing reciprocity and cementing relationships as well as status within the community.

Complex land tenure systems are the rule rather that the exception in New Guinea. Land and use rights to land remain the greatest source of wealth in rural New Guinean societies, therefore the management of these rights is an important component of village affairs, and disagreement over land and resource rights is a main source of conflict in village societies. Rural land is rarely bought or sold and is not thought of as a commodity. Instead, rights are leased to harvest some resource or to carry out agriculture on the land. Although there are many communal aspects to New Guinean rural societies, land and specific use rights are usually owned by specific clans or individuals, not by the community as a whole.

Ceremonial burial cliff in Kukukuku (Angan) country. Ancestors' bodies arranged in traditional cliff site in the Aseki area of the northwestern sector of the SE Peninsula. Photo: Ulla Lohmann

Burial practices vary widely from culture to culture in New Guinea. The Dani of WNG and the Aseki people of ENG formally place the recently dead out in the elements, where they desiccate and decay over time, after which the bones are retrieved and stored in a special place. Death is one of the most important events in the village and leads to a series of rituals, carried out by the family and the village.

Cannibalism and *headhunting* were indeed a part of the cultural practices of many traditional groups inhabiting New Guinea. Of course, these practices essentially ceased with government pacification practices, which officially forebade tribal war, in the hinterlands in the early to mid-20th century. The Yali, who practiced ritual warfare and cannibalism into the 1960s on the southern slopes of the Western Ranges, wore wrappings of cane as body armor during battle. The Fore people of the Eastern Ranges practiced ritual cannibalism of their most-revered ancestors, and elaborate body preparation of the dead included removal of the brain, which led in the 1970s to the appearance in their community of the neurodegenerative disease, transmitted through infectious proteins (prions), known as Kuru, which afflicted mainly the adult women who were tasked with preparing the dead for ritual consumption. For readers distressed by discussion of these practices, recall that certain Christian churches practice the ritualized and stylized weekly consumption of the body and blood of Jesus Christ as a sign of proven religious devotion.

CULTURAL AND LINGUISTIC EXTINCTION

One inevitable byproduct of economic progress and Westernization of developing nations is the loss of traditional cultures and languages. This is happening in New Guinea today and probably impacts all traditional societies—nor is this a new phenomenon. More powerful and richer societies supplant poorer and weaker societies. The result is loss of languages and traditions.

Here are three commonplace but simplified examples. One: Western traders arrive at a village and begin flooding the community with inexpensive machetes (called "bushknives" in New Guinea) and steel axes. That event spells the end of the tradition of making greenstone axes. After two generations, no one in the community knows how to manufacture such a tool, because the knowledge is strictly orally transmitted and once lost remains lost. Two: a Christian missionary arrives in an isolated village as the first Westerner to be encountered by the uncontacted group. The missionary convinces the group to gather up and destroy all its traditional magical artifacts that relate to the community's traditional belief system. The community converts to Christianity and gives up its traditional beliefs as well as the making of various belief-related artifacts. Within a couple of generations, there is only the haziest knowledge of many of the old beliefs, and the beautiful and unusual artifacts that were associated with the traditional village cosmology are lost forever. Three: a large and aggressive New Guinean society expands its range to take over the underdeveloped land of a small and subordinate society. Through several generations of intermarriage and population swamping, the language of the subordinate group is replaced with that of the more

Lonely hamlet with gardens and planted *Casuarinas* in the mid-montane interior of ENG.

aggressive group, with only a few ancient elders able to speak the language of the lesser group. Soon the lesser language is dead.

The Christian missionary argues that he has "saved" a people and replaced a repugnant and violent belief system with a benign and charitable system. Perhaps, and yet what about all the traditional oral knowledge and origin stories that get lost in the transition? Lose an ancient language, and so much knowledge of the local environment (wildlife, poisons, traditional remedies, access to possibly important bioactive plant-based molecules) is lost with it. With the discarding of every word and name in that lost language, knowledge is lost or only very imperfectly transmitted to the new and dominant language. The overtaking language is associated with an entirely different knowledge system and local religion, not consonant with the dying language and society. Recall, also, that the oral transmission of knowledge is a very imperfect medium, even under the best of circumstances.

Every effort should be made to conserve and write down local languages, local knowledge, local origin stories, and local names and uses for forest products and forest animals and plant species. Each traditional society has an obligation to do this before all is lost. This needs to be done by the local community, with the technical assistance of outside groups specializing in cultural conservation. New Guinea is the front line of cultural loss, and there should be substantial investment in cultural conservation using cutting-edge digital tools. This should be a core activity practiced today in every traditional society in New Guinea, and should be fostered and funded by the appropriate government departments.

15 Coastal Marine

Island and Reef Environments

THE GREAT ISLAND OF New Guinea is distinctive for its high mountains and extensive humid tropical forests, but the New Guinean Region is also remarkable for its fringing islands, reefs, and nearshore tropical marine ecosystems. These occur within the Coral Triangle of the western equatorial Pacific, home to the richest tropical reef ecosystems on Earth.*

Tropical reef systems inhabit shallow and warm, clear-water seas. These waters are notoriously nutrient-poor. Why, then, are reefs so rich in species? It is because corals are animals with their own associated photosynthetic algae—plants that convert the sun's energy to energy-rich organic molecules. Thus the reef's corals feed themselves through the sun's energy without the need to extract this energy from the surrounding seawater.

Tropical coral reefs, like rainforests, are home to rich assemblages of plants and animals, and the reef's species, much more colorful than those of the forest, are readily visible to anyone willing to snorkel or dive below the surface. One of the great pleasures for a naturalist visiting the New Guinean Region is to spend time leisurely exploring a local reef ecosystem. Snorkeling over a reef off Port Moresby or in Milne Bay or in the Raja Ampat Islands is something like flying by hang glider over a rainforest but with much more to see. Glimpsing a cuscus or tree kangaroo in the forest is like finding a needle in a haystack. By contrast, when snorkeling over a reef one sees schools of colorful fish, variously shaped corals, sea stars of varying shapes and colors, and those amazing giant clams. Almost everything is right there to be seen. Only a few creatures are hiding (such as marine worms, lobsters,

Preceding pages: Nearly exposed corals on a reef flat at low tide, Raja Ampat Islands.

Opposite: Two Coral Groupers forage among smaller fishes and a glorious live reef setting in the Raja Ampat Islands.

* This chapter is based on the following references: Wells (2007), Allen (2007), Erdmann (2007), and Allen and Steene (1999).

and moray eels). This is why it is such a wonderful surprise for a rainforest ecologist to put on a swimsuit and mask and take a look at the other richest tropical ecosystem on Earth.

This can be done in an array of places, the best of which are typically located off one of the myriad islands and island groups surrounding New Guinea away from its silty river mouths.

ISLAND GROUPS

New Guinea is home to some of the most complex and beautiful island groups on Earth. In the far west lie the **Raja Ampat Islands** (NW Islands, in our geographic nomenclature), featuring Waigeo, Batanta, Salawati, and Misool Islands (the "Four Kings"), plus Kofiau, Gam, Gag, Wayag, and many other small islands. These islands lie off the western beak of the Bird's Head. The Raja Ampats, justly famous for their diving and snorkeling options, host several beautiful eco-resorts as well as a number of low-cost home-stay lodgings. Here one can snorkel in shallow water with foraging Manta Rays. A project led

Two Giant Manta Rays forage on the sea surface in the shallows of the Raja Ampat Islands. Photo: Mark V. Erdmann

by Conservation International in partnership with the Worldwide Fund for Nature and the Nature Conservancy has created a network of marine protected areas managed by local communities in this island group. This has much reduced the illegal fishing carried out by visiting Bugis fishing boats coming from islands to the west. North and northeast of Waigeo Island lie the low and atoll-like Ayu, Asia, and Mapia Islands. These are among the most isolated islands in the New Guinean Region.

The **Cenderawasih Bay Islands** (Bay Islands) include Yapen, Biak, Supiori, Numfor, and Mios Num Islands, plus islands off the Wandammen Peninsula. This area also has a large marine protected area and several dive resorts. It is famous for its Whale Sharks.

South of the Bird's Neck lie the **Aru Islands**, composed of uplifted limestone—former reefs in the Arafura Sea. This is where Alfred Russel Wallace first observed displaying Greater Birds of Paradise.

Off the northern coast of central ENG lies a scattering of small islands—mainly recent volcanic cones, some still active. These include the **Schouten Isles** to the west and the

Acropora table corals in shallow reef waters of the Raja Ampat Islands.

Preceding pages: Schools of Yellowstripe Snapper and Neon Fusilier over a reef in the Raja Ampat Islands.

Vitiaz Strait Islands to the east. The largest of these are (from large to small): Umboi, Long, Karkar, Manam, Bagabag, and Crown.

Off the tail of the SE Peninsula of ENG are the SE Islands of the Milne Bay region. There lie four major island groups: the **D'Entrecasteaux Archipelago**, the **Trobriand Islands**, the **Woodlark Islands**, and the **Louisiade Archipelago**. These four groups, sometimes known as the Milne Bay Islands, bracket a large expanse of shallow water and reefs that compete with those of the Raja Ampat Islands for best reef-diving on Earth. Each of these four island groups is physiographically and biologically distinct. There are probably more types of reef systems found in this remarkable marine ecosystem than any place on earth.

REEFS

Coral reefs have been present on Earth for more than 400 million years. Selected lineages have successfully weathered the evolutionary challenges posed by several global mass extinctions as well as substantial periodic global changes in climate. Today's tropical coral reefs are currently about 5,000 years old—a period of relative climatological and sea level stability that followed the last ice age, when, at 24,500 years ago, sea levels dropped as much as 130 meters relative to today. At 6,500 years ago the sea level was ca. 3.5 meters higher than today's sea level, inundating some of the Digul lowlands in the south and the Sepik-Ramu lowlands of the north. So even in the recent past, New Guinea's reefs have had to adapt to sea level change.

Whereas Australia's Great Barrier Reef receives an immense amount of international attention and is thought of as the prototype for the world's coral reefs, New Guinea's little-known and infrequently visited tropical reef systems are more diverse, more species-rich, and in most cases in better condition that those of Australia. All the high species counts for reef fishes, mollusks, and corals come from New Guinea's eastern or western ends. The reason for this globally extreme richness can be attributed to two factors: equatorial position and ongoing interaction between tectonic plates.

The most important reefs in the New Guinean Region lie in the Raja Ampat Islands, the Milne Bay Islands, and in Cenderawasih Bay. Smaller but important reefs also can be found around the Onin Peninsula and near Kaimana and Etna Bay of the southern Bird's Neck, along the coast east of Port Moresby, and in the Astrolabe Bay area near Madang, ENG. Anyone visiting New Guinea should try to do some snorkeling or diving in one or more of these hot spots.

REEF LIFE

The coral reef ecosystem is so much more than the coral. There are scores of kinds of plants and animals that inhabit or visit the coral reef. Below, the most prominent groups are reviewed.

Above: A species of giant clam showing its colorful mantle on a reef flat in the NW Islands. Photo: Igor Tichonow/Creative Market

Left: A cryptic *Hemiscyllium* walking shark rests on a shallow-water reef in the NW Islands.

Sponges These are among the oldest and simplest animals inhabiting the reefs. Sponges have remained essentially the same for 450 million years. They are nature's vacuum cleaners, filtering microscopic particles from the water column. Using thousands of threadlike cilia, sponges pump large amounts of water through their bodies and harvest a wide range of microscopic organisms. Nearly all of the 10,000 species of sponges are marine dwelling. Some sponges form symbioses with blue-green algae and serve as hosts for various marine invertebrates such as crabs and shrimps. Sponges tend to be difficult to identify because of the variability of the species.

Jellyfish Jellyfish come in various shapes, colors, and sizes, some with meter-long tentacles and some with the main disk 40 centimeters in diameter. Many species of jellyfish possess nematocysts, stinging cells that can prick the skin upon contact. Some produce painful wounds. Therefore, all jellyfish encountered in New Guinean waters should be treated with caution.

Hydroids Jellyfish relatives that are common in reef ecosystems, hydroids are colonial creatures with feeding parts and reproductive parts. Many are feathery plantlike animals that literally cover the reef. Other hydroids look like underwater ferns. Fire coral

Giant Trevally (foreground) and a Napoleon Wrasse (top center) eye a hunting Whitetip Reef Shark on a reef in the Raja Ampat Islands, Indonesia. Fusiliers school in the background. This is an example of a very healthy reef supporting a high biomass of fish.

is a hydroid that looks like a branching hard coral. The Portuguese Man-of-War, another hydroid, produces a painful sting, as does the fire coral.

Sea anemones These are relatives of hydroids and jellyfishes. Classic anemones look a bit like flowering plants that have a stumpy stalk. The symbioses between species of clownfish and anemones are among the more colorful and interesting interspecies interactions found on the reef—well known, of course, because of Disney's Nemo films. The larger clownfish anemones can live for more than a century.

Corals Scleractinian (or hard) corals are the key building block of reef ecosystems. They are not as species-rich as mollusks or crustaceans, but what they lack in species richness they make up for in mass. The calcified exoskeleton of the coral is the three-dimensional matrix upon and in which so much reef life builds and lives. J. E. N. Veron reported that there are ca. 800 hard coral species worldwide. Conservation International's Rapid Assessment Program, conducting marine surveys, recorded 465 hard coral species in the NW Islands and 362 species in the SE Islands. C. C. Wallace's study of the *Acropora* staghorn corals showed that Indonesia and PNG host more species than any other countries.

The calcium-carbonate skeletons secreted by the coral polyps form the limestone platform upon which the reef is elaborated. Cores drilled into living reefs in the tropical Pacific have shown that some platforms are more than 100 meters thick, indicating a gradually sinking reef. An individual coral polyp is a fleshy sac surmounted by a ring of tentacles that surrounds a central operculum or mouth. This sits within a limestone casing, which is secreted by the polyp itself. Some hard corals have unicellular algae (zooxanthellae) living within each polyp. The algae trap sunlight and combine that energy with carbon dioxide to produce enriched organic compounds, which provide much of the polyp's nutritional needs. Other corals, those lacking the symbiotic algal zooxanthellae, subsist on microscopic or macroscopic reef organisms, captured using their stinging cells.

The soft corals and sea fans are also a prominent part of the visible reef environment. In some places they have the look of fields of undersea flowering plants. They are most abundant 10–30 meters below the water surface. These soft corals are among the most beautiful life forms on the reef, with blazing colors and a myriad of forms. These differ from the hard corals in lacking the limestone skeleton. The differing colors of the soft corals are produced by symbiotic algae, which operate in much the same manner as they do in hard corals. The soft corals include the gorgonian fans, whip corals, black corals, and spiral corals, as well as the beautiful and filamentous sea pens.

Marine worms Flatworms, polychaete worms, ribbon worms, and acorn worms inhabit the reef ecosystem in astounding abundance, living in the nooks and crevices of the reef structure or burrowing in the sand at the base of the reef. Some look more like soft corals or sea pens or nudibranchs than worms. Many are colorful and handsomely patterned.

Crustaceans The crustaceans are among the dominant predatory life forms on the reef, though many of these arthropod species are tiny in size and cryptic in behavior. The common groups include the shrimps, lobsters, and crabs, which all have ten legs. Brightly colored cleaner shrimp occupy permanent stations that are visited by a variety of fishes, which hover patiently while they are carefully groomed by the shrimp, which remove parasites from the fish's mouth, gills, body, and fins. Shrimps and crabs form a wide array of symbioses with both plants and animals of the reef ecosystem. Believe it or not, barnacles are crustaceans even though the more common forms resemble mollusks.

The mantis shrimps are large and colorful reef predators, some growing to 30 centimeters in length. Mark Erdmann reported that more than 450 species of mantis shrimps inhabit tropical shallow-water reef and sea-grass habitats. Surveying a single lineage of mantis shrimps in the Raja Ampat Islands, Erdmann recorded 37 species. This is the highest species count for any location on Earth. By comparison, Queensland's Great Barrier Reef supports 26 species.

Mollusks Represented by more than 100,000 species worldwide, mollusks are exceedingly species-rich in the shallow seas of the tropics. They are also morphologically diverse, ranging from a microscopic snail to the 12-meter-long Giant Squid. Marine rapid assessments cataloged 643 species of mollusks (of individuals >1 centimeter) from Milne Bay and 699 species from the Raja Ampat Islands. In a long-term study based at the Christensen Research Institute in Madang, northern ENG, 536 species of mollusks were recorded. A. J. Kohn recorded 62 species of true cone shells from a single reef platform fringing Laing Island, north of Madang. F. E. Wells collected 44 species of cowries in the NW Islands.

The shells of the gastropods (snails and relatives) are the most common on the reef. They are diverse and beautiful—wonderful natural artifacts—and collectors love them. Each time these souvenirs are looked at, they remind the owner of a visit to a special part of the world. The most prominent gastropods are the cowries, cones, murexes, mitres, olives, strombs, helmets, and trumpets. The larger and more beautiful shells of the gastropods of the Coral Triangle are among the most desirable collectibles for shell fanciers around the world.

The bivalves (clams and relatives) include the famous giant clams, the biggest shells on Earth; the largest, with an age in excess of 100 years, reach a breadth of 120 centimeters and weigh more than 180 kilograms. The best-known bivalves include scallops, cockles, clams, oysters, and mussels. Many of these make excellent eating.

Nudibranchs Members of the Mollusca, nudibranchs are treated separately here because they are so distinctive and beautiful and so easily observed on the reef. Most nudibranchs have no shell and move about on the reef foraging in full daylight. They feed on a variety of reef life both plant and animal. Many nudibranchs are chemically defended, hence their bright colors and striking patterns—which are signals, known as aposematic warnings, to potential predators.

Cephalopods The octopuses, cuttlefishes, squids, and nautiluses are cephalopods, which include some of the most advanced invertebrates known. All are marine predators, and some grow to considerable size. These creatures are famous for squirting a black ink to avoid predators and also for the ability to change coloration and skin pattern to avoid being seen.

Sea Stars and Relatives The so-called starfishes are beloved by all who enjoy the sea and its abundance of wildlife. The reef is home to a gorgeous collection of colorful and diversely shaped starfish, most showing a radial pattern of five arms. The brittle stars, basket stars, and feather stars are more bizarre relatives that can resemble underwater filmy ferns and anemones, but they are more mobile. They are all predators of planktonic reef life. The Crown-of-thorns Starfish is huge, sports venomous spines, and consumes coral polyps. This species exhibits periodic population explosions that lead to the destruction of patches of coral.

Sea Urchins and Sand Dollars These sea star relatives are mainly nocturnal foragers on the reef. The spiny species must be avoided, as punctures from these can be very painful (some are venomous). Dozens of species inhabit the Coral Triangle.

A newly described species of flasher wrasse (*Parachilinus nursalim*), discovered in Triton Bay, WNG. The male is "flashing" (fins extended, colors on) to the orange female in front.

Sea Cucumbers Dowdy and slow-moving, sea cucumbers look like a version of the sea slugs (a type of nudibranch), but they are actually a relative of the sea stars. This group yields the bêche-de-mer (or trepang), a seafood speciality popular in China that has been harvested from the coastal waters of the Coral Triangle since the 1500s.

Sea Squirts Common filter feeders, sea squirts are primitive chordates that look more like sponges. They are colorful and diverse and difficult to characterize.

Reef Fishes No fewer than 2,150 species of coral reef fishes are known from the coastal seas around New Guinea. The NW (Raja Ampat) Islands support the world's richest assemblage of coral reef fishes. Gerald Allen and Mark Erdmann have studied the area since 1996, and their current fish species count for the area is 1,575 species. Species rich-

Whale Shark surrounded by a school of small fish. This giant but gentle shark species is widely distributed through the tropical Pacific and is regularly observed at foraging sites in the Bay Islands of WNG. Photo: Mark V. Erdmann

ness tends to center on the heart of the Coral Triangle, which aligns with the NW Islands. There are 138 species of damselfishes known from Indonesia, 109 from ENG, and 95 from northern Australia, while just 34 species are known from the Red Sea, and only 15 from the Hawaiian Islands. The 114 species of damselfishes known from the NW Islands support the notion that this island group lies at the very heart of the Coral Triangle. No other reef system on Earth supports more damselfishes, and the same is true for many other fish families.

Focusing on the NW Islands, 60 percent of its fishes are widespread forms, and only 20 percent are of restricted geographic distribution. This is because most species have a wide-ranging pelagic larval stage. Allen has reported that during a typical survey dive of 90 minutes, from 100 to 374 fish species can be recorded from the waters of the NW Islands. The total of 374 species still remains as the absolute highest count from hundreds of survey sites throughout the Indo-Pacific region. There is no place on Earth where these numbers can be exceeded; the nearest rivals are the Togian and Banggai Islands of Sulawesi. Several species with very small ranges are known from the NW Islands and from the SE Islands. These are species with brief larval stages, and most exhibit parental care.

Rays and Sharks These related fishes are common in New Guinea's coastal waters. Sharks are seen more frequently and can be found in shallow water by the beach or cruising deep blue-water channels that cut through reefs. The rather small Blacktip Sharks and Whitetip Reef Sharks are probably the most common sharks of New Guinea's waters. Whale Sharks are known to visit certain areas in Cenderawasih Bay, and Giant Manta Rays are fairly common throughout.

Sea Snakes and Sea Kraits These handsome and graceful swimming snakes are generally docile and unaggressive. They do possess venomous fangs but rarely strike. It is common to see groups of these snakes roosting under beach litter and riprap onshore, so care must be taken even when not in the water. In spite of their docile nature, it is best to avoid these creatures unless you are a professional herpetologist.

Sea Turtles Six species of sea turtles visit New Guinea's waters, and four species breed on its beaches. The region sees Green, Loggerhead, Leatherback, Olive Ridley, Hawksbill, and Flatback sea turtles. Hawksbills and Olive Ridleys nest on the north coast of ENG; Leatherbacks nest on the north shore of the Bird's Head and north coast of the SE Peninsula; Green Turtles nest extensively through the region.

Marine Mammals The species that visit or reside in the reef-strewn waters of the region include the Dugong, Bottlenose and Spinner Dolphins, Humpback Whale, Dwarf Fin Whale, Bryde's Whale, Blue Whale, Fin Whale, Sei Whale, Killer Whale, False Killer Whale, Sperm Whale, Pygmy Sperm Whale, pilot whales, and various other smaller whales and porpoises. Fifteen species of cetaceans (whales and dolphins) were identified between the years 2011 and 2015 by Apex Environmental, working in collaboration with the various conservation organizations establishing marine protected areas in the NW Islands.

Dangerous Reef Animals Aside from the sharks, stingrays, sea snakes, and sea kraits mentioned, there are a few additional dangerous animals inhabiting coral reef ecosystems that the snorkeler and diver need to take note of. Gerald Allen divides these into the biters and the stingers. The biters include barracudas, razorfishes, pufferfishes, and triggerfishes. Any large fish with obvious teeth should be treated with respect. Various octopus species possess horny teeth that can inflict painful bites. And, of course, a bite from the infamous, highly venomous Blue-ringed Octopus, though small and unprepossessing, can prove fatal. Crustaceans with large pincers should be avoided or else handled with great care. The Coconut Crab, common along the coast and on islands, can sever a finger.

The stingers come in various forms and include almost any kind of creature with spines. Fish that have rigid fin spines can inflict nasty puncture wounds. Some fish possess venom-producing spines. These include stingrays, catfishes, scorpionfishes, and rabbitfishes. The Stonefish, which is a species of scorpionfish, is deadly poisonous. Box Jellyfish, Portuguese Man-of-War, fire corals and other hydroids, and sea anemones can sting and are potentially dangerous.

A villager fishing from a dugout canoe by a village in the Raja Ampat Islands. Fish form an important source of protein in coastal-dwelling communities in the New Guinean Region.

Most mollusk shells can be safely picked up, but certain species of cone shells wield a harpoon-like apparatus that can inject a sting that is potentially fatal. Sea urchins and Crown-of-thorns Starfish have venomous spines and should be avoided. An encounter with a bristle worm can cause a severe dermatitis that may last a week.

Having read the preceding several paragraphs, many readers may lose all interest in snorkeling in New Guinea's coral reefs. Nonsense. Just be smart, know what you are seeing, and take care not to handle creatures you do not know. Also, it is worthwhile to wear diving gloves while snorkeling and diving.

THREATS TO REEFS

New Guinea's coral reefs face various threats today. We discuss them below.

Pollution Dumping of solid and liquid waste in areas close to reefs has been a problem near most urban areas. Plastic bottles and bags especially end up in reef habitats. Isolated island beaches throughout the New Guinean Region are littered with global marine trash that can originate thousands of kilometers away. This ruins the wilderness nature of these wonderful places and needs to be addressed at the global level. Bans on plastic bags and plastic bottles should be enforced worldwide. Diving on fringing reefs in the Sagewin Strait off south Batanta Island in the Raja Ampat Islands was ruined for the author by the abundant trash dumped by the Indonesian state-run (PELNI) ferry that passes through the strait. Indonesia discards billions of plastice bags each year.

Dynamite Fishing This practice involves setting off explosive charges in the waters over reefs to stun or kill reef fish, which are then collected as they float to the surface. This is illegal in Indonesia and Papua New Guinea and presumably is not as widespread as it was in the late 20th century, when recovered World War II munitions were sometimes used.

Shark Finning The demand for dried shark fin remains high in Hong Kong, China, Malaysia, Canada, Singapore, Peru, and Russia. Shark-fin soup is considered a delicacy and is even served in Chinese restaurants in the United States. Indonesia is a major exporter of shark fin. The shark population of the NW Islands was decimated by years of shark finning—removing the fins of living sharks—by Bugis fishermen and others. Those targeting sharks in island settings set large baited hooks on stout line and anchor the lines on shore. The lines are checked daily. The sharks usually are found dead on the line because of drowning. Fortunately, in 2013, a total ban on the harvest of sharks and rays was put in place for the Raja Ampats, and as a result, populations of these fascinating creatures have bounced back, a boon to dive tourism in the area.

Coral Bleaching Hot seawater causes coral polyps to expel their symbiotic zooxanthellae, causing the coral to turn white. If hot water bathes the reef for long periods, these corals die. Coral bleaching has increased in intensity over the last decade as tropical Pacific waters have heated up. Bleaching has been much the worst in Australia's Great Barrier Reef. The SE Islands have seen moderate bleaching, and the NW Islands the lowest level of bleaching. This variation is presumably a product of several factors—water temperature, access to cold-water upwelling, biotic diversity of the reef systems, levels of the sun's radiation, and pollution impacts.

Sea Level Change Over the medium term, the rising sea level will drown coral reefs. As sea levels rise, reefs will be forced to raise themselves to keep at the proper mean depth for greatest coral health. Whether the corals can respond quickly enough to the current sea level rise is not known. ■

16 In the Field

The Foja Mountains

HAVE YOU EVER WONDERED where the most faraway place is? If you live on the East Coast of the United States, it may be the Foja Mountains of western New Guinea. The summit of this isolated north coastal range lies about 209 kilometers due west of the provincial capital of Jayapura, which lies on the north coast of Indonesian New Guinea, just west of the border with Papua New Guinea. The Foja Mountains trend nearly east-west, from about 130 kilometers west of Jayapura westward to the gorge of the mighty Mamberamo River. The range rises out of the lowlands to a high point of 2,200 meters elevation. The entire mountain range is quite circumscribed—only about 110 kilometers long and some 32 kilometers across. The auto road nearest to the base of the range is probably more than 60 kilometers distant—up on the north coast. The nearest habitation is the forest hamlet of Kwerba, near where the base of the range meets the Mamberamo River. Kwerba has a small mission-built grass airstrip that is immediately adjacent to the small settlement of about 150 people.*

In 2005, the Foja Mountains remained the biologically least-known mountain range on the island of New Guinea and hence a priority for biological field survey. This was the reason a team of biologists was eager to visit this very faraway destination. For such a team, the journey from the headquarters of Conservation International in Washington, DC, to the Foja Mountains required a number of flights and several stages. The journey makes clear just how isolated this mountain range is. Here is the route that I took in 2005: flights from Washington, DC, to Chicago, Illinois; Chicago to Tokyo, Japan; Tokyo to Jakarta, Indonesia; a pause of a week in Jakarta to secure necessary research permits; then eastward from

Preceding pages: A helicopter view of a mountaintop bog that served as an access point for researchers surveying the Foja Mountains. The field camp was situated in the forest interior to the upper right of the clearing.

Opposite: Herpetologist Paul Oliver searches for frogs near a field camp in the uplands of the Foja Mountains, situated in the NW Lowlands (WNG).

* Sources for this chapter include Beehler (2006, 2007c, 2008, 2010).

A small single-engine bush plane prepares for landing at the grassy Kwerba village airstrip. Kwerba served as a base camp for scientific teams seeking to gain access to the interior of the Foja Mountains.

Jakarta on an overnight series of three flights to Makassar, Sulawesi; then Biak Island; and finally Jayapura, Papua Province, WNG. Another several days were required in Jayapura to obtain the required provincial research permits. Finally, a charter flight in a single-engine bush plane took us from Jayapura west, about an hour, to the small landing ground at Kwerba. This is where the lowland alluvial forest meets the foothills of the southwestern corner of the mountain range. To get into the highest sector of the mountains we either had to cut a trail up from Kwerba or get a chartered helicopter to drop us and our cargo onto a dry lake bed at 1,650 meters above sea level—after eight flights over two weeks. Only then could we begin our survey of the biodiversity of the mountain range's upland forests. Not only was the journey long, it was also uncertain. In Jakarta and in Jayapura, there had been no advance guarantee that we foreigners would be able to obtain our proper paperwork. We had to sweat it out.

That very uncertain journey back in 2005 was worth the effort and led to two follow-up expeditions. Our field trips in 2005, 2007, and 2008 to this very isolated mountain range in WNG were a revelation—no villages, no litter, no logged-over or gardened areas, no roads, no walking tracks, no hunting, not even any sounds of civilization except for the occasional Indonesian passenger jet flying high overhead. Instead, we encountered novel species of birds, mammals, plants, frogs, and butterflies. This chapter paints a picture of what it is like for a modern-day natural history expedition to explore a wild corner of Earth that happens to be in the NW Lowlands of WNG.

Finding the Foja Mountains to be a place rich with undescribed species emphasized how little we know of some corners of Planet Earth. Experiencing the Foja mountain range firsthand helped us to better understand the links between plate tectonics, mountain building, and the evolution of new species. And, ironically, visiting the Fojas provided us with a stark lesson in the relentless process of extinction that even stalks game species hiding in the great rainforests of New Guinea.

Isolated from other mountain ranges by the vast Mamberamo basin and rising out of the surrounding lowlands to 2,200 meters elevation, the Foja Mountains represented one of the last unsurveyed major mountain range on the island of New Guinea, itself a piece of real estate that had produced quite a few "last unknowns" over the preceding two centuries. By the late 1970s, New Guinea was, in fact, pretty well studied biologically, but there were corners that were still unvisited, and the Foja range was at the top of this short list.

The Fojas were special because of three scientific mysteries: a bowerbird, a bird of paradise, and a tree kangaroo. The two bird mysteries take us back to the Victorian era, the time of aristocratic cabinet naturalists, who relied on adventurous souls to brave the jungles to collect new plants and animals to be described and named back in the comfort of patrician estates in western Europe. In Victorian times, the naming of plants and animals (especially butterflies, beetles, birds, and orchids) was a competitive and popular "sport" among the aristocratic elite of Europe. The cabinet naturalist who nabbed the first specimen of a particular species could publish a paper describing the new species, giving it a name and immortalizing himself at the same time.

Let me explain how the system worked. The cabinet naturalist (typically a rich amateur or museum scientist) would receive a wooden crate from the Far East, let's say. Cracking open the box, the naturalist, at his self-styled museum (or "cabinet of curiosities"), would find the crate filled with dried and stuffed mummy-like prepared skins of birds, each with a collector's label attached to the crossed legs. The naturalist would shuffle through these, looking for something that might be novel—a bird that had never been described by Western scientists—not featured in any article or book. Finding a series of specimens of an apparently new species, the naturalist would happily set about writing a paper describing this novelty, perhaps naming it after some member of the royal family, seeking to curry favor with that august and all-powerful group. Thus did the ornithologist A. B. Meyer in 1894 name a gorgeous black-and-white bird of paradise from New Guinea *Parotia carolae* in the *Bulletin of the British Ornithologists' Clu*b. Thereby, Meyer immortalized Queen Carola of Saxony and at the same time associated his own name forever with that wonderful ground-displaying bird of paradise. Because a scientific name is associated with the namer in the technical literature, even today Carola's Parotia is known scientifically as "*Parotia carolae* Meyer." This is how the science of taxonomy works. The creature gets a permanent name, and the namer gets the credit for the naming. Each species scientifically described has one accepted species name that becomes that species' permanent epithet.

Thus, in 1895, Lord Walter Rothschild, on his great familial estate in Tring, west of London, opened a crate from the Dutch trader C. W. R. van Renesse van Duivenbode that contained, among other things, three specimens of a strikingly beautiful and novel gardener bowerbird of the genus *Amblyornis*. It was similar to the other known species of the genus, but, most remarkably, the male sported a gorgeous golden mane that stretched from the base of its beak to the middle of its back—a long silky erectile crest that makes this male one of the most beautiful of the bowerbirds.

Rothschild wrote up the description of the new species for publication in his own scientific journal, *Novitates Zoologicae* (he had his own museum, his own scientific journal, and his own staff ornithologist, Ernst Hartert, to help with the work). Rothschild named the bird *Amblyornis flavifrons* (meaning "dull bird with a yellow front"). For the bird's range, Rothschild noted "Dutch New Guinea." Herein lay the mystery: the specimens had apparently been collected by indigenous hunters from an unknown location. Given the size and inaccessibility and undeveloped nature of WNG at the time, it was not a simple thing to locate, after the fact, the precise home of this lovely bowerbird.

Likewise, in 1897, the German ornithologist Otto Kleinschmidt described a new "six-wired" bird of paradise, *Parotia berlepschi*, from trade skins in the private museum of Hans von Berlepsch, almost certainly from the trader Duivenbode. This was a velvety-black bird with (in lieu of a crest) six erectile head wires, or threadlike plumes, each with a little spatulate tip. It also had an iridescent throat patch of metallic feathers, and striking white erectile flank plumes. As with the bowerbird, this bird apparently originated from some unknown location in WNG.

At least a dozen expeditions were mounted to New Guinea in the subsequent 60 years in search of the homeland of Rothschild's bowerbird and Kleinschmidt's bird of paradise. These expeditions, led by the likes of Anton August Bruijn, Ernst Mayr, E. Thomas Gilliard, Sten Bergman, and S. Dillon Ripley, all failed to find the home of these two lost avian treasures. They scoured the poorly surveyed Weyland, Wandammen, Tamrau, and Cyclops Mountains, but to no avail. Dillon Ripley had attempted to penetrate the Foja Mountains (then known as the Gauttier Mountains) from the north coast in 1960, but was unable to get into the range's uplands. It turns out he was on the right track.

Following in Gilliard's footsteps, UCLA professor Jared Diamond had been surveying the isolated mountain ranges of New Guinea since 1964, when he and fellow ornithologist John Terborgh had made a preliminary survey to the Eastern Ranges of ENG. After heavily working ENG in the 1960s and early 1970s, Diamond began to focus on the less well-studied WNG—then called Irian Jaya. On one expedition, in 1979, he was able to drop by helicopter onto a gravel river bar at the base of the Foja Mountains. He struggled into the uplands and there glimpsed the lost bowerbird, which built its maypole bowers on forested ridge crests. Diamond returned in 1981, this time getting to 2,000 meters, and he observed a number of

novel bird populations. He published a seminal paper in 1985 that described his discoveries, and Diamond's evocative description of the pristine environmental conditions he found in the Fojas set many tropical biologists alight with interest. Here was a place that begged for follow-up surveys. Who knew what other undescribed plants and animals lurked in corners of this ever-so-isolated mountain range?

A helicopter drops off a field team in the clearing of the Bog Camp in the heart of the Foja Mountains. Researchers Kris Helgen, Henk van Mastrigt, Chris Milensky, and other team members hastily unload the chopper. This site in the interior Foja Mountains is accessible only by helicopter.

Moreover, when Diamond was struggling through the vast interior forests of the Foja Mountains, he glimpsed a reddish-pelaged tree kangaroo. What species was it? No red-colored tree kangaroo had been recorded from WNG as of 1981, nor had any member of this lineage been described from the north coastal ranges of New Guinea, east or west. It was not until 1993 that Tim Flannery discovered and described the Golden-mantled Tree Kangaroo from a tiny remnant population in the eastern Torricelli Mountains of ENG, far to the east of the Foja Mountains. Might Diamond have observed this newly described creature—thought to be the rarest and most beautiful of the tree kangaroos?

I first seriously discussed exploring the Foja Mountains with colleagues when serving as a summer fellow at the Smithsonian Institution in 1977, in the research laboratory of ornithologist and Smithsonian secretary (CEO) S. Dillon Ripley, who had, himself, attempted unsuccessfully to get into the Foja range in 1960, ascending about 97 kilometers up the Tor

River from the north coast. Ripley and I both wanted to get to the summit of the Fojas, and we knew nothing of Diamond's developing plans. In 1982, at a press conference at the National Geographic Society in Washington, DC, Diamond announced the results of his two Foja field trips and his rediscovery of the bowerbird. Diamond stunned us with his announcement and beat us to the punch, but this news only whetted our appetite to get there ourselves.

In 1987, I got a first glimpse of these fabled mountains in a Cessna overflight of the range. On that crystal-clear morning I looked down on a huge expanse of undeveloped montane forest, broken only by the occasional landslide. No villages, no logging tracks, no visible means of ready access. The mountainous interior of the Fojas looked a bit like the Great Smokies—verdant forested mountains and rocky stream gorges, but the relief was considerable, and the closest access points were on the far side of a trailless jumble of steep forested ridges interdigitated by rainforest torrents in deep gorges. As our plane approached the high western summit, I glimpsed a tiny dry lake bed at about 1,650 meters elevation—a perfect place to land a chopper in the mountainous interior.

A lot happened between 1987 and 2005. Ripley and I spent more than a decade working to obtain permission from the Indonesian government to conduct this expedition. Ironically, permission from the Indonesian government did not arrive until after I had moved from the Smithsonian to the Wildlife Conservation Society, to take a job that focused only on Papua New Guinea. Opportunity lost ...

I moved in 1994 to Conservation International (CI), where I was able once again to take up the campaign to explore the Fojas, this time through a Rapid Assessment Program (RAP) expedition sponsored by CI. A CI team once again overflew the Fojas, and we restarted discussions with the Indonesian government regarding permission to go there. No luck. I then departed Conservation International for a position at the US Department of State. Returning to CI in 2000, I once again restarted the discussions about a field trip to the Fojas. In early 2005, I took yet another bushplane overflight of the Fojas and saw the original dry lake bed on the ridgetop. Then, out of the blue, in the early autumn of 2005, a clearance letter arrived from the Indonesian Institute of Science (LIPI).

At this point we learned that the LIPI letter was just the start of a massive paper chase. We needed national-level clearances from immigration, forestry, interior, and the police, and then three additional provincial clearances. Most problematic was that these permits would not be obtainable until the entire international field survey team had arrived in country.

In mid-November, the overseas team of four arrived in Jakarta: Steve Richards (herpetologist), Kristofer Helgen (mammalogist), Wayne Takeuchi (botanist), and myself (ornithologist). A fifth expat fieldworker, Brother Henk van Mastrigt (entomologist), awaited us in Jayapura, where he resided. In addition, we had a counterpart team of six Indonesian scientists who would meet us in Jayapura, once we had completed our clearances. These included the scientists Dr. Yohanes Mogea, Dr. Yance de Fretes, Edy Sambas, and Burhan Tjaturadi, as well as several graduate students from the two universities in Papua. Also, we

The Pinocchio Frog, discovered in 2008 in the uplands of the Foja Mountains. This new species, *Litoria pinocchio*, is known only from the collection site. Its drooping nose stands erect and elongates when the frog is singing.

had a strong field support team led by a British naturalist, Nev Kemp, and the Indonesian field officers who managed CI's Mamberamo basin conservation program.

With the politically adept guidance of our CI office staff in Jakarta, and a lot of advance legwork, the international team collected its Jakarta permits in four working days and moved on to Jayapura—the provincial capital of Papua Province (the new official name for WNG). An additional two working days in Jayapura produced the local permits. We had threaded the bureaucratic needle!

Our local team had already arranged the transport of the field supplies into our lowland forest base camp at Kwerba. On November 15, the scientific team shuttled in to this jungle staging site. Kwerba airstrip lay fifty-five minutes due west of Jayapura. We flew out of Sentani airstrip, which had been constructed in World War II by the US Navy's Seabees (construction battalions), under the leadership of General Douglas MacArthur, who based himself on a hilltop overlooking Sentani airstrip in 1944. The RAP survey team and remaining cargo were ferried in on four Cessna charters, piloted by a group that services the needs of far-flung Christian missionaries scattered in the backcountry of WNG.

The sound of our arriving plane drew the entire village out to the airstrip to greet us and help us with our loads of baggage. Kwerba is situated near the eastern bank of the Mamberamo, where the Foja foothills descend to the river. Kwerba, thus, was the logical gateway into our mountain promised land. The village is typical of modern lowland jungle villages around New Guinea—small (about 150 people), surrounded by forest, and a product of the magnetic attraction of the airstrip and the organizing power of evangelical Christian missionaries. In other words, Kwerba was like so many of New Guinea's isolated villages with airstrips—modern Western constructs. Throughout this great island, such villages serve the

Preceding pages: Untouched forest in the high interior of the Foja Mountains. Notice the mossy coating to every tree trunk as well as the small tree ferns. This is true "moss forest."

convenience of governments and churches by organizing forest peoples into accessible and manageable units. Before the advent of airstrips, many indigenous groups lived scattered about through the forest, in dispersed family compounds.

That said, the presence of Kwerba was of use to us as well. We needed informants, naturalists, and guides for our work, and here they were, brought together conveniently right next to the grassy airstrip, which individuals trimmed by hand using a long, curved metal grass knife every few weeks. Our Conservation International field team had been working out of Kwerba for more than a year, so CI was familiar to the people, and we also had established ourselves by constructing a spacious conservation field center right in the village proper. The people of Kwerba shared claim of the Foja uplands with a neighboring group from Papasena, about 20 kilometers east. Members of Papasena's leadership joined those from Kwerba in hosting our visits to the Fojas. The field center's big thatched hut made of local materials would be our operational base for the expedition, where CI field staff would be able to organize, plan, and dine. Given that the CI support staff had to provision 24 fieldworkers and assistants in two separate camps over three weeks, this was a daunting support mission that required considerable planning and logistics.

The RAP team's objective was to survey birds, mammals, butterflies, plants, frogs, lizards, and snakes at three elevational zones: lowland forest (around Kwerba itself); the hill forests northeast of Kwerba, to be reached on foot; and the interior montane forest, to be accessed by foot or by helicopter drop-off onto the dry lake bed at 1,650 meters above sea level.

The Kwerba environs are a biologist's paradise—the confluence of New Guinea's richest terrestrial environments—verdant forested foothills descending to a great river system and vast expanses of alluvial and swamp forest. The physiographic diversity creates abundant habitats for the flora and fauna. On our first morning there we were greeted by a rich dawn chorus of rainforest birds. This chorus actually begins in full darkness and swells in volume as first light grades into dawn. The pioneers in this remarkable phenomenon are the night callers—the little boobook owls and the Marbled Frogmouth give their last croaks of the evening, mixing with the crepuscular whistles of the Hook-billed Kingfisher and the Shovel-billed Kookaburra, which mingle with the low hooting of the Greater Black Coucal and bubbling jumble of the Northern Variable Pitohui. Following that overture, dozens of species then chime in, wakening even the groggiest sleeping field biologist. For us, this is the very best sort of wake-up call.

Kwerba's forests pulsed with life—large fruit bats, tiny insectivorous bats, wallabies and tree kangaroos, scuttling forest rats, more than 120 species of birds, Northern Death Adders and Cat-eyed and Small-eyed Snakes, frogs large and small, more than 100 species of butterflies, and hundreds of jungle plants including palms, pandans, mahoganies, figs, laurels, and the like—making for a biotic wonderland. The whoops and hoots and whistles of birds of paradise came from all directions. We had never been to a jungle with as many jungle birds of paradise. In short order, I listed: King, Lesser, and Twelve-wired Birds of Paradise, plus Magnificent Riflebird, Pale-billed Sicklebill, and Glossy Manucode. More were to be found in the hills and mountains above.

The prime objective of the expedition was to complete a first multidisciplinary survey of the flora and fauna of the Foja Mountains region. Achieving this objective was going to be a challenge for several reasons. First, our field party was too large for a single camp, so we decided to establish a hill forest camp for half the team and a mountain team for the rest. Second, we did not have a location for the hill forest camp and were uncertain about trails to the interior. Third, there were logistical problems with obtaining a helicopter to ferry us up to the mountain camp. Fourth, the weather was poor because the rainy season was just beginning. And, fifth, we were in the middle of nowhere, and things have a way of going wrong so far from civilization.

The helicopter issue was fraught. There were no helicopters available for hire in Jayapura. Instead, these machines were scattered about in local centers that provided support to businesses related to mining and logging (primarily at the enterprise hubs of Nabire and Timika). These centers were far from Kwerba. Helicopters are fragile and expensive machines, and we had only so much money to invest in their hourly rental. HeliMission, a nonprofit Christian missionary assistance group based in Wamena, agreed to allot us a chopper for a single day inbound and a single day outbound. This was all the charter time they could spare. The days they allotted to us—November 22 and December 7—gave us pause. The first was the anniversary of President John F. Kennedy's assassination, and the second was Pearl Harbor Day—not a propitious pair of dates to Americans. Given the uncertain weather and conditions in WNG, we were not brimming with confidence.

Dividing our big group into a mountain team and a hill team was politically sensitive and had to be finessed so as not to create friction or jealousy. It was first agreed that CI staffers Yance de Fretes and Neville Kemp would lead the hill forest team, which would hike into the hills and establish a camp on the nearest ridge that reached 1,000 meters elevation. The mountain team, on the other hand, would chopper into the upland lake bed at 1,650 meters. Our final decision on personnel assignments would be made after an initial field reconnaissance of the Foja hill forest.

In order to choose a good spot for the hill forest camp, I led a small advance team of Kwerba naturalists on a rapid walking tour of the foothills northeast of the village in hope of finding ready foot access to the higher elevations where we could expect to find endemic montane species.

Brother Henk van Mastrigt seeks to net a high-flying butterfly at the edge of the bog at the Bog Camp.

An adult male Bronze Parotia scolds from the forest edge at the bog. This is one of the bird species endemic to the Foja Mountains. It has been distinguished from the similar Carola's Parotia by the shape of the crest, the color of the face, and the color of the male's iris.

We conferred in depth with our Kwerba hosts, and they assured us they could guide us to an elevation where we could encounter the special plants and animals of the uplands. We took them at their word. After all, they were the local landowners, and they were familiar with the near-mythical Golden-fronted Bowerbird and the mysterious red tree kangaroo.

In Kwerba village, prior to this exploratory trek, I pored over a brightly colored topographic map prepared by CI's cartography unit. I envisioned following the valley of the Kali Ibem (Ibem Creek) to a ridge spur that leads gradually up to the cloud forest. I then chatted with the village men about this route, and they agreed that this might be a possible path into the interior. It turns out they were just being polite.

After wading up the Kali Ibem for three brutal days, we arrived in territory none of the men had ever visited. I quickly learned why. The river here had cut a deep gorge that becomes treacherous when it rains in the headwaters. Before we were able to get to the promising ridge that led to the uplands, the river sent us a clear warning signal. In the pitch dark of the third night, I was jolted awake by someone shouting: Banjir! (Flood!) Several flashlight beams swept crazily across my tent like lightning flashes. I heard the rumble of boulders striking boulders. The river sounded as if it were headed right into my tent. Only then did I recall where I was—truly up a creek, in an isolated corner of Indonesian New Guinea, at two o'clock in the morning. Over the din of the rain and the river, one of my

Kwerba village guides—shouting, "The river is coming!"—warned that we must pack our gear and prepare to skedaddle uphill. Looking out of my tent I saw the six Kwerba village guides packing madly. My headlamp illuminated the rising river, now just a few centimeters below the lip of the bluff. The Ibem had risen more than 2.5 meters as we slept. The water was the color of poured concrete and was growling an angry chant of destruction.

That alarming night of rising waters threatened but did not flood our camp after all. We were able to go back to sleep after an hour on tenterhooks waiting to see what the river would do. The next day, several hours' hike upriver brought us to a place even more harrowing than where we had already been. Here the sun barely penetrated the narrow chute that was our valley of discontent. There was no credible access to the ridgeline above. At that point I admitted defeat, and our team turned back. In retreat, we were now aware that we would not be safe until we had escaped from the depths of this verdant but menacing canyon. A flash flood at the wrong moment could spell death. In places, because of cliffs, we were forced to ford the river where the swirling waters were neck deep.

With bruised feet, swollen from slogging for days in water, we dragged ourselves back to Kwerba village. We had found no ideal site for our hill forest survey camp and had only a vague idea of where to send the hill forest team. The trek up the Kali Ibem was one of those bad ideas that looked great on paper. We escaped harm by the skin of our teeth.

But in doing so we got to visit an area that had not seen humans for at least a generation. At dawn and dusk the river edge teemed with wildlife—we had marvelous close encounters with stolid and staring Northern Cassowaries, beach-foraging Lowland Wallabies, placid Grizzled Tree Kangaroos, unwary Victoria Crowned Pigeons, even speedy monitor lizards. I had never before had such close brushes with big game in New Guinea, where the wildlife is famously shy. The Kali Ibem was a naturalist's Eden. Yes, the punishing river walk was rudely unforgettable, but the wildlife encounters were a sweet chaser to the bitter medicine of defeat. Sometimes failure has its own rewards.

The reconnaissance was an education for us. It was clear that the Fojas were not going to give up their secrets without resistance. We now understood how little the current generation of local Kwerba people knew of the interior Foja Mountains. There were no walking tracks, few hunting traces, and little real understanding of the deep backcountry by even the best hunters in Kwerba. These people had forgotten their past relationship with the mountain range. Yes, they had many stories of the wildlife of the mountains, but they themselves had become sedentary. Hunting conditions were so good near the village that there was no reason for them to range farther. Cassowaries, pigs, wallabies, and tree kangaroos existed in abundance within an hour's walk from the village. Crocodiles and various fish inhabited the Siri and other rivers. This was the land of plenty. As a result, the local naturalists did not know the ridges leading up into the clouds like their grandfathers did. Can you blame them?

We had hoped to cut a ready access trail to 1,000 meters elevation a couple of days' walk from Kwerba. Now that hope was fading. We were unsure of how high the hill forest team could set their camp. Thus the success of our expedition depended on a helicopter.

Mammalogist Kris Helgen checking a small mammal trap in the upland forest of the Foja Mountains.

Would it come? Would the weather permit us access to the mountain interior? Would we be stuck in the lowlands, with the bowerbird and other biodiversity mysteries just out of our grasp?

November 22 was our helicopter pickup day. In anticipation, we were all up before dawn, packing tents, weighing baggage, and nervously pacing and listening for the distinctive cadenced sound of the aircraft. We hoped for an early arrival, before the clouds began to build over the mountaintops. After what seemed like an eternity, the unmistakable d-d-d-d-d-d-d-d-d sound of whirling rotor blades brought a shout to move cargo out to the airstrip. Brian, the pilot, refueled, and we packed the craft to bursting with four passengers and a lot of bulky but lightweight baggage. With a full gas tank, the pilot needed to travel light on his first sortie up the hill. This is especially so because he was heading into an unknown mountain zone that could require some agility. At this point, the only guidance the pilot had was our set of approximate coordinates, an elevation, and a GPS.

Thank heaven for the GPS! This little miracle device helped the pilot keep his eye on the target destination even though clouds obscured it from view. Though I was fast losing hope, apparently the GPS allowed the pilot to be patient, understanding that with passage of time and a crack in the clouds, the mission could be achieved.

As we drifted back to the southeast, the clouds parted and the boggy lake bed was now just below us. We could finally exhale. The chopper dropped to the landing zone, and the pilot debated about where to touch down. Was the area of thick marsh grass firm? Or was the zone of bare earth better? The pilot chose the bare earth, and the ground held as he ever-so-gently reduced the rotors' lift. Within seconds we were clambering out of the noisy machine with the blades whirling above us, hunched over, clawing at the mass of baggage, lugging it to the grassy part of the lake bed just out of reach of the deadly blades. Four minutes later the machine lifted off and disappeared over the brow of the ridge. The sound receded, and the four of us, stunned, stood in the place we had so wanted to visit for so long.

It was late morning, and the sun shown through the swirl of misty cloud that was rising up to this high pass on the main spine of the range. It was quiet but for a Melidectes honeyeater gurgling in the forest and a few other bird songs that I did not recognize. We stared about in wonder. We then decided we needed to improve and mark the landing ground. The lake bed was in fact a sphagnum bog interlaced with tiny channels of flowing water. Some areas were quaking and waterlogged, other were firm. We checked out various patches and decided the pilot's original instincts had been best. We thus marked out a landing zone by pegging down pink flagging tape and laying down some stout saplings as landing supports. We then started cutting a path into the adjacent forest, for we needed a campsite before the afternoon rains.

The chopper returned three more times in 40-minute intervals. Each time, people and baggage and supplies were disgorged in a swirl of wind and echoing rotor sound. Each return produced a heart-pounding scene with people and cargo moving wildly to and fro, while the deafening sound of the great machine made it difficult to communicate instructions. The sound echoed across the ridges surrounding the boggy lake bed. Nothing breaks the silence of the pristine wilderness quite like a hovering helicopter.

We selected a flat knoll in the forest as our campsite, and the Kwerba men quickly cleared the area and selected dozens of saplings as building timber. The fourth helicopter run was a close call. Clouds arriving up the ridges from the humid lowlands were closing in on our new forest home when the pilot punched through and delivered his cargo. The fateful fifth run was not to be. The weather ended all hope of that. We had all of our mountain camp fieldworkers—12 in all—but we were missing 200 kilograms of equipment and supplies. The rest of the day we were socked in by dark clouds, as rain fell on and off. By the end of the day we knew our helicopter was gone. Would it be able to return to deliver our critical supplies on another day?

We now were in an old dry lake bed atop a flat ridge high in the interior of the pristine and uninhabited Foja Mountains. Most of the south side of the lake had filled in and was firm and walkable. There were patches of open water on the north side. Thickets of rhododendrons and other shrubs formed a wall around the bog's border, and tall montane forest rose up beyond this border. With the clouds obscuring the sun, our surroundings presented a stark and wild scene. We were far, far from home. This was our Bog Camp—our home for the next two weeks.

When we all met for a late lunch on our first day in the mountains, several of the party mentioned their encounters with a weird bird with dangling orange facial wattles. I initially thought they were describing a Wattled Ploughbill, a cordilleran species unexpected in this north coastal range. But our informants noted that the bird in question also had a bright red face. I got mixed descriptions from the various informants, so I was confused but intrigued (one of the Kwerba men said its face "looked like a rooster.")

I didn't actually see the bird well for another five days, and when I did I saw what all the talk was about. Our colleagues had been describing a bird species new to science. This bird, which we quickly named the Wattled Smoky Honeyeater, was very much like its widespread cousin the Common Smoky Honeyeater. In fact, before I had figured things out, I assumed that the *Melipotes* honeyeater I was seeing *was* the widespread Common Smoky Honeyeater. But no, the bird here in the Fojas was distinctive. Attached to the bright orange facial skin was a dangling wattle of skin of the same color as the face, a feature shared by no other honeyeater in all of New Guinea. We had a new species!

Then there was the "lost" bird of paradise I wrote of earlier in this chapter, the mysterious *Parotia berlepschi*, described by Kleinschmidt. Decades after its description, Ernst Mayr treated this bird as a subspecies of *Parotia carola*e in his influential *List of New Guinea Bird*s, published in 1941. With time, this mystery bird was, in essence, forgotten by the ornithological world in a way that the Golden-fronted Bowerbird was not, the difference being the relative unimportance of a subspecies versus a species. In birds as little known as these, such a taxonomic decision by an expert can be quite arbitrary when based only on a comparison of study skins in a museum collection.

On our second day at the Bog Camp, a male and a female *Parotia berlepschi* appeared at the edge of our camp and put on a display that mesmerized those of us present. We stood in awe as the male romped about in some low saplings around our entrance trail, flicking his wings and white flank plumes, and whistling his sweet two-note song for the female. He then dropped down to the ground in the middle of the path, hopping to and fro in full display. We were too spellbound to go get our cameras—the encounter would have made a stunning series of photographs. We informally gave the species an English name—Bronze Parotia.

On subsequent days, this male would traipse through the canopy of the forest at the edge of the bog, singing and moving about conspicuously, announcing himself to the world. Three days before we departed, we were able to trace the male on his route to his terrestrial dance ground in a thicket in the forest. Here was his secret trysting site, where he would bring females for mating. We were never privileged to see that love interaction, though we did see the male dance and prance and pose with a ball of moss in his bill, perched on a branch above his dance floor. At one point, an immature male came and watched from the overhanging branch as the adult male did his ballerina routine on the ground.

The minute we saw this Bronze Parotia male we could see it was distinct from Carola's Parotia. Unlike Carola's, Berlepsch's was essentially a black bird with white flank plumes, and its voice and eye color were distinctive as well. Here was yet a third bird species unique to the Foja Mountains, joining the wonderful Golden-fronted Bowerbird, which Diamond had rediscovered here in the Fojas, and the Wattled Smoky Honeyeater. Suddenly, the Foja Mountains had become an important area of endemism for birds in New Guinea. In subsequent trips, an Australasian robin would be added to this list, as well as a new imperial pigeon (the two are still not yet described). These five novel birds represented just the tip of the iceberg, however. Over three expeditions, Steve Richards and Paul Oliver were to assemble a collection of at least a dozen new species of frogs from the Fojas. Wayne Takeuchi identified some five new plant species. Brother Henk found five new butterflies, and Pak Yohanes Mogea found a half dozen species of new palms. We expect that Kris Helgen will describe a handful of new mammals once he gains access to the collections held at the national museum in Cibinong. Lots of new species. In addition, biologist/photographer Tim Laman was able to document all this activity through his participation in the latter two field trips of the three.

This was, indeed, a lost world—a land that in many ways had been overlooked and left behind. Even the village landowners had little knowledge of this forest so many days' walk from any village. They had heard stories told by aging relatives around the campfire but had no firsthand experience. Like us, our local Kwerba and Papasena hosts were seeing all sorts of novel things in their first visit up the mountain.

Accompanying us at the Bog Camp was a group of six local landowners, including the two senior leaders from Kwerba and Papasena villages (Pak Isak and Pak Timothy, respectively). Here is the remarkable thing about their knowledge, all learned through informal teaching by way of stories told by elders. Isak and Timothy, although they had never seen this site and had penetrated only the verges of this isolated range on hunting trips, knew all about the wildlife up here. We had learned this the preceding week spent back in Kwerba, when we queried them on the mammals and birdlife, using illustrated books to focus the discussion. Without prompting, the men eagerly pointed out obscure and little-known montane species and indicated that these indeed lived in the Foja Mountains—species such as the Golden-mantled Tree Kangaroo, the Golden-fronted Bowerbird, and the Bronze Parotia (for this last they would point to Carola's and say "the Foja species looks a bit like this but is different"). The oral tradition clearly thrived in this corner of WNG. This meant that ancestors had spent time in the mountain interior and that they had shared their knowledge of the mountain fauna with their offspring and grandchildren. The two village elders with whom we were camped up top were as excited as we were when the team located one of these creatures known to earlier generations.

The Fojas were special because they were pristine, untouched, uncropped, unvisited. The island of New Guinea is cloaked in forest, but few of New Guinea's forest tracts are pristine—never visited by the traditional landowners. Most isolated mountain forests are visited by hunters searching for wild game, or travelers heading cross-country to a distant destination, or shamans in search of special plants for sorcery. People use the forest in ways we can rarely imagine in our urbanized and commercialized Western world.

But the Fojas were different. The human population in the area is so small and so scattered and so confined to the edges of this vast upland world, that the core forest block is apparently, even today, *entirely* free of human influence. In our two weeks ranging out in all directions from the Bog Camp, our team of 12 never encountered any evidence of humankind present or past. It was a wild land given over to wild nature.

Places such as these are now so very rare on Earth that it is difficult to appreciate their significance. For these are, in fact, the remaining "natural Earth prototypes" that have escaped being colonized and modified by humans over the last several millennia. In the early 1980s, Diamond had written eloquently about the significance of such pristine worlds like the Fojas. We now saw firsthand what he was talking about. We quickly came to realize the global significance of such a precious environment that is free not just of humans but of the feral cats, dogs, Black Rats, Norway Rats, and various invasive plants they bring in their wake.

Our time in this lost world went by with remarkable speed. Each day we worked from before dawn until after dark. Some of us rose before five o'clock each morning to record birdsong. Others went out after dark searching for frogs until a few hours before dawn. Hunting parties launched out in the evenings in search of unknown mammals higher up the ridges. We wandered far and wide in search of the Foja Mountains' secrets.

Some aspects of our work were easy (e.g., encountering the new smoky honeyeater and the lost bird of paradise). But there were tough times as well. Because of persistent rain and fog, our entomologist, Brother Henk, could hunt his butterflies only about an hour a day. We were cloud-free only in the early morning and after dark. Shortly after the sun rose, the clouds billowed up from the lowlands and filled this pass between the mountains. We had rain for some part of every day we were here. On most days it rained or drizzled four or five times. Heavy mist settled on the forest for hours at a time. The ground was saturated, and the walking paths around camp became quagmires. I never once wore on my feet anything but my high rubber boots—in the camp or out in the forest. The camp itself became a horrible mucky bog of mud because the several big plastic roof tarps all drained improperly. And we had no place to bathe.

My days on the mountain tended to follow a routine. I rose in the cool predawn hours and tromped out to the bog to make dawn birdsong recordings. I then opened the mist-nets. Then I either visited a small blind to observe the display of the Golden-fronted Bowerbird or conducted a walking bird census. I alternated checking the nets, measuring and recording the birds netted, and doing midday and afternoon censuses. I also surveyed and marked new walking tracks. What I found myself doing, mainly, was walking. I must have walked 10 hours each and every day. By eight o'clock at night I was physically spent, and I crawled into my mountain tent, stripped off my mud-encrusted clothing, and was asleep in minutes. I was lulled to sleep by the sounds of the Papuan Boobook owl and the Feline Owlet-nightjar.

Everybody found something new. This was the field expedition that every one of us had dreamed about. There simply was not enough time to catalog all that we were encountering. We could see that the 15 days we spent at our mountain camp allowed us to get only part of the job done. This was especially so for those studying the plants and the mammals—two important components of the biota. Both surveying groups suffered because much of their survey equipment and traps had been left behind (the helicopter never did come back to deliver that 200 kilograms of stuff). But Kris and Wayne labored on in spite of this setback. Kris was heavily dependent on the Kwerba men to hunt mammals at night. One night they came back with an Eastern Long-beaked Echidna, which herpetologist Steve Richards found right on our main ridgetop trail. Richards put the large and heavy creature in a sack, and the men happily carried it back to camp. We spotted three individuals of this rare species in a five-day period.

The most wonderful mammal we encountered was Diamond's mysterious red tree kangaroo, which turned out to be the Golden-mantled Tree Kangaroo, described by Tim Flannery in 1993. The Kwerba men encountered this wary species several times in the forest at night but had great difficulty keeping up with it. They finally brought an individual in to

Indonesian entomologist Harry Sutrisno collecting moths and other arthropods attracted to lights shining on a hanging white sheet on a rainy evening.

camp early one predawn, and the shouting that followed woke us all. This golden-and-red-furred beast sported powerful clawed fore and hind paws for climbing trees and a yard-long tail that helped it balance when climbing. This was New Guinea's analogue to a Red Colobus, a familiar monkey in central African forests. We now had a formal record of the species as a new large mammal for Indonesia—closing the circle on Diamond's earlier observation.

Wayne collected more than 700 different plant samples. Some were so bizarre that he immediately knew they were new to science. He has spent many months working out species determinations for this prodigious collection. Given that few plant species are flowering at any particular time in these tropical forests, Wayne was able to survey only a small sample of the flora. Additional visits were necessary to continue the work.

Our departure day, December 7, came all too quickly. With some regret, we rose early to pack. All of us felt good about what we had achieved, and once we were inured to inevitable departure, we began thinking about the luxuries we would regain at the Kwerba lowlands—bright sunny days, bathing, a mud-free camp, lazing about in sandals and shorts.

The morning broke clear and promising, but one hour passed to the next with no sound of rotor blades. Noon came and went, and we listlessly went through the motions. Eating, repacking, checking the details of our exit plan. We began to wonder: What would we be facing if some people got out and others did not? Who got to depart first, and who would come last? What equipment and supplies would we leave, and what would have to accompany us? How could we avoid overloading the helicopter? How could we make certain that anyone stranded up top had sufficient supplies to last until a helicopter could come back to get them? We were as nervous as cats. We were now thinking that all sorts of unplanned outcomes could leave things in a bad way.

All of a sudden the helicopter came rushing in from above and dropped right down to the helipad. We quickly loaded up cargo and people, myself included, and the pilot lifted the chopper and headed out—into a great gray wall of cloud. We probed here and there, but the pilot could find no break in the wall. After five minutes of frustration we dropped back to the landing zone and took a breather.

A bit before five, we saw some indication of hope and piled back in. Up we lifted, and the pilot picked his way through cracks in the cloud, and we were over the ridge and heading down. But then, every way we turned, there were obscuring walls of cloud. We could move, but not in the direction we wanted to go. Tom, the pilot, zigged and zagged, and we found ourselves in a maze of mountain ridges and low cloud—not good. It was not certain we could make our way back to the Bog Camp, and yet we couldn't see a way down to Kwerba.

Tom drifted lower and lower into a forested ravine, looking for passage. The clouds formed a solid ceiling above us. I looked down in search of a place to put down if necessary. Tom radioed in to his base to say he had to return to the Bog Camp, and turning to do this, he glimpsed a ray of light to the left and made for it. We squeaked through this into another small clearing in the clouds, and slowly but surely began to extract ourselves from our frightening predicament. My fingers began to unloosen their grip on the seat, and I started to believe we would, indeed, make it to Kwerba that day. For a long moment I had been steeling myself for the unpleasant experience of spending the night in a rocky stream gorge after an emergency landing.

Suddenly the forest below exploded with birds—the snowy white of Sulphur-crested Cockatoos, the black and red of New Guinea Vulturine Parrots, and the black and white of Blyth's Hornbills. It was as if they were rising up to show us the way down to Kwerba.

The most remarkable thing about this helicopter trip was that once we had escaped the cloud, we found ourselves with a straight shot to Kwerba, and we passed over ridge after ridge getting there. I looked down at that forest wilderness, all uninhabited, and rather than think about how wonderful it was, I thought about how horribly long it would have taken to make the hike from our mountain Bog Camp back down to the Kwerba lowlands. Each time I thought we were finally there, more forest passed below with no sign of the airstrip.

Finally we saw a garden, then another, then the grass strip! As the chopper was gently lowered to the landing ground, Kwerba felt like home sweet home.

Some of us got to bathe in the lovely stream pool that night, but others remained stranded up top in the mists. It was not until the next day that our pilot extracted the rest of the team and cargo from the mountaintop Bog Camp. By midday the groups from the hill camp and mountain camp held a joyous reunion at our research station in Kwerba. People were bubbling over with excitement, sharing discoveries and stories. Virtually everyone had found something new and of interest. We were now all back from the interior, safe and healthy. We had done it! We had explored a fascinating corner of the Fojas!

After two days in Kwerba—washing, drying, mending, labeling, organizing—we found ourselves in a milling crowd of village people, young and old. This was our farewell party, and every human in the Kwerba area was here to celebrate. We pooled our food resources, and a feast was laid. Our group donated many exotic items that were a special treat to the Kwerba residents. But before eating, a pastor said a benediction, and then many of us made public speeches, praising one another and the success of the effort. With the closing of the public speeches there was much hugging and then the free-for-all with the abundant food. Millions of tiny gnats joined the party, attracted by the bright lanterns that had been hung. Before long we were all drifting back to our tents, exhausted by all the excitement. We were drained from the three weeks work without let up and now were ready to pack up and head home for the fast-approaching Christmas season. We had spent Thanksgiving up in the bog, and we wanted to spend Christmas with our families.

This remarkable process was repeated in 2007 and 2008, with teams of varying composition. More challenges were faced. More new species were discovered.

The real wonders of the Foja Mountains were the new frogs and plants. Steve Richards and Wayne Takeuchi brought in species that were unlike any they had ever seen or studied. They were stunned by what they found, even though they were used to locating new species wherever they ranged on this great island. There is different, and then there is way different—and some of the Foja novelties were in the latter category.

When Conservation International put out a press release announcing the discovery of dozens of new species in the Fojas, it touched a chord with people around the world. It was the single issue that resonated with readers—the phenomenon of discovery itself awoke a dormant passion in many people, who e-mailed CI from far and wide. People have a primal fascination with something new in the world, something that had eluded the naturalists of the world until the discovery.

The issue of discovery is allied to the issue of unknown and unvisited environments, also of great interest to the reading public in the 21st century. Most people today think of the world as mapped and scrutinized and easily visited via Google Earth. In fact, there are little-known corners of the globe that have been, in effect, "forgotten," and that are pristine and unstudied. These are waiting to be "discovered" by Western science (local people, of course, know of these places and their significance). These are the wonderful lost worlds that will, as they are visited and announced to the Western world, excite the imaginations of children and adults alike, giving hope for the future and reminding all of us that other little-known parts of the world remain.

A telling of the geological origin of the Foja Mountains can help us understand why there are endemic species living up there. The first hint is the rock that one finds atop the summits—dark gray deepwater shales. The fragment of Earth that constitutes the Foja Mountains was undersea and disjunct from New Guinea 2 million years ago. A million years ago the former island arc that became the Foja Mountains was a newly conjoined patch of lowlands that had recently rafted into New Guinea's north coast. This tectonic collision

The author removes a Wattled Smoky Honeyeater from a mist net at the Bog Camp in the Foja Mountains. Distinguished by its pendent facial wattle, this honeyeater was described as new by Beehler and colleagues.

started the compression that led to the uplift of that former patch of seafloor into what would become the Foja Mountains. We can surmise that the highland habitats that support all those Foja endemic species did not come into being until perhaps a half million years ago. It presumably took some time for the montane plant life to colonize this new "island" of mountain habitat that had been lifted from the sea not long before. These montane plants dispersed from the central cordillera, which lies south of the Mamberamo basin. This must have been followed by the arrival of predecessor species of birds, mammals, frogs, butterflies, and so forth, which, in isolation, differentiated into new-minted endemic species.

In effect, the Foja range is a new "island" of isolated montane habitat into which a whole biota has recently colonized, adapted, and in some cases, differentiated. How did those montane species actually get to the isolated summits of the Fojas? Our best guess is that the process was aided by Pleistocene cooling, well after the summits had been uplifted. Here is what happened, we think: During a period of global cooling, montane plants and animals in the central cordillera shifted their elevational ranges downward into the lowlands. These downward shifts could have approached 1,000 meters of elevation over time (and for millennia at a time). Thus species that lived at 1,000 meters elevation during "normal" times shifted down to the foothills during the cold period. Upland species flooded into these areas. When climate conditions ameliorated and temperatures rose, these displaced upland populations began to filter back up the mountainsides, and presumably those populations living in the foothills of the new Foja Mountains ascended into the Foja uplands, providing a "seeding" of cold-loving forms from the central cordillera. This climate-driven process required no long-distance dispersal from the distant central cordillera to the south. The species, instead, crept up into the Foja Mountains, following the cool climate as it retreated up the hill in the face of warming. The Foja Mountains offer a textbook example of the interplay between plate tectonics, mountain-building, climatic fluctuation, and the evolution of a new montane biota.

Earth history includes both the ebb and flow of species. I learned about mammalian extinction in the forests of New Guinea on this expedition thanks to an informal field education from Kris Helgen and the examples of the Golden-mantled Tree Kangaroo and the Eastern Long-beaked Echidna. I found that the mammal story differs from the bird story.

My own study of the bird fauna taught me that few species of forest-dwelling birds in New Guinea are threatened by hunting, as long as large expanses of forest remain in place. Thus, if we conserve blocks of natural forest, no birds will go extinct, we believe.

What I learned from Kris Helgen is that a number of New Guinea mammals have suffered extensive local extirpation and that some more vulnerable forms have disappeared altogether in the recent past, the results of nothing more than chronic traditional hunting. There seem to be ongoing hunting pressures today that are threatening certain of New Guinea's largest native mammals.

This situation is exemplified by the echidna and the tree kangaroo. The 6-kilogram Eastern Long-beaked Echidna is slow moving and is much appreciated for its very tasty meat by hunters all around New Guinea. Once widespread in New Guinea and Australia, this echidna is recently gone from Australia and very rare in New Guinea, now found only in places where there are few people and minimal hunting pressure, mainly in the mountain uplands farthest from villages. The story of the tree kangaroo is more extreme. Tim Flannery had heard local stories about this species in ENG's north coastal range, where tribespeople from several areas had reported a red tree kangaroo that had once been a favorite food but that now was gone. After several years of searching, a member of Flannery's team located a single individual on an isolated mountain at the easternmost terminus of the range. By all accounts, the species had been hunted out from more than 95 percent of its known habitat. The lesson learned is that mammals as large as echidnas and tree kangaroos are vulnerable to extinction through subsistence hunting in continuous forestlands. The secret to the subsistence hunter's extreme impact is canine. Men hunting with

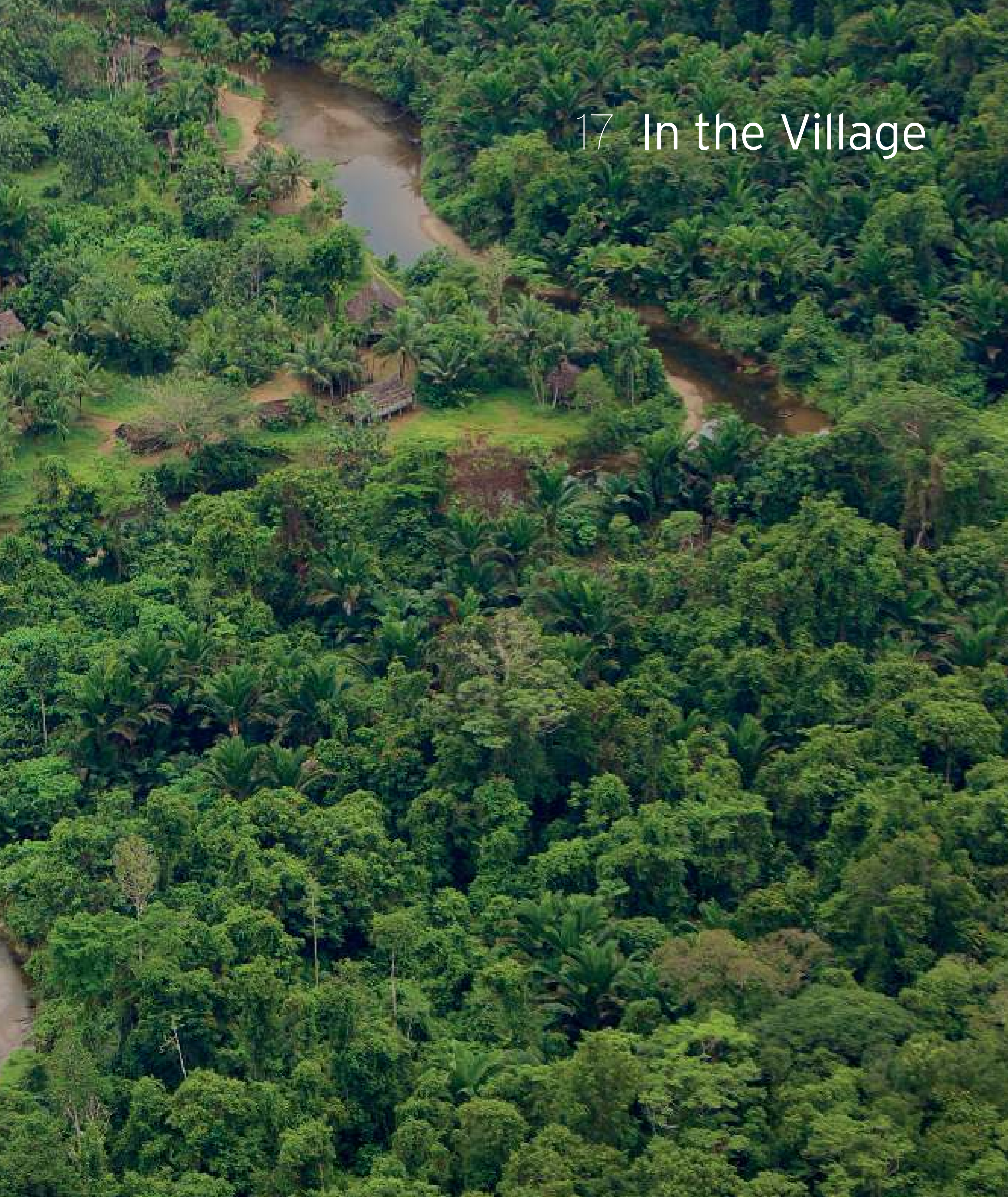
A helicopter view into the heart of the Foja Mountains. Only tiny portions of this isolated mountain range have been explored and surveyed. Future research will undoubtedly find scores of additional unknown or little-known species of plants and animals, perhaps even the rumored black tree kangaroo.

dogs can find every last individual of these threatened mammals, thanks to the dog's keen sense of smell. So it is not just a matter of conserving forest but of conserving forests free of hunting. Discovery of the Golden-mantled Tree Kangaroo and the echidna in the Fojas made us all happy, because we knew that here was a vast forest tract free of hunting or any other human disturbance. Here, the critically endangered tree kangaroo and the bizarre echidna could live in safety.

Each day, in the untouched forests of the Foja Mountains, Dwarf Cassowaries with no knowledge of human hunters search for fruits on the forest floor. New Guinea Harpy-Eagles perch like gray ghosts in the mossy canopy, waiting for unsuspecting giant rats. The magnificent, saber-tailed Black Sicklebill birds of paradise rattle their advertisement songs at dawn. And Golden-mantled Tree Kangaroos forage in solitude. In this superbly peaceful environment, I could walk quietly up to the display bower of the Golden-fronted Bowerbird, sit on a fallen log, and watch the male carry out his courtship routine at his "love tower" of sticks and moss. Ignoring my presence, the female would sneak in to an adjacent perch, sending the crested male into a frenzy of excitement. He collected a tiny blue fruit in his beak and posed stiffly, beak-upward, facing the moss-and-stick tower, muttering weird sounds as if under his breath, expanding his golden crest to prove his biological worth to the choosy visitor. What a pleasure to know that this beautiful and little-known bird species can continue to follow its annual cycles of construction and passion and reproduction in a rainforest that stands apart, isolated from the heavy hand of humankind.

Have we now robbed this lost world of its protective and seductive mystery? Not exactly. Fourteen years after the first field trip, the Foja Mountains remain undisturbed and undeveloped. We still talk about the mysterious black tree kangaroo that may lurk in the highest forests of the Fojas. Whether it was actually seen, or not, by our local naturalists on our first trip—that is hard to tell for certain. Subsequent trips did not encounter it. Other hunters near Kwerba brought us the skull of a tree kangaroo from the Fojas that is larger than any living *Dendrolagus*. What might this be? It is difficult to say without more data. These are mysteries for future expeditions into the jungle. Lost worlds will continue to haunt our dreams. ■

17 In the Village



Rural Life

EVEN TODAY, MOST PEOPLE inhabiting the great island of New Guinea live in rural villages, distant from cities and towns. Some of these villages are accessible by road or a rough jeep track, whereas most are not. Those not accessible by road may be linked to the nearest urban center by a navigable river. Others are accessible only by bush airstrip, yet others remain accessible only by foot track—some several days' walk from the nearest town or road head. It is safe to say that New Guinea supports what is the most rural and isolated populace on Earth. There are few highways, and these are difficult to maintain because of the rainy season's downpours and the frequency of landslips and local flooding. To this day, no major road link manages to cross the main barrier of the central cordillera. When that is finally accomplished, the drive will remain long and arduous because of the mountainous terrain, the continuous environmental assault on the road itself, and the lack of government resources to ensure suitable road maintenance year-round. This means most New Guinean villagers live surrounded by nature and are literally part of "natural" New Guinea.*

I have visited scores of rural villages in both Papua New Guinea and Indonesian New Guinea over four decades, and even though the two nations are very distinct, indeed, life in these villages exhibits more similarities than differences across the international boundary. In fact, the range of variation of custom and habit within each nation is more extreme than between the two nations. Perhaps the biggest difference is between villages in the mountains versus those in the alluvial lowlands (which could be a distance as short as a dozen kilometers). In addition, village life today is very distinct from village life before

Preceding pages: A lowland village in the Karawari drainage in the Sepik-Ramu, ENG. This is truly a forest community—notice the closed forest on the right bank of the stream.

Opposite: The highland village of Tonsep in the YUS ecosystem of the Huon, ENG.

* Sources for this chapter include Beehler (1991, 2008) and additional publications in the references section.

Western contact (prior to the 1950s and '60s). Recognizing all these sources of variation, we take the liberty of treating life in the village New Guinea–wide rather than focusing on one or the other nation, even though our "model" village, described in the following paragraphs, is situated in WNG.

In the last chapter we spoke of Kwerba village at 75 meters elevation in the Mamberamo basin of WNG. The research teams spent a number of weeks in Kwerba and got to know it well. Let's use Kwerba as the model for a rural village in New Guinea. This is perhaps a good choice because it is neither highland nor lowland, as it is in the foothills, and it thus exhibits characteristics shared by both.

Kwerba is typical of isolated rural villages in New Guinea in the early 21st century; it has a nearby river, a grassy airstrip, a cluster of houses, a Christian church, a small school, and a scattering of gardens that have been cleared from the surrounding forest (and in various stages of activity or fallow). Each family inhabits a house its members have constructed themselves (with the help of friends), mainly built from materials harvested from the surrounding forest. In the early 20th century, traditional housing forms were employed, and each region of New Guinea exhibited distinctive styles, most designs quite handsome. In the central highlands, houses were low and rounded, with conical roofs. In the alluvial lowlands, houses traditionally were elevated off the ground and in many cases were "longhouses" that were occupied by groups either of men or of women and children. These days, most village housing is in the rectangular Western style. In the hot lowlands, houses are elevated on posts to provide better air circulation and avoid seasonal flooding, whereas in the chilly highlands, houses tend to be low, enclosed, and smoky, sitting on a packed-earth floor.

The typical house in the interior foothills (such as Kwerba) is framed from timbers hand-fashioned from forest saplings, and the flooring is woven cane or bamboo laid atop a series of timbers or split black palm stems. The walls are of woven cane or of Western-style planks fashioned from forest timber or made by using a chain saw set in a portable sawmill frame. Doors and windows follow the Western style, and the front door may feature a store-bought lock. Windows lack glass or screens but can be shut using fitted wooden panels with store-bought hinges on top and a stick to hold them open for ventilation. The roofing is layers of palm thatch laid atop the sapling-strip roof frame. The thatch remains waterproof for several years in houses where a cook fire burns daily, prolonging the roof's longevity. Small home gardens of chilis, non-native ornamental flowers, and fruit trees (Papaya, avocado, *Canarium*, *Terminalia*, Betel Nut Palm) typically surround the house, greening the home environment. A small stepladder leads up to the front door, which allows dogs (but not pigs) to enter. The house, depending upon size, may have three rooms—a main living room, a kitchen, and a bedroom. The kitchen and living room will typically feature a fireplace set on the floor. This usually consists of a wooden frame and base filled with sand. The fire burns atop the sand. There is no chimney, so the smoke escapes through the eaves. Most houses in New Guinea are smoky, which can be very annoying to Western visitors but provides a benefit to residents by deterring biting insects such as mosquitoes. A long-term cost of a smoky house is respiratory complaints. That said, many villagers over the age of 12 in isolated villages such as Kwerba smoke home-grown tobacco, so the house smoke may be the lesser health issue. Family members sleep under a mosquito net.

Lighting after sunset in isolated rural villages is provided by firelight, by burning of tree resin, by kerosene hurricane lanterns, or less commonly by battery-powered flashlights or LED lighting. Kerosene is expensive and heavy and difficult to transport, and therefore the fuel-hungry pressure lanterns are uncommon. Hence in evenings, the typical village is dark, the homes poorly lit by the wood fires in the living room and kitchen and the occasional small kerosene hurricane lantern. Rural village life is such that it is common for people to go to sleep early and to rise before dawn.

Typically, villagers consume two meals a day—predawn and after dark in the evening. All the cooking is traditionally performed by the women of the family—wife, older girls, or an auntie. Most meals are dominated by garden fare (or sago in swampy lowlands). Depending on the location, the main meal will be root crops: Sweet Potato, yam, Taro root, or Manioc. These will be boiled or roasted in the ashes of a fire. Added to the tubers might be pumpkin, pitpit (bush asparagus), and various edible greens (boiled in a pot of water or steamed in a

Village matron planting her Sweet Potato garden. The large mounds produce good drainage. Notice the banana plants around the garden's verge.

large bamboo tube). These various vegetables make up the evening meal. Small portions of bushmeat or river fish might accompany the meal, if available, but these generally are specialties served only from time to time. Lunch consists of leftovers from the morning meal—a cold piece of Sweet Potato, yam, or Taro root wrapped in some sort of leaf and stored in a small woven string bag (bilum in ENG, noken in WNG) carried over the shoulder. Given that most villagers subsist on their vegetable gardens and the forest, many forest products are occasionally collected and added to the meals: wild mushrooms, large white longicorn beetle grubs dug out of fallen timber or split-open Sago Palm stems, birds' eggs (especially the huge eggs of brushturkeys and megapodes), and essentially anything edible caught in the forest—including bats, songbirds, and other minor tasty vertebrate species.

Children playing on the shore at a Misool Island coastal village. Note the mature Coconut Palms along the back of the beach. Most communities in the NW Islands are situated along the coast.

Store-bought white rice and tinned mackerel are very popular but usually not available in villages without road access to a town or city. Flying in store-bought goods to a rural village such as Kwerba is prohibitively expensive.

In a foothills riverine habitat such as Kwerba, the village will foster stands of Sago Palm (*Metroxylon sagu*), which is grown in swamp forest and then cut down before the palm matures and flowers, so that the starch can be extracted from the soft interior of the palm's trunk. The starch extraction is a complicated process that involves the whole family. The men cut down the palms and split open the trunk. The women extract the interior of the palm and wash the starch out of the matrix, usually with the help of the girl children. The white starchy pulp becomes sago flour, which can be cooked as porridge or roasted into a sort of unleavened bread. One palm can yield several hundred kilograms of sago starch for eating. Most Westerners do not find cooked sago to be an enticing meal, but throughout New Guinea and the Moluccas, many rural forest-dwelling lowland and foothills villages subsist on this starchy fare.

Before dawn, the adults in the house will rise and stir the fire, set a teapot to boil, and put some tubers into the hot ash to bake. People rise very early in the rural countryside, as in farmlands around the world. Parents wake the children and ready them for school (which in Kwerba is a walk of less than 100 meters). After that, the women of the village pack their string bags and pick up their digging sticks or trowels and head to the garden for a morning's worth of work. A gardening woman will take her infant, carried in a large string bag. The infant in the string bag will be hung up in the shade of a small roofed but unwalled garden shed while the woman gardens.

Swidden (slash-and-bush) gardens are the fundamental unit of the village economy in a place like Kwerba (aside from the stands of Sago Palm). Men clear a patch of forest with axes and then after the fallen trees have dried for a number of months, the garden area is burned. Where the garden is made in young secondary forest the burning clears the entire plot. Where old-growth forest has been cleared, it is not uncommon for the garden to be cultivated in and around the huge fallen tree trunks, which are too heavy to move and too big to burn completely. One can only imagine the nuisance for the women planting and tending these. A typical garden may produce a variety of crops for one to three years, and then the plot is abandoned for a new garden placed elsewhere. The old garden is allowed to regenerate back to forest and, depending on land needs, may not be reused for 25 years or more. Families usually manage multiple gardens in several stages of maturity to ensure the availability of subsistence food the year-round.

Swidden gardening is the preferred agricultural practice for rainforest peoples around the world. Although the reader might assume this practice leads to deforestation and habitat degradation, such occurs only when the population is above a certain density, as is found in New Guinea mainly in the mid-mountain zones. In foothills interior sites such as Kwerba, populations remain sparse, and the forest patches cleared for gardens quickly revert to forest after abandonment. Given that humans have been gardening in New Guinea's forests for

Opposite: Women returning from their scattered gardens carry *bilums* (string bags) across a handmade bridge. Note the timbers of the bridge are secured by lashings of rattan vines.

many thousands of years, it is not surprising that they have determined the best method for extracting agricultural value from the forest without permanently damaging the environment.

The swidden gardens usually feature some favored crops such as Sweet Potato, Taro, a species of yam, cooking banana, pumpkin, Manioc, corn, chilis, and English potato, as well as other staples such as various greens and peanuts. Tree crops are planted beside gardens and around homes: galip nut (*Canarium indicum*), okari nut (*Terminalia complanata*), Papaya, karuka (nut pandanus), marita (red pandanus), Breadfruit, Jackfruit, Coconut Palm, sweet banana, and avocado. With advancing climate change, highland gardens have come to look more like foothills gardens, and Coconut Palms now produce mature fruit above 1,000 m elevation.

Villagers make plantings of Betel Nut Palm (*Areca catechu*) in sunny openings where they can be tended and looked out for. This slim-stemmed palm produces a nut with a large white seed that is wrapped, with some ground limestone, in a pepper fruit or leaf and chewed to produce a mild narcotic high. Many people chew betel nut in New Guinea. Tobacco is also planted, and smoking is widespread in most communities. In fact, the smoking of tobacco and chewing of betel nut are considered staple activities that make the hard work of gardening, house building, and forest clearing less onerous. Moreover, the exchange of betel nut and tobacco cements relationships and is an important part of the village social fabric. Regardless of the social benefit, the consumption of these two substances has led to a high incidence of oral cancers.

Aside from the harvest of planted species, rural villagers collect useful wild plant species from the surrounding forest. Some serve as foods, others as medicines, and yet others are employed in ritual sorcery. A recent study identified more than 3,000 useful plant species identified by more than 250 ethnic groups across the island. Presumably, this is just a portion of the species used. Women and children spend considerable time in the forest seasonally collecting these. These products probably constitute an important noncash component of each village's economy.

Men and women carry out distinct duties in the rural village. While the women are tending the gardens or harvesting in the forest, the men are clearing forest for new garden sites, constructing dugout canoes, splitting saplings for fencing, building new housing, and hunting. Prior to village pacification by government and the destruction of traditional belief systems by Christian missionaries, men were engaged with important social and religious rituals, village defense, interclan conflict (war parties), and hunting and fishing. Although less traditionally employed in the village today, men are particular handy with all sorts of manual tasks and can manufacture or repair just about anything (a product of the need to be self-sufficient). Western research teams that work in partnership with local communities in New Guinea find the experience productive and satisfying.

Hunting is typically a social activity for the men and is a sporadic yet important part of life in the rural village. These days, hunting is often driven by the need to supply meat to mark the celebration of some approaching important village event on the calendar—the

A Waigeo Island man washes the pith extracted from the large stem of a Sago Palm. This process extracts the sago "flour," which is used to cook various types of starchy fare. Sago is an important food for many lowland New Guinean communities.

christening of a new church, Christmas, a wedding, school graduation, and other important social activities. These special days call for a feast, and New Guinean villages take the notion of a feast seriously. In the ENG highlands, domestic pigs would feature prominently. In a foothills rainforest village such as Kwerba, where domestic pigs are fewer, the meat to enliven a feast mainly comes from the forest. A small group of men will plan a hunting trip (much as a group will do in rural western Pennsylvania in late autumn). The trip will require several nights out in the forest, to allow the hunters to get out beyond the halo of overhunted lands that surrounds the village. Most favored game has been extirpated within a day's walk of the village; hence the first day will be spent getting into prime game territory (though the hunters from Kwerba do not have to travel nearly so far out of their village to find game). For Kwerba, the focal wild game includes Wild Boar, Northern Cassowary,

Grizzled Tree Kangaroo, two wallaby species, two species of crocodile, Victoria Crowned Pigeon, Papuan Python, Eastern Long-beaked Echidna, and various smaller animals (bandicoots, cuscuses, ringtails, fruit bats, and giant rats). In most parts of New Guinea, Wild Boar is probably the most highly prized target for hunters because of its excellent meat. Wild Boar is an exotic invasive species in New Guinea. It can be found in most forests and even into alpine grasslands in some locations.

For most hunting parties, the key to success is having accomplished hunting dogs. These typically are small, wiry, and buffy tan, and have a special knack for the chase. The men head out into the forest with the dogs and let the dogs do much of the work—cornering a boar or cassowary or treeing a tree kangaroo. Hunters carry heavy wooden-tipped spears; handmade black palm bows with arrows constructed of strong cane reeds and featuring various tips for differing game; perhaps an air rifle (in WNG); and of course the all-purpose machete (called a "bushknife" in ENG and a parang in WNG), which can be used in various roles in the hunt. The intent of a typical hunt is to gather as many kilograms of wild game as possible, to field dress and smoke the game in the field, and then to carry this bush protein, wrapped in leaves and secured to the back with vines, to the village for the celebration.

Often, while the men are hunting, some children and women will be fishing for eels and other river fish to be contributed to the feast. In many parts of New Guinea, the feast's food will be prepared in a traditional cooking process called muu-muu. A pit is dug and laid with dried hardwood timber. The fire is set, and many large stones are laid atop the fire. The stones are heated till red-hot and then grasped with large wooden pincers and stacked to the side of the pit. The bottom of the pit is then laid with banana leaves, and the meat and fish and various vegetable tubers are layered in the pit, each layer separated by the big green leaves. Finally, the red-hot stones are laid atop the food layers, and then more leaves are laid atop the stones. Water is poured over the stones occasionally to create steam for cooking. The result is a homemade pressure cooker. After a few hours, the leaves and stones are removed, and the steamed meat and vegetables are put on leaf-trays for the feast.

Christianity is widespread through the rural villages of both ENG and WNG. (Even though in Indonesia Islam is the dominant religion, WNG has been heavily missionized by an array of evangelical Christian sects from Europe, Australia, and the United States.) ENG was first proselytized in the 1870s by the London Missionary Society (various evangelical Protestant groups), followed by the Church of England (Anglican/Episcopalian), Roman Catholic, and then by newer evangelical sects: Baptist, Seventh Day Adventist, New Tribes Mission, Four Square, and so on. Indonesian New Guinea was initially proselytized by the Dutch Reformed, Roman Catholic, and most recently the various evangelical Protestant sects. These days, the evangelical sects predominate, receiving continuing suspicion and pushback from the Indonesian government, which is predominantly Muslim. Today, PNG is perhaps the most heavily Christianized nation on Earth—virtually all citizens are churchgoing practitioners. Rural villages may have two or more competing churches vying for villagers' souls. Kwerba is serviced by a Presbyterian/Congregational Protestant church known as

Gereja Injili di Indonesia. Any public village event will include some sort of benediction by the Kwerba church pastor or a lay church leader.

Prior to the arrival of Christian missionaries, each traditional village society in New Guinea practiced a complex ritual belief system tied to unique origin stories, ancestor worship, social and ethical rules of conduct, fertility, sexuality, sacred sites, secret and magic objects, rites of passage, sorcery, and taboos. In their nature and purpose, these local "religions" were not unlike religions practiced today around the world. These systems of belief were reinforced by village elders, typically men of importance and power. And they were tied to knowledge of place and of environment. One of the first tasks of a Western missionary entering an uncontacted village was to discern the nature of the original belief system and then attempt to replace that with the Christian canon, leaving only the original tradition's remnants that most closely allied with the Christian sect's tenets. This process is well described in two books by Don Richardson, *Lords of the Earth* and *Peace Child*.

This practice means that more than 1,000 ancient knowledge systems and cosmologies were actively dismantled (with more or less success) by the missionary invaders. Remnants of the villages' ancient traditions survive, hidden beneath the dominant Christian practices that prevail in nearly all rural villages today. Of course, it is impossible to discern how much remains and how much has been lost forever, as people are secretive about practices that are, themselves, secret and today considered illicit by the predominant Christian culture.

To destroy willfully the rich cosmologies of more than 1,000 ethnic groups across the largest island on Earth should be considered a crime against traditional humankind. And, of course, the loss of one's knowledge system is the first step toward the loss of other important traditions, with attendant degradation of the local culture and depreciation of ethnobiological knowledge that could have global significance. We have witnessed firsthand the rapid loss of oral tradition and knowledge with the change of generations under Christian belief. Perhaps the important point here is that geographically isolated Kwerba village, hidden in the forests of the Mamberamo basin and far from any road, is today a largely Western construct, with little remaining of the people's ancient traditions, knowledge systems, and worldview. If that is so, then that is unfortunate for us all.

One aspect of original belief systems remains in the rural New Guinean village—sorcery. Christian missionaries were unable to stamp this out, nor can current government or constabulary authorities. For Westerners, sorcery is difficult to understand for two reasons. First, most of us have no firsthand experience with it in our daily lives, and we do not believe in its efficacy. Second, sorcery is a deep secret that village people are very reluctant to speak about (especially with curious outsiders). There are secrets in the village that Westerners will never be privy to. I have seen no evidence that the prevalence of belief in the power and existence of day-to-day sorcery in rural village life has diminished over my four decades working in rural New Guinea. Sorcery resides side by side with Christian faith in the minds of New Guineans. This demonstrates the remarkable ability of the human mind to hold in its consciousness two beliefs seemingly in conflict.

Lest we feel smug about Western advances, recall that sorcery was very much a part of Western belief systems in the 1600s. The Salem witch trials took place at the very end of the 17th century. And even today, many people in the West invoke lucky charms and other superstitions to improve their fortune in life.

For a Westerner, the most indelible example of the importance of sorcery in New Guinea is that most rural New Guineans today do not believe in a natural death. The belief is that people die from some explicit act of sorcery. A person dies because an enemy of that person has "worked a spell" and caused the person's death through this spell. Rural village communities typically have one or more sorcerers, and these experts can be contracted to work spells. The remarkable thing is that we Westerners absolutely do not believe in the efficacy of sorcery, whereas our counterparts in rural New Guinea absolutely believe in the workings of sorcery. No more need be said.

A hunter with a bow and arrows heads from his village into the forest in search of pigs, cassowaries, and other species. Typically, he will be accompanied by several hunting dogs, used to track the game.

Schooling in rural villages in New Guinea is a hit-or-miss thing. A lot depends upon whether the provincial education department can provide a good teacher for the duration of the school year for that isolated rural school. Teachers are poorly paid. Many are typically raised in distant communities speaking distinct local languages. Think of the hardship the teacher must face to spend months or years based in a small bush house without electricity, in a village that speaks a foreign language, with no access to stores or visits to the city. Many teachers find the challenges of rural village life unbearable and simply "go home for Christmas," never to return. It often takes years to replace that teacher. The students, then, must do without.

The village school itself is hand-built by the community from bush materials. It is typically a single rectangular room, with students' benches facing a chalkboard in the front of the room. The students typically have no books and may have no pencils, and instead practice on the chalkboard or on small handheld chalk tablets (no iPad here). Much of the pedagogy is based on memorization and recitation. Some schools are taught in the local village language, whereas others are taught in Bahasa Indonesia (in WNG) or in Neomelanesian Pidgin or English (in ENG).

As the sun rises, the women head out to tend their gardens, the older children head to the community school, and the pre-school-age kids play in the village open spaces—often kicking a soccer ball (if available) or a ball manufactured from local materials. Soccer is a huge sport in rural New Guinea. Most children go barefoot and wear shorts and a T-shirt. These clothes are purchased by a parent on a trip to the nearest town. The clothing is commonly castoffs from Europe or the United States, bundled into bales and sold to wholesalers in developing countries. It is thus not uncommon to see a diversity of Western logos on shirts worn by villagers. These are balanced against an array of Chinese knockoffs. Many T-shirts sport incongruous references to faraway places and cultures entirely unknown to the populace of the village. It is not uncommon to see a toddler, naked from the waist down, wandering about in front of the house, proudly waving about a kitchen knife and sporting a T-shirt emblazoned with the logo of some American sports team or high-end designer. These little ones are left by parents under the care of older children or aunties. Young children are free to wander at will in a manner long forgotten in the West.

Dogs move about, with the dominant ones periodically beating up on their inferiors. Village dogfights are commonplace, broken up by a swift kick from a nearby adult. To say it's a dog's life in a New Guinea village is an understatement. Cute little puppies may receive some feeding and affection from owners, and the best hunting dogs are often treated with the best pick of kitchen scraps, but most adult dogs are left to fend for themselves. They are often scrofulous and underfed and treated with contempt. They compete against young pet cassowaries, chickens, and village pigs for any household scraps that hit the ground. Tiny toddlers, chickens, dogs, pigs, and young cassowaries wander about the village green in search of food or entertainment. A pet cockatoo, tethered to a perch under a nearby porch, might screech loudly to attract attention. It's all part of life in the rural village.

The more farsighted rural villages fence their pigs. Other villages allow their pigs to wander at large and to sleep at night under the elevated houses. This ensures that inhabitants are awoken at least a dozen times each night by either squealing fights between the porkers or the commonplace rubbing by the largest pigs against the house posts, causing the house to sway as from a local earthquake. Pigs allowed to roam a village create unsanitary conditions. In fact, in general, villages are not sanitary places. Short-term Western visitors, staying in a field station and bathing in a distant upstream locale, may avoid health problems, but people who live in the village certainly cannot. First and foremost in rural lowland and foothill New Guinea, there is the threat of malaria, which is endemic to the populations of most rural villages below 1,000 meters elevation. This means that most inhabitants of these villages carry the malarial parasite and can potentially transmit it to others when the parasite reproduces in the bloodstream. Other common rural diseases and parasites include hookworm, roundworm, tapeworm, giardiasis, tuberculosis, common cold, hepatitis A, and diarrheal complaints. A particularly common and pernicious problem comes from *Staphyloccus aureus* infections of the skin of the legs and feet, which are called tropical ulcers. Often these are initiated by an insect bite that gets scratched and then infected with staph germs. Left untreated, these grow and swell and penetrate deep into the muscle. In the village, there usually is no access to oral or topical antibiotics to treat such open sores. A tropical ulcer can be debilitating to anyone who has one.

A domestic scene in Kwerba village. It is afternoon, and the rainbow indicates that a thunderstorm has come and gone. Note that the wall of the house in the foreground is constructed of split stems of Sago Palm fronds. The house's roof is made of palm thatch. Virtually every component of the house is harvested from the surrounding environment.

In spite of the threat of disease, I have always found visiting a village such as Kwerba a pleasant experience. Village residents are curious but polite and are always interested in assisting with the fieldwork that is being done. I typically sleep in a tent set at a distance from the noise and bustle of the village center. People are very hospitable to visitors and offer gifts of fresh coconuts for the refreshing coconut water, ripe pineapples, sweet bananas, and papayas. For many of us who have worked across New Guinea, this is familiar village life, much the same whether in ENG or WNG.

It may appear that village life in New Guinea is an ancient construct, long predating the arrival of Western explorers, but that is not so. The villages that we know and see today are mainly the result of the imposition of Western governance and religion as well as the magnetic attraction of departure points to civilization. Although it is difficult to generalize

A typical rural village school in the Crater Mountain Wildlife Management Area in the Eastern Ranges of ENG.

about societies of more than 1,000 language groups, it is apparent that prior to Western contact, many societies did not live a village existence. Instead, the social unit was the extended family group, and small clusters of houses were scattered across the landscape. There were no large village settlements. In each small grouping, men lived in a men's house, women and children lived in one or several women's houses, and these were scattered through a mix of planted tree crops and vegetable gardens. Exceptions to this were river-dwelling lowland peoples such as the Asmat, who did cluster for protection from attack by enemy tribes. So across the island, from coastal lowlands to chilly highlands, there probably was quite a range of communal dispersions, but dispersed probably dominated over clustered.

Upon the arrival of government patrols to pacify uncontacted peoples, which continued until the 1970s, and the arrival of Christian missionaries, these two sources of outside influence sought to bring together scattered populations in order to efficiently govern them, provide health and judicial services, and proselytize. Government patrol officers selected sites accessible to a river, or missionaries selected locations where an airstrip might be constructed. Then inducements were offered to encourage family groups to relocate to what would become a village. The government offered medicines and new agricultural products. Missionaries offered a promise of salvation, a church, a school, and other benefits, much like those offered by government.

Prior to the arrival of colonial government, settlement was scattered and temporary. Families moved about with the seasons to carry out particular economic or agricultural functions. And living compounds were not long-standing. People moved with considerable regularity because of shifting swidden garden locations and the arrival of perceived health

Children playing soccer on the Kwerba village airstrip. The grass of the airstrip, which has multiple uses, must be cut regularly for both soccer as well as landing aircraft.

and/or sorcery threats. This brings us to one of the most remarkable aspects of New Guinea customary society. These traditional societies tended to have very little material wealth, and they shared what little they had. Land was seen through a lens of use rather than ownership. And people owned little of permanence. Homes were temporary structures, meant to last perhaps six or seven years. Art was temporary, meant to be discarded after use. Wealth was exchanged and shared, and the wealthiest men were those who had loaned the most pigs to their neighbors, incurring acknowledged debts.

Although much has changed, rural villages in New Guinea remain fascinating to outsiders who make the effort to visit one. The warm and hospitable welcome one receives, the natural beauty of the village setting, the ready access to life being lived for all to witness, makes the New Guinea rural village a wonderful experience. It is as if one travels back in time, to a kinder and more gracious era, where communal good is still a widespread concern and where outsiders are welcomed as family. ■

18 The Future

Towards Sustainability

Preceding pages: Children walk to school passing a village coffee plantation. Coffee is an important cash crop in the uplands of ENG. Photo: Ulla Lohmann

Opposite: A string bag filled with ripe coffee beans (called "cherries") grown in the YUS uplands of the Huon Peninsula, ENG. These will be husked, which removes the skin and pulp; the silver-colored beans will be dried in the sun and then bagged for shipment to the coast for international sale. The beans will be roasted in the consumer's country. Photo courtesy of the Tree Kangaroo Conservation Program and Woodland Park Zoo

COMPARED WITH MANY TROPICAL REGIONS, New Guinea is blessed with a relatively small human population, and much of its native forest remains intact. Most New Guineans live in rural communities and—thanks to abundant rainfall and the equatorial sun—sustain themselves through subsistence agriculture supplemented by the harvest of fish and game, rarely resorting to substantial cash purchases for their daily needs. These rural communities are thus relatively prosperous compared with similar societies in parts of tropical Africa and South Asia, without need for livelihood interventions by the government (except during periodic severe ENSO droughts). This happy condition, however, may be starting to change. Human societies and enterprises are altering the landscape of the New Guinean Region, and eventually economic adjustments will be required to maintain general welfare across the island. This chapter discusses economic development across New Guinea, finishing with speculation on the possibility of establishing a sustainable future for this great tropical island and its societies.*

First, let's step back to review the respective impacts on the New Guinean environment of traditional versus Western societies over the last several centuries. Traditional societies on the island certainly have impacted the environment but in ways quite different from the impacts wrought by the colonial forces from the West, which arrived over the past century. The indigenous peoples have been subsisting on the island for at least 47,000 years—a stunningly long occupation when compared to the Western occupation of less than a couple of hundred years. The early Melanesian settlers probably hunted to

* Sources for this chapter include Sekhran and Miller (1995), De Fretes (2007), and Beehler and Kirkman (2013), as well as additional publications in the references section.

extinction some of the larger game mammals living on the island—oversize cassowaries, kangaroos, and other marsupials. This follows the pattern seen in Australia and North America, where the megafauna was quickly extirpated. Details are lacking because of the very limited paleontological record for the humid and forested habitats in New Guinea, in which fossil preservation is poor. But recall that for much of the Pleistocene, Australia and New Guinea were one landmass, hence what was happening in the better-studied Australia must have applied to the lesser-known New Guinea. Tim Flannery's *Future Eaters* provides a book-length exposition on this fascinating subject of a traditional people consuming its megafauna (though recent research now provides a differing interpretation of the data—stressing the impact of abrupt changes in climate).

A timber company's log pile, with two village pigs foraging in the foreground. Virtually all logging in Papua New Guinea is carried out by foreign-owned companies, mainly from East Asia. Most of the harvested timber is processed and used in China. Photo: Bruce Beehler

The introduction of pigs and dogs by Melanesian colonists probably produced substantial impacts on the biota and the vegetation. As mentioned earlier in the book, dogs that ran wild became important predators on the marsupial and monotreme fauna, and perhaps led directly to the extirpation of the New Guinean populations of the thylacine (with the most recent New Guinean subfossil record from 8,000 years ago). Today, feral pigs cause serious disturbance to the forest understory and are major seed predators. Where pig populations are high, there may be major impacts on forest succession and the understory flora. Pigs probably arrived in New Guinea in the late Holocene, though there are less well-documented records in the literature from considerably earlier. Suffice it to say, pigs have been in New Guinea's forests for thousands of years, disturbing the ecosystem.

When Western explorers arrived in force on the New Guinea mainland in the 1800s, there was limited evidence of wholesale human conversion of forest to non-forest habitats by the activities of the resident Melanesian societies. Swidden agriculture was carried out but did not foster long-term forest loss, except perhaps in some of the most populous mid-montane valleys and in dry zones susceptible to dry-season annual burning. Pollen core studies indicate extensive grasslands in the uplands dating back several thousand years. But it is possible that today's areas of high population density, such as the Baliem and Wahgi valleys, are relatively recent population phenomena, resulting from the late introduction of the Sweet Potato, by some accounts not arriving in New Guinea until the 17th century.

The important point is that while the traditional Melanesian occupants of New Guinea did, indeed, cause environmental impacts on the island, they were minor when compared

An open-pit mining operation in Papua New Guinea. Mining is an important source of foreign exchange income for both Papua New Guinea and Indonesian New Guinea. Photo: Bruce Beehler

to what has happened since Westerners set foot on the island. Only then did the manifold changes begin: establishment of cities, mining, road building, commercial fisheries, industrial logging, plantation agriculture, and plantation forestry.

WESTERN DEVELOPMENT

Spanish explorer Yñigo Ortiz de Retez first landed on the New Guinea mainland near Sarmi (WNG) in 1545. The first European fort was constructed at Triton Bay in the Bird's Neck region of western New Guinea in 1828 by the Dutch. Dorey (now Manokwari), on the eastern side of the Bird's Head, was the first regularly used harbor for Western traders. It was followed by Sorong and Port Moresby. Early explorers were hoping to find gold. They did not. The products of greatest value in this corner of the world in the late 17th century were spices from the Spice Islands, just to the western of New Guinea, in the Moluccas. New Guinea itself had some trade goods of interest—massoi bark, some nutmeg, as well as trepang (dried sea cucumber), and, of course, plumes of birds of paradise. These plumes first made their way to the courts of Europe and created a sensation. Crocodile skins were also valuable for trade, and these were harvested along the larger waterways.

New Guinea was slow to be developed for three reasons: the indigenous populace was not welcoming; the island was distant from European markets; and colonial explorers found little of trade value along New Guinea's coastlines. So even though New Guinea had been partitioned among the Dutch, English, and Germans by 1884, relatively little transpired here in the following few decades. Hence the natural environment changed relatively little.

The first serious economic development on New Guinea came in the form of colonial copra (Coconut Palm) plantations established in coastal lowlands and commercial trade of plumes of birds of paradise. This was followed by development of rubber, teak, coffee, and tea plantations, the last two mainly in the 20th century. The economic results during the colonial period, whether Dutch, German, British, or Australian, were not very substantial. In fact, the economic development of New Guinea really did not begin in earnest until the 1950s and 1960s—and mainly by the Australians in the eastern half of the island. The Dutch, colonial masters over the western half, moved slowly on economic development, and by the early 1960s had been displaced by the young Indonesian state. Believe it or not, on both sides of the island, there were still uncontacted indigenous societies living their lives without knowledge of the outside world in the 1960s. But even these groups had imports—tobacco, iron axes, and marine ornamental shells, traded from the ouside world.

MODERN ECONOMIC DEVELOPMENT

Today timber, monoculture plantations, minerals, and petroleum products are the major focuses of the industrial economy. Offshore is an important pelagic fishery, and there is opportunity for seafloor mining of valuable ores once the technology is established. Tourism and green enterprises remain minor contributors to the economy, in spite of their recognized potential.

Timber Extraction Small-scale industrial logging operations began in the latter half of the 20th century. These mainly serviced local building needs in the towns of eastern and western New Guinea. Given Indonesia's forest wealth in Java, Sumatra, and Borneo, WNG was not looked on as an important timber resource, because of its isolation and the difficulty of operation. On the island's eastern side, Australian colonial administrations initiated a range of experimental forestry operations in order to determine how best to extract value from ENG's forests. At that time, commercial operations harvested the giant araucaria trees of the Bulolo Valley. Industrial logging has expanded a great deal since Papua New Guinea's independence in 1975, focusing on the lowland forests of the northwest, southwest, and south-central sectors. Because most logging in New Guinea has been selective, the logged forests are left standing to regenerate over time. The big questions are, how quickly and well will these selectively harvested forests recover their ecological function, and to what extent are the endemic species threatened by this timbering activity?

Today, timber is harvested on an industrial scale mainly by Asian-owned companies exporting unprocessed logs to China and other East Asian consumer nations. New Guinea has been a prime target of Asian predatory logging companies since the 1990s, as part of a global push to co-opt much of the world's remaining primary forest and lock it away in large-scale concessions. In spite of their protestations to the contrary, these companies have not carried out environmentally sustainable logging, although their yield apparently has been highly lucrative to the secretive Asian timber barons who own the operations. Their machinations involve large-scale underreporting of export quantities, transfer pricing (in which the seller purposely undervalues reported log sales to an offshore counterpart company that actually owns the onshore logging company), and their operations certainly do not benefit local communities in any substantial way. These logging regimes do much damage to residual stands of trees below harvestable size. Much of the logging is done in areas where negative social impacts on the rural resource-owning communities can be substantial. In general, New Guinea's commercially logged forests have received little or no environmental management, and the logging operations are carried out with no consideration for their impacts on biodiversity and employ methods that cause considerable ecosystem degradation.

An oil palm plantation in Manokwari Regency, WNG. Oil palm is a major threat to lowland alluvial forest in New Guinea. Creating a plantation requires removing the entirety of the lowland rainforest and its rich biodiversity.

The idea of trying to harvest timber on a more sustainable, smaller scale has been tested locally in ENG, especially through the use of portable ("walkabout") sawmills that local communities can easily move to the standing timber, but the competitiveness of this approach has yet to be proven, and it has been unable to serve as a credible alternative to the Asian model. With regard to industrial logging, perhaps the saving grace for New Guinea is its rugged and mountainous nature, the lack of dominant timber species, and the absence of a major road network. Many areas cannot be profitably logged using current practices and thus are not under logging threat today.

Plantation Forestry Currently, there is relatively little large-scale monoculture plantation forestry in New Guinea, though there are plans for expansion in southeastern WNG. In the 1960s, the Australian government planted experimental plantations of *Pinus caribaea*, *Araucaria cunninghamii*, *Araucaria hunsteinii*, and Teak. More recently, plantations of the fast-growing *Acacia mangium* have been planted in PNG's Madang Province and in southeastern WNG. These are still early days for plantation forestry on the island of New Guinea. The hope is that long-rotation selective extraction of original forest will be the model of choice, as this is better for the environment than monoculture forestry.

Dr. Lisa Dabek confers with a village elder about coffee production in a village in the YUS ecosystem of the Huon (ENG). Dr. Dabek's Tree Kangaroo Conservation Program, based in Lae, supports agricultural projects in the YUS ecosystem as a benefit in exchange for the communities' active management of the YUS Conservation Area. Photo: Bruce Beehler

Plantation Agriculture Coastal copra (Coconut Palm) plantations were put in place during the colonial decades. Some continue to operate, but their economic potential appears limited. In addition, rubber monoculture has been established in various places in New Guinea. But those operations are dwarfed by the extent of Oil Palm cultivation across the lowlands of the island. Oil Palm is the big ticket in terms of long-term conversion of forests to managed estate lands for profit. The good news is that most of New Guinea is not suitable for Oil Palm because of topographic relief. Thus the palm plantations are confined to extensive lowland alluvial flatlands, mostly associated with rich soils and low relief. These can be found around Popondetta (SE Peninsula), in the Sepik, south of Jayapura, and in southeastern WNG.

The bad news is that development of an Oil Palm plantation requires the wholesale destruction of large stands of old-growth lowland rainforest—New Guinea's richest and most diverse terrestrial environment. To prepare an area for Oil Palm, every plant and animal is removed from the land, everything is burned, and then the soil is tilled. Nothing survives. So Oil Palm is substantially more destructive than industrial logging, which is selective and which allows the forest to recover and regenerate. Moreover, these palm monocultures are biodiversity deserts. The wholesale conversion of broad expanses of old-growth forestland to Oil Palm in Malaysia has been a tragedy. This should not be repeated across the landscape in New Guinea, particularly on peatland soils.

Oil Palm also perpetuates a range of negative social and cultural impacts, and is highly inappropriate for sustainable development in any forested area on the island. The quantity and kind of labor needed to create and maintain Oil Palm estates cause serious social dislocation, especially among traditional, conservative Melanesian societies that maintain tenure over their forestlands. Smallholder Oil Palm farming has been introduced in some parts of ENG, but this too has its social and economic pitfalls. In ENG, the Roundtable for Sustainable Palm Oil attempts to mitigate the social and environmental ills, though with uncertain results.

Coffee and cacao offer much greater potential for village and smallholder operations, especially when crops are farm-direct and when market access is feasible. These offer low-impact plantations that are integrated within a forested landscape and that follow fully organic practices (but which are not certified, because of cost). The main issues for isolated growers are processing that meets international standards and getting the crop to market in a timely and cost-effective manner. Tea is grown mainly in the Western Highlands Province of PNG but at a relatively small scale. It serves primarily a local market. Vanilla orchid is being planted in some parts of PNG.

Minerals and Petroleum New Guinea has large stocks of valuable oil, gas, and minerals, but their extraction has caused environmental problems, especially in fragile wetlands and across large forested catchment areas. The first gold rush took place in 1877 along the Laloki River just outside of Port Moresby. It fizzled. The first successful gold strike came on Tagula (at that time called Sudest) Island in 1888. In 1896 there was a strike in the Mambare catchment (now Oro Province, PNG), and in 1909 another in the Lakekamu basin (now Gulf Province, PNG). This last strike led to the discovery of one of the major gold deposits in the Wau-Bulolo region, when Arthur Darling shared information with Shark Eye Park, who in 1921 made his discovery in the Koranga Creek of the lower Wau valley. This ore body is still being tapped today, by both a large-scale industrial operation (Hidden Valley) and local resident miners working river sediments of the Bulolo and Watut Rivers (Morobe Province, PNG).

Most New Guinea gold sits atop the central cordillera, including the high-mountain source of the Wau and Lakekamu lode, and is the product of major mountain-building processes. The four largest ore bodies yet discovered are the Ertsberg and Grasberg lodes, developed by the Freeport operation near the glaciers of the far west, the Ok Tedi mine in the western borderlands of ENG, and the Porgera lode, in Enga Province of west-central PNG. These huge mines produce quantities of gold, silver, and copper. In addition, a Chinese company is operating a nickel mine in the Finisterre Range of north-central ENG, with a major tailings collapse in 2019. Other smaller mining operations are scattered widely across the island.

Oil and gas have long been extracted from sites near Salawati Island and the western Bird's Head of the far west, and another large natural-gas operation is BP's Tangguh operation in Bintuni Bay of the Bird's Neck. These appear associated with successor basins that overlap terrane boundaries. Large-scale operations in the Kikori River floodplain and Lake Kutubu (Gulf Province, PNG) produce petroleum and natural gas that are being piped to coastal terminals (Chevron, ExxonMobil). The natural gas, after being chilled, is exported from New Guinea via ship as liquid natural gas.

Fisheries Both Papua New Guinea and Indonesia support large stocks of valuable marine fish species, especially migratory tuna. PNG is a signatory to the South Pacific Tuna Treaty of 1988, which is currently under renegotiation. The main challenges to protecting fish stocks relate to regulating sustainable harvest by legal fishing vessels, and patrol of the seas to prevent unlicensed foreign long-line and purse-seine boats from illegally harvesting within the exclusive economic zones of the two nations. A major cannery in the Aru Islands has been accused of unsafe and predatory employment practices.

Subsistence Agriculture Land clearance for subsistence gardening is sometimes considered to be the main cause of forest loss in New Guinea, a claim that is often made in defense of commercial logging. Recent estimates indicate that several hundred thousand acres are cleared annually for gardens, but it is likely that a large portion of such clearing is of secondary forest that has regenerated from earlier gardening episodes. In areas of relatively low human population density, as in much of New Guinea, such swidden agriculture seems to be environmentally sustainable. These small plots regenerate quickly back to natural forest and can be exploited once again after a few decades of fallow. Serious deforestation from subsistence agriculture happens mainly in the densely populated upland valleys of interior WNG and ENG. In these areas, forest is indeed disappearing, converted to grasslands. So indeed deforestation is now occurring through subsistence activities where the population densities are high.

Road Building New Guinea, both east and west, has the least-developed road network on Earth. Because of the extreme rainfall, regular seismic activity, land slippage, harsh physiography, and the small populations to be served, it simply is too expensive for national or provincial governments to construct regional road networks. That said, Indonesia has grand plans for roads traversing WNG, whereas PNG promises few if any new regional road links, except when funded by outside sources, such as enterprises from Asia or external donor governments. The lack of roads creates serious hurdles for economic development and natural resource development. In most instances, large international resource companies are forced to construct access roads in order to make their field projects feasible. Time will tell whether Indonesia's grand plans for western New Guinea materialize. The suspicion is that harsh environmental conditions and deep river gorges will make the development of a comprehensive road network a slow process in WNG.

Deep-Sea Minerals Deep-sea mining of massive sulfide deposits on the seafloor of the mid-ocean ridge in the Bismarck Sea has been under discussion in ENG for more than a decade. Plans for extracting mineral deposits from a back-arc basin in water depths of

Villagers drying tiny fish in WNG. Fishing is an important pastime for every coastal village in the New Guinean region.

Dried coffee beans packed in sacks in the YUS uplands of the Huon Peninsula, ENG, are ready for air freighting to Lae for international export. Arabica coffee from PNG is appreciated in Australia, Europe, and the United States. Photo courtesy of the Tree Kangaroo Conservation Program and Woodland Park Zoo

1,800 meters have proven controversial, mainly because of pollution concerns. The area under consideration is a vital ecosystem for a number of cetaceans and other important marine species. The economic sustainability of such an operation remains unproven. Coastal communities that look out over the Bismarck Sea have opposed the operation, fearing pollution of their nearshore waters.

THREATS

In the following sections, succinct descriptions of the various threats to New Guinea's natural wealth are explored.

Logging and Forest Loss It was not until the end of the 20th century that substantial forest loss began to be detected across the island of New Guinea. Existing enclaves of non-forest habitat had been generated over the centuries by the agricultural and burning activities of indigenous populations in WNG (the Baliem, the Asmat, the Arfak Mountains, near Jayapura) and in ENG (the Sepik, the Wahgi valley, the Wau-Bulolo valley, the Snake River valley, the Markham valley, the Port Moresby environs, the Safia-Pongani Gap). As mentioned above, this process appears to be accelerating along with local growth in population in the interior upland valleys.

Expansion of large-scale industrial logging took place in ENG in the early 1990s and blossomed in WNG in the chaos that followed the Asian financial crisis of 1997. The operations in WNG have never equaled those in ENG, where political and regulatory conditions permitted widespread development of logging operations in the richest expanses of lowland

and hill forest that were readily accessible for log-export operations. Millions of hectares of old-growth forest were logged in ENG. Most depleted concessions have been allowed to naturally regenerate, with neither follow-up silviculture nor forest conversion activities. Overall, the logging does not appear to lead directly to deforestation, but what does the future hold for these logged-over areas? Do these degraded lands serve as productive forest reserves for endemic and threatened species of wildlife?

Fire and ENSO Fire has also been identified as a potential threat to New Guinea, especially in the wake of the forest fires that raged across the island during the great El Niño droughts of 1997–98 and 2014–15. That said, fires are a part of the El Niño–Southern Oscillation drought cycle, and have periodically burned large areas of New Guinea in the past, aided by the fire-loving tendencies of the local populace. Certain fire impacts need to be closely monitored, especially in association with industrial logging and habitat conversion, but at the moment fire is only a minor threat to biodiversity in New Guinea, except perhaps in the environmentally sensitive high-alpine habitats, which appear to suffer during severe ENSO events.

Live Wildlife Trade The illegal trade of living wildlife has been an important part of the black market in WNG for decades, with known association with the military. The main focus of the trade is parrots (especially lories and cockatoos), but it also includes other wildlife (e.g., birds of paradise) and plants such as orchids. Recently field investigations indicate the bird trade, in particular, is massive. It is unclear how serious the impact is upon the target populations, but it is certainly worthy of scrutiny. It also appears to be on the increase in ENG and thus should be closely monitored there.

Exotic Invasive Species The island of New Guinea is home to millions of endemic species—plants and animals that live nowhere else on Earth. The island is also now a new home for thousands of exotic species of plants and animals—transported to the island either purposely or inadvertently. Exotic species are now a fact of life around the world, even in the most isolated places, because of the peregrinations of modern humankind. Seeds are brought in unwittingly lodged in dirt on the bottom of someone's boots. Marine invertebrates are introduced through the dumping of a ship's bilgewater. Plant fanciers bring in seedlings to plant in gardens. Aquaculturists bring in exotic fish for the aquarium, and these are thrown into a nearby stream when the family moves. Trout have been deliberately introduced to some mountain streams.

New Guinea is vulnerable to invasive exotic species. Witness the devastation wrought by exotic species in Australia, New Zealand, Guam, and Hawaii. Today, New Guinea is home to a wide range of exotic plants, as well as a few vertebrates about which we should be concerned. The invasion of lower sectors of the Sepik River by the Giant Salvinia waterweed has been prodigious, causing all sorts of problems for local communities and transportation. Invading vertebrates include the Common Myna, House Sparrow, Eurasian Tree Sparrow, Rusa Deer, and Crab-eating Macaque. Rusa are creating problems in SE WNG. The macaque is perhaps the greatest source for concern. This highly adaptable, widespread primate species has a large natural range across mainland Southeast Asia, the Philippines, and Indonesia as far east as Halmahera. It has also been introduced to a number of places, notably Mauritius, where it has had a devastating impact on native bird populations. A small but persistent population of the macaque currently inhabits an area of northeastern WNG near the border with ENG. Although this population seems to be small at this time, it could cause serious damage to native vertebrate populations if it spreads, especially since many of these natives have evolved in environments with very few opportunistic and adaptable predators like this primate. It is imperative that authorities address the macaque issue before it gets out of control. Lastly, certain invasive plants (e.g., *Piper aduncum*, an exotic shrub) are posing threats to subsistence agriculture in interior upland areas.

Climate Change The warming of Earth's climate threatens islands, local coastal zones, sensitive habitats, coral reefs, and agricultural systems, among other environments. The rapid melting of New Guinea's glaciers makes clear that the local climate is warming.

Victor Eki, project officer of the Tree Kangaroo Conservation Program, using a GPS to map boundaries of conservation lands in the YUS Conservation Area (Huon Peninsula, ENG). Photo courtesy of the Tree Kangaroo Conservation Program and Woodland Park Zoo

The nature of future impacts is difficult to anticipate but could be extensive. The phenomenon encompasses much more than melting ice. Growing impacts today are most obvious to subsistence farmers, who report changes in seasons and growing conditions. Coconut Palms in the 1950s were found only in the hot lowlands but now are being planted in villages at 1,200 meters elevation and higher. Rainfall seasons are now reported to be much less predictable, with heavy rains in the dry season and periodic droughts in the rainy season. Seasonality is breaking down, and the harvest of coffee and garden crops is becoming more aseasonal. Modeling of future climatic conditions for New Guinea predicts three major changes: (1) increased annual rainfall in the wetter areas, (2) annual temperatures exceeding those maxima now known in the interior basins, (3) greater seasonal extremes in certain areas, and (4) more frequent and extreme ENSO events. It is not clear how these changes are impacting the natural environment and wildlife, aside from the obvious upslope retreat of many species. This century will undoubtedly be a time of great change, and although some plant and animal species will benefit, others will lose, and some may disappear altogether. Habitat for alpine and mountaintop species, in particular, will shrink.

Sea level rise associated with ongoing climate change has disrupted livelihoods in some low-lying island groups. The New Guinean Region supports a number of populated low island groups (in both WNG and ENG) that are now threatened by sea level rise and storm surge. Perhaps the Carteret Islands of eastern ENG is the best-known example, in which some islanders have already been relocated to safer territory. There problems are exacerbated by land subsidence.

Human Population Growth This is a major underlying threat that looms on the horizon. With low population, subsistence agriculture and local forest and coastal resource extraction is sustainable. With higher population density, sustainability disappears. The demographics of population growth may determine the level of impact. If rural youth abandons the village for the city, urban intensification will absorb the impacts, and backcountry ecosystems may survive. On the other hand, secondary effects, such as loss of traditions and abandonment of subsistence systems, may pave the way to large-scale habitat conversion by foreign economic interests.

The human population on the island of New Guinea is growing rapidly. In most rural areas, population growth leads to permanent deforestation. Forests near any population center disappear as demand for new gardens and fuel wood rise. Most readers probably would guess that industrial logging is the main cause of deforestation in New Guinea, but this is not so—it is agricultural expansion in association with population growth. More family planning programs are needed to ensure rural communities do not outgrow their resource base. As we have seen in dry regions of Africa, such resource loss leads to a downward cycle of poverty. Communities with rich natural resources are well off because of the many noncash benefits provided by nature—clean drinking water, rich agricultural soils, abundant wood and fiber for building and fuel, and rich assemblages of species for game and spiritual well-being.

Changes to Customary Land Tenure Across New Guinea, rural forest-dwelling people claim their traditional lands as their own. This claim is recognized and affirmed in ENG, but the situation in WNG is not nearly so clear. On both sides of the island, developers seek to gain permanent access to these traditional forestlands for plantations and industrial-scale extractive enterprises. This sets up court battles between traditional landowners and powerful outside interests seeking to "open up" these "underdeveloped" areas. Indigenous ownership of forestlands in New Guinea has ensured the existence of millions of acres of old-growth forests across New Guinea. These forests are immensely valuable as they are (their "existence value"). Conservation of these forests in partnership with the local landowners should be a priority for national and provincial governments. The recent scandal in PNG over the development of "special agricultural business leases" (SABLs) shows that powerful illicit forces are seeking to grab land from traditional landowners. Similar activities are occurring in WNG. These usually have the tacit support of elements within the government.

Urbanization There are few urbanized areas on the island of New Guinea—Port Moresby, Lae, Jayapura, Abepura, Manokwari, Timika, Sorong, and Biak town (all small by global standards). There is much greater opportunity for serious urban development in WNG because of the eastward movement of migrants from populous western Indonesia. These migrants mainly or exclusively settle in urban centers, where there are employment opportunities.

The question is to what extent these growing urban centers begin to draw migrants from the rural hinterlands, leading to depopulation of the interior forested regions of New Guinea. This has happened in many parts of the tropical world and may indeed happen here. This tends to be a double-edged sword with respect to the future of the forest environment of the interior. Whereas a smaller interior population will place less direct pressure on the forest and its wildlife, the migration of rural forest dwellers to the cities can lead to loss of on-site advocates for the forest, putting the "abandoned" forests at risk.

THREATENED SPECIES

Although New Guinea hosts a fair share of rare species, most of these are naturally rare, and human-caused threats are exceptional. Thus far no species in the region is known to have become extinct historically. Perhaps the most critically threatened species are five mammalian game species—three species of long-beaked echidna, the Golden-mantled Tree Kangaroo, and Mrs. Scott's Tree Kangaroo (Tenkile)—all of which are hunted with dogs. Other mammals listed as critically endangered include the Telefomin Cuscus, Black-spotted Cuscus, Northern Glider, Black Dorcopsis, New Guinea Big-eared Bat, Lowland Brush-Mouse, and Eastern Shrew-Mouse. No bird species in the New Guinean Region is known to be critically endangered. Species with the most geographically restricted ranges include the Queen Alexandra's Birdwing of the SE Peninsula, the Fire-maned Bowerbird of the Adelbert Mountains of ENG, and the Waigeo Brushturkey from the uplands of Waigeo Island (NW Islands).

NATURE- AND CULTURE-BASED TOURISM

Most international tourists to New Guinea come to experience the wildlife and the traditional cultures. Because of the expense of traveling to New Guinea, this remains a niche operation, with small numbers annually. The largest activity relates to hiking the wartime Kokoda Track in the SE Peninsula of PNG, which may reach 5,000 hikers per annum.

Packaged bird-watching and high-end cultural tours bring small groups to locations in both ENG and WNG. Most tourists originate in Australia, the United States, and western Europe. Favorite locations in ENG include the Tari and Mount Hagen valleys of PNG, the Sepik River (by boat), the Fly River (various remote lodges), and the Sogeri Plateau above

A rough jeep road in high mountains of the Western Ranges. The Indonesian government has an ambitious plan for road building in both provinces of WNG.

Port Moresby. Favorite locations in WNG include the Baliem valley of the Western Ranges and the Arfak Mountains of the Bird's Head.

Reef diving is popular, often via a live-on dive boat. Target areas include the Raja Ampat Islands and Geelvink (Cenderawasih) Bay of WNG, and the Milne Bay Islands and islands off Madang (ENG).

Most tourism has been developed by outside interests and provide only marginal benefits to local communities. There has been some development of locally-led tourism opportunities, and this should be fostered by national and provincial governments in both ENG and WNG. This includes traditional home-stays, local birding lodges, and traditional cultural experiences. Maintaining the long-term sustainability of these operations is a challenge because of funding constraints, management issues, and transportation problems.

The two substantial barriers to increasing tourism revenues are local crime in PNG and political instability in WNG.

There is great potential to expand and improve tourism to the New Guinea region, but it will require substantial financial investment in tourism support activities, more and better training of local operators and guides, and improved and more reliable in-country transportation. It is expected that, decade by decade, the international market for tourism to New Guinea will grow. Eventually, tourism will replace resource extraction as the leading source of foreign exchange in both Indonesia and Papua New Guinea. Both governments should recognize this today and restrain the environmental and cultural damage being wrought by unconstrained resource-extractive activities, to make sure there is a beautiful and traditional New Guinea for tourists to see and appreciate in decades to come.

NATURE CONSERVATION

Habitat conservation on the island of New Guinea is a tale of two very different government systems. In Indonesian New Guinea, the nature conservation mandate has focused on the top-down creation (mainly on paper) of a network of large national protected areas, driven by agencies in Jakarta. In Papua New Guinea, the realities of local land tenure have made the creation of national protected areas difficult, and the story is more one of community-based habitat conservation at a smaller scale. With regard to species conservation, both Papua New Guinea and Papua have followed a CITES-mandated legislative approach, banning the export of protected species but permitting their harvest at the local level for traditional use.

PNG poses many challenges to Western-style conservation by resisting establishment of national parks and reserves. Since nearly all land is still in the hands of the traditional landowners and not held by the state, establishment of national protected areas has been deemed incompatible with local land tenure. A diversity of national, provincial, and local protected areas totals slightly over 2 million hectares, operating with varying degrees of success under various different national and provincial laws. Most are poorly managed or not managed at all, and in most cases the protection afforded does not prevent extractive or economic development taking place within their boundaries. The national government lacks the political will to establish a representative network of substantial conservation areas to protect the richest and most unusual forests and coral reef ecosystems. There is a new national protected areas policy, which has not yet been implemented. There are an abundance of laws as well as a national environmental agency (Conservation and Environment Protection Authority—CEPA), but the most effective on-the-ground conservation takes cooperation among local communities and national and international nongovernmental organizations. The establishment of the YUS Conservation Area, protecting a large expanse of montane forest on behalf of the endangered Huon Tree Kangaroo, is perhaps the best example of working nature conservation in PNG. It is recognized by CEPA and the Global Environment Facility as a model for field conservation in PNG and is being expanded to encompass an entire local landscape.

The YUS program established the country's first nationally protected conservation area in 2009 (classified by the IUCN as a category VI protected area) and is the only protected area of its type in PNG—providing protection at the landscape scale, wholly owned by local people, and with the support of the PNG government for long-term protection. Providing the highest level of land protection in ENG, the YUS Conservation Area extends from the coast of the Bismarck Sea to 4,000-meter-high peaks in the Saruwaged Range, preserving a complete elevational spectrum of natural habitats free from resource extraction.

Under PNG's customary land tenure system, in which local people own all rural forestlands, long-term habitat protection relies on the committed participation of the local communities that depend on the forest's products and services. To ensure the long-term sustainability and local management of the YUS Conservation Area, a local nongovernmental organization (NGO), the Tree Kangaroo Conservation Program (TKCP), based in Lae, was established to implement the program. Together with local landowners and communities, TKCP partners with PNG government agencies, conservation organizations, universities, research institutions, and other NGOs to build local capacity for the sustainable management of the YUS Conservation Area and the surrounding landscape. In partnership with Conservation International and the Woodland Park Zoo, TKCP also established a $2 million trust fund to support the management of the YUS Conservation Area in perpetuity. Through

Bird-watching in WNG—a group of birders watching the display of a bird of paradise high in a tree in the Arfak Mountains. In the foreground is Aren Mandacan, who has transformed his village economy by protecting forests for birds and building guesthouses for visiting birders.

these partnerships, local residents build a strong connection between their commitment to conservation in YUS with improved livelihoods for their families and communities.

TKCP's community-based strategy improves the standard of living for the more than 12,000 people in 50 villages throughout the YUS area. Indigenous landowners and community members participate in TKCP's work, including patrolling, scientific research, land mapping, education, health, sustainable livelihoods, and conservation outreach activities.

Indonesia has established a nationally mandated network of reserves, sanctuaries, and parks across WNG, both of forest and reef ecosystems. At this time there are more than 60 national marine and terrestrial reserves, covering more than 12 million hectares of the forests and nearshore waters of WNG. This includes the 2.5-million-hectare Lorentz National Park, the largest protected area on New Guinea. On paper, this is an impressive achievement. It and other large parks are depicted on many maps of WNG. Unfortunately, many of these "protected" areas have not received full legal authorization. Moreover, the indigenous inhabitants of these areas in many instances have not been informed that they

Bird tour leader Shita Prativi discusses birds with a villager and his family. Birding tourism can be an important source of income for villagers who offer guiding and lodging services.

are now living within the confines of a national protected area, nor have management plans been completed, approved, or implemented. What is the future of these nationally mandated reserves under a regime of decentralization and local decision-making in Indonesia? The good news is that there appears to have been minimal extractive development within these protected areas, although the boundaries of Lorentz National Park were redrawn to accommodate the expanding mandate of the great Freeport mine.

New Guinea has undergone considerable conservation planning and biodiversity priority setting over the past two decades. There is an abundance of authoritative analysis of what resources are worth conserving in both WNG and ENG. Conservation planning is relatively inexpensive and international experts are happy to volunteer to draw polygons on a map, showing their preference for where parks and preserves are needed. Now it is a matter of generating the political will to negotiate the conservation of the areas that have the highest merit. This must be done before the trees are removed or the fish and reefs decimated. This must be followed by decades of good management and protection—a tall order, indeed.

SUSTAINABLE DEVELOPMENT

In ENG we see conflict between local landowners and national or external interests pushing ambitious extractive economic development. Sometimes the local landowners win, and at other times the national interests win. Large-scale resource development in ENG never happens without a fight.

In WNG, national and provincial authorities have substantial power to develop the forest and waters that are claimed by indigenous resource owners living in the rural hinterlands. The rural inhabitants of WNG do not have constitutionally mandated ownership over the natural resources they have long depended upon. How can they gain their proper voice in these resource-focused conflicts?

In both ENG and WNG, the solution to balancing nature conservation with economic development is good and transparent *planning* that involves all the various stakeholders. In most instances around the world, this sort of large-scale planning is driven solely by economic development needs. In fact, the proper planning must give equal voice to nature conservation needs as well as economic needs, and these must be examined together, as two sides of the same coin. Both are of economic importance to the resource in question. The sin of Indonesia has been its conservation planning for WNG carried out in faraway Jakarta. WNG's network of protected areas needs to be ratified and reformed through a transparent national-plus-provincial process that involves the appropriate local stakeholders.

The sin of PNG has been the failure of either the national government or provincial governments to carry out formal resource-use planning as a way of defining future conservation action balanced against smart and well-located economic development. Sustainable development must balance the desires of the majority with the needs of the minority, as well as balancing long-term versus short-term economic well-being. As each decade passes, the existence value of the forests and reefs of New Guinea will grow. Non-extractive uses of the lands and waters will become ever more valuable. Smart development includes conservation offsets. Will the leadership of these two lands, one in Asia, the other in the Pacific, have the wisdom to balance development with preservation? ■

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Preceding pages: A male King Bird of Paradise perches on a vine in his courtship territory in the lowland forests of the Vogelkop Peninsula, WNG. Males pair up in the forest, maintaining song posts that average 70 meters apart—in vocal but not visual contact. His two central tail feathers have been modified into thin wires with disk-like whorls at the end.

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Following page: Ornithologist Edwin Scholes searches for display sites of the Splendid Astrapia on a misty morning in upper montane forest around Lake Habbema with the rocky heights of Puncak Trikora in the background.

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A Blyth's Hornbill (*Rhyticeros plicatus*) interrupts displaying Red Birds of Paradise in their lek on Waigeo Island, Raja Ampat Islands, WNG.

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Author and Principal Photographer's Biographies

The Author

BRUCE BEEHLER is an ornithologist and research associate in the Bird Division of the Smithsonian Institution's National Museum of Natural History. He completed his undergraduate studies in American civilization at Williams College and received his master's and PhD degrees in biology from Princeton University, where he studied the behavioral ecology of four species of birds of paradise. Afterward, Beehler worked for a decade at the Smithsonian's National Museum of Natural History. Before returning to the museum in 2014, Bruce worked for Conservation International, the Wildlife Conservation Society, the US Department of State, Counterpart International, and the National Fish and Wildlife Foundation. Beehler is a Fellow of the American Ornithological Society and is the author of 12 books, including both a field guide to and a taxonomic checklist of the birds of New Guinea and the recently released books *North on the Wing* (Smithsonian Books) and *Encounters with Nature* (Yale University Press).

Beehler's research career has focused mainly on the interactions between birds and forests. His doctoral work highlighted the specialized fruit-eating habits of the birds of paradise and their impact on seed dispersal and the regeneration of rainforests. This was followed by two decades of work documenting the biodiversity of the great island of New Guinea. In all, Beehler traveled to New Guinea more than 50 times, and conducted 30 field expeditions on the island. When he was not doing research, his time was occupied with fostering conservation of rainforests and coral reefs in the Southwest Pacific. Today, Beehler has turned his focus to the natural history of North America and is particularly interested in the boreal forests of the Great North Woods and the continent's great migratory systems.

Principal Photographer

TIM LAMAN is a field biologist, wildlife photojournalist, and filmmaker. He received his PhD from Harvard University for his pioneering research in the rainforest canopy in Borneo, and the Asia-Pacific region has been a primary focus of his research and photographic work ever since. His photography credits include 23 feature stories in *National Geographic* magazine and wildlife cinematography credits with the National Geographic Channel, BBC, and Netflix, and he has been director and producer of award-winning short films. Other awards include Wildlife Photographer of the Year 2016 and a World Press Photo award.

Tim is the cofounder of the Birds-of-Paradise Project with Edwin Scholes at the Cornell Lab of Ornithology, and has made over 25 expeditions to the New Guinea region documenting this extraordinary group of birds and the biodiversity of New Guinea both above and below water. Other long-term projects include collaboration with his wife, Cheryl Knott, documenting research and conservation issues facing orangutans in Borneo. His scientific contributions include over 20 papers on rainforest ecology and birdlife. He is a research associate in ornithology at Harvard, a founding member of the International League of Conservation Photographers, and a fellow of the Explorers Club.

Hand-carved wooden bowl
from ENG filled with various
cone shells collected from
the waters surrounding the
great island.