FRESHWATER BIOTAS OF NEW GUINEA AND NEARBY ISLANDS: ANALYSIS OF ENDEMISM, RICHNESS, AND THREATS

Dan A. Polhemus, Ronald A. Englund, Gerald R. Allen

Final Report Prepared For

Conservation International, Washington, D.C.

November 2004

Contribution No. 2004-004 to the Pacific Biological Survey

Cover pictures, from lower left corner to upper left: 1) *Teinobasis rufithorax*, male, from Tubetube Island 2) Woa River, Rossel Island, Louisiade Archipelago 3) New *Lentipes* species, male, from Goodenough Island, D'Entrecasteaux Islands

This report was funded by the grant "Freshwater Biotas of the Melanesian Region" from Conservation International, Washington, DC to the Bishop Museum with matching support from the Smithsonian Institution, Washington, DC

FRESHWATER BIOTAS OF NEW GUINEA AND NEARBY ISLANDS:
ANALYSIS OF ENDEMISM, RICHNESS, AND THREATS

Prepared by:

Dan A. Polhemus
Dept. of Entomology, MRC 105
Smithsonian Institution
Washington, D.C. 20560, USA

Ronald A. Englund
Pacific Biological Survey
Bishop Museum
Honolulu, Hawai‘i 96817, USA

Gerald R. Allen
1 Dreyer Road, Roleystone
W. Australia 6111, Australia

Final Report Prepared for:
Conservation International
Washington, D.C.

Bishop Museum Technical Report 31

November 2004
Contribution No. 2004–004 to the Pacific Biological Survey

Published by

BISHOP MUSEUM

The State Museum of Natural and Cultural History

1525 Bernice Street

Honolulu, Hawai'i 96817–2704, USA

Printed in the United States of America

ISSN 1085-455X

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Effective conservation of regional biotas requires accurate information on the distribution, endemicity, local richness, and taxonomic composition of species assemblages across multiple geographic scales. This is especially true in the Melanesian region, which contains ten percent of the world's biota on its numerous islands scattered across thousands of kilometers between Fiji and the Moluccas. Although certain important biotic components within this region, such as birds, have been reasonably surveyed, many others, particularly freshwater organisms, remain poorly understood.

To this end, a systematic survey program for freshwater fishes and invertebrates on New Guinea and nearby islands was undertaken over the last 10 years, involving an array of research organizations with long-standing interests in Melanesia, including the Bishop Museum, Smithsonian Institution, the Indonesian science ministry (LIPI), the Papua New Guinea National Museum and Gallery, and Conservation International. This work has also been augmented by partnerships with private sector entities operating in the region, most notably Chevron Niugini and P. T. Freeport Indonesia. These surveys have revealed previously unsuspected levels of species richness and endemism among New Guinea freshwater organisms, and the remarkable number of new species discovered during these surveys has also highlighted the fact that similar knowledge gaps and potentially similar levels of undocumented freshwater biodiversity remain through much of the rest of Melanesia beyond New Guinea.

To the extent that they are now understood, Melanesian freshwater biotas appear to be characterized by foci of high endemicity clustered around tectonic provinces within individual large islands, such as New Guinea, or on geologically allied groups of smaller islands, such as the Louisiades and Solomons. In lotic systems, such as streams and rivers, this endemicity frequently displays a marked turnover in species elements along the length of individual catchments, linked to segregation of individual species by altitude, water temperature, substrate, bed profile and terminal reach salinity gradients. By contrast, lentic systems often harbor suites of localized endemic species centered around individual lakes or wetland complexes. Although known in a broad sense based on scattered collections made during the past 200 years and distributed among major museums, freshwater biotas of islands in the Melanesian region remain for the most part under-surveyed and poorly characterized taxonomically.

Although the overall condition of freshwater ecosystems in the New Guinea region is currently excellent, there are obvious threats to the biota that tend to manifest themselves on local rather than regional scales. These threats may be grouped into three general categories: 1.) physical alteration of habitat; 2.) utilization of biotic resources, and 3.) invasive species. Threats from habitat alteration to freshwater ecosystems include but are not limited to industrial logging, shifting cultivation, oil palm plantations, mining, petroleum development, and hydroelectric schemes. Utilization of biotic resources such as the live aquarium fish trade or the harvest of native fish for food are deemed a much lower threat. While invasive species have not yet caused large-scale perturbations to freshwater systems they are a looming threat that is becoming increasingly problematic.

INTRODUCTION

Effective conservation of regional biotas requires accurate information on the distribution, endemicity, local richness, and taxonomic composition of species assemblages across multiple geographic scales. This is especially true in the Melanesian region, which contains ten percent of the world's biota on its numerous islands scattered across thousands of kilometers between Fiji and the Moluccas. Although certain important biotic components within this region, such as birds, have been reasonably surveyed, many others, particularly freshwater organisms, have remained poorly understood.

To this end, a systematic survey program for freshwater fishes and invertebrates on New Guinea and nearby islands has been undertaken over the last 10 years, involving an array of research organizations with long-standing interests in Melanesia, including the Bishop Museum, Smithsonian Institution, the Indonesian science ministry (LIPI), the Papua New Guinea National Museum and Gallery, and Conservation International. This work has also been augmented by partnerships with private sector entities operating in the region, most notably Chevron Niugini and P. T. Freeport Indonesia. These surveys have revealed previously unsuspected levels of species richness and endemism among New Guinea freshwater organisms, and the remarkable number of new species discovered during these surveys has also highlighted the fact that similar knowledge gaps and potentially similar levels of undocumented freshwater biodiversity remain through much of the rest of Melanesia beyond New Guinea.

To the extent that they are now understood, Melanesian freshwater biotas appear to be characterized by foci of high endemicity clustered around tectonic provinces within individual large islands, such as New Guinea (Polhemus, 1992; Polhemus & Polhemus, 1998), or on geologically allied groups of smaller islands, such as the Louisiades and Solomons. In lotic systems, such as streams and rivers, this endemicity frequently displays a marked turnover in species elements along the length of individual catchments, linked to segregation of individual species by altitude, water temperature, substrate, bed profile and terminal reach salinity gradients (Polhemus, 1992; Polhemus & Polhemus, 1996, 2001). By contrast, lentic systems often harbor suites of localized endemic species centered around individual lakes or wetland complexes (Allen, 1991).

Although known in a broad sense based on scattered collections made during the past 200 years and distributed among major museums, the freshwater biotas of the islands in the Melanesian region have until now been for the most part under-surveyed and poorly characterized taxonomically. For example, recent freshwater surveys in the Louisiade and D'Entrecasteaux island groups of Milne Bay Province revealed previously unsuspected assemblages of endemic sicydiine gobies, damselflies, and water striders, resulting in the discovery of over thirty new freshwater species in a matter of weeks. Similar results will likely be obtained from many of the other remote high islands in the Melanesian region, such as the Solomons, the Bismarcks, and Vanuatu. At the same time, the freshwater biotas on many of the islands in the region are under clear threat, due to alterations of aquatic environments resulting from logging, mining, and rapid human population growth. To address this looming problem, Conservation International provided funding for an initial synthesis of information on freshwater diversity in the New Guinea region, augmented by field surveys in selected areas where knowledge gaps still remained. This report represents a summary of that work, providing guidance and prioritization for freshwater biodiversity conservation efforts.

The current report is divided into two parts, the first dealing with areas of freshwater endemism in the New Guinea region, and the second with an evaluation of threats to the regional freshwater biota. Although this report summarizes our incipient base of knowledge for the freshwater biota of New Guinea and proximate islands, most of the island groups to the east have never been the subject of similarly intensive aquatic surveys. This deficiency can only be addressed by future field surveys in key areas such as the Solomons, the Bismarcks, Vanuatu, Fiji, and New Caledonia. Such a program would build upon the model provided by the current partnership in New Guinea that has resulted in this report, extending a comprehensive freshwater conservation strategy to the remainder of Melanesia.

AREAS OF SPECIES ENDEMISM

Polhemus (1993), in an analysis prepared for the Papua New Guinea Conservation Needs Assessment, defined 29 areas of freshwater endemism within New Guinea and closely adjacent islands, based on the distributions of certain aquatic insect groups, primarily aquatic true bugs (Heteroptera), damselflies (Zygoptera), and whirlygig beetles (Gyrinidae). These hypotheses of regional endemism were further refined for western New Guinea by D. A. Polhemus, G. A. Allen and D. Wowor as part of the Irian Jaya Biodiversity Conservation Priority-Setting Workshop, held in Biak, Indonesia in January 1997. By using detailed vegetation maps that accurately depicted the extent of mangroves and lowland swamp forest, and by integrating additional data from freshwater fishes and crayfishes, the group was able to produce a detailed map of freshwater endemism for Irian Jaya (now Papua Province), with unit boundaries more precisely defined; this map was published in 1998 as an inset on the back of the larger conservation planning map resulting from that workshop. The results of this re-analysis indicated that the 1993 analysis of Polhemus was to a large degree accurate, but that certain units within New Guinea, particularly in the central mountain chain, had been too broadly defined and ought to be subdivided. In addition, as noted above, the precise boundaries of certain units were also modified based on additional faunal and vegetational data.

Since that time, further freshwater faunal surveys in eastern New Guinea and offshore islands, funded in part by Conservation International, have provided a wealth of new data from the Papuan peninsula and the D'Entrecasteaux, Louisiade, and Marshall Bennett island groups. As with western New Guinea, these surveys have generally validated the areas of freshwater faunal endemism proposed by Polhemus (1993), but have also forced refinement of unit boundaries and dictated recognition of certain new areas of endemism such as Rossel, Tagula and Woodlark islands that were not treated in previous analyses due to a lack of information. As a result, the current analysis recognizes 40 areas of freshwater endemism on New Guinea and nearby islands, grouped into 6 broad regions, with many of these endemic areas consisting of single islands or island groups (Table 1). In addition, 12 lacustrine subunits, comprising individual lakes or lake complexes with distinctive endemic biota, are recognized nested within the classification above (Table 2). This analysis differs from the two previous analyses mentioned above in that it omits the Bismarck Archipelago, which will be dealt with subsequently after better freshwater data becomes available from surveys planned during the next several years.

Areas of endemism as treated herein refer to regions within New Guinea that contain assemblages of endemic species that appear on the basis of current knowledge to display similarly circumscribed distributions. These areas of endemism are considered to be equivalent to nested sets, with larger areas often containing smaller distinctive subdivisions within them. These areas of endemism are outlined in Tables 1–3, figured on Maps 1 and 2, and described in the text below. It must be stressed that the areas of endemism defined herein apply to freshwater aquatic organisms only, and may not be congruent with those exhibited by other groups of plants and animals.

The approach of defining areas of endemism on the basis of congruent species distributions was used in a previous report dealing with Sulawesi (Polhemus and Polhemus, 1990). In that study it was found that the single island of Sulawesi could be viewed as at least five separate islands in terms of the distribution of its freshwater biota. The situation in New Guinea is similar but even more complex, and complicated to a degree by the island's large size and complex history of geological assembly, coupled with a continuing absence of faunal survey data from many key regions. As a result it has been difficult to ascertain the definitive contact zones between many of the areas of endemism defined herein, and the boundaries depicted on Map 1 in particular should be viewed as speculative in many cases, and open to further refinement as more detailed distributional data becomes available.

Collecting aquatic biota on Sariba Island, Milne Bay

Paddling to sample stream estuary near Tufi

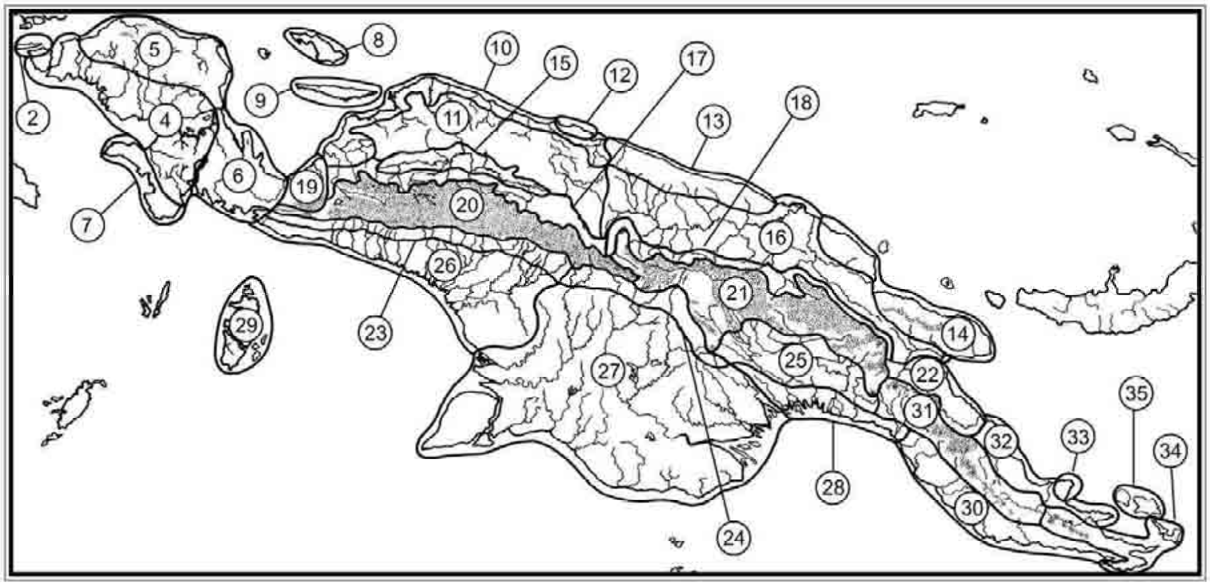

Figure 1. Areas of freshwater endemism on New Guinea and nearby island groups. For explanations of area definitions and numbering see text. Certain areas of endemism on offshore island groups occur beyond the boundaries of this figure and are depicted in Figure 2. Stippling indicates areas above 2,000 m elevation.

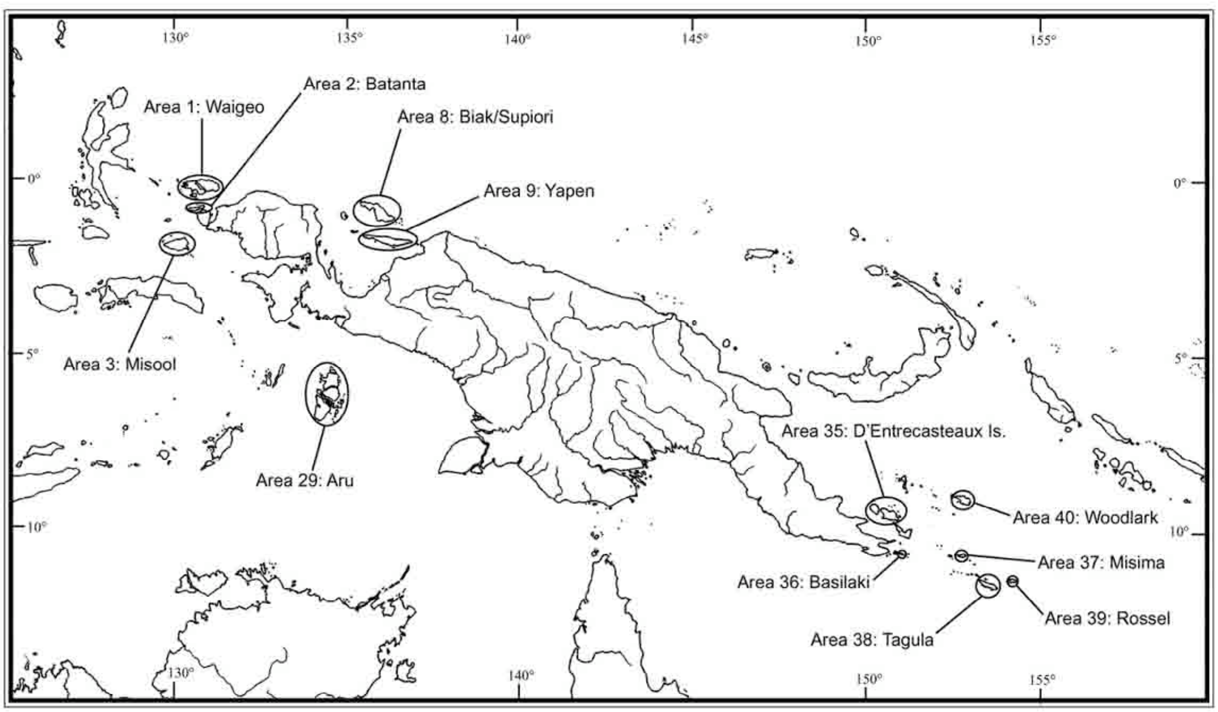

Figure 2. Offshore areas of freshwater endemism in the New Guinea Region.

METHODS

Groups used in defining areas of freshwater biotic endemism in New Guinea

Three major groups of organisms were used to prepare the current report: freshwater fishes, crayfishes, and aquatic insects. All have diverse and regionally distinctive species radiations within New Guinea. Since these groups have all had individual biogeographic histories in the region and have received differing degrees of attention by collectors, the distributions of their constituent species and the areas of endemism they occupy are not strictly congruent. None of the groups utilized in this analysis contain species representatives in all of the areas of endemism defined, while in other cases a single regionally endemic species may occur across several areas of endemism. Even so, the observed patterns of distribution display remarkable similarity throughout the various groups studied, and indicate that the endemic areas they define are likely to pertain for the remaining elements of the island's aquatic biota. Photographs of representative taxa within these groups may be found in the Appendix.

Fishes

Data for freshwater fishes has been derived primarily from Allen (1991, 2003a, 2003b), Allen *et al*. (2000), and from additional unpublished collection records compiled by Allen. Four genera in particular proved to have large numbers of insular species with restricted distributions that were useful in defining areas of endemism: *Melanotaenia*, *Mogurnda*, *Allomogurnda* and *Hephaestus*. These genera were particularly important since they contain species endemic to single lake basins, and therefore define areas of lacustrine endemism not well depicted by crayfish or aquatic insects (see Table 2).

Crayfishes

Data for New Guinea crayfishes were obtained from the publications of Holthuis (1939, 1950, 1956, 1982). The one group of particular interest was the genus *Charax*, which contains a set of 14 species that unambiguously define areas of endemism south of the island's central divide, and contains certain lacustrine endemics, particularly in the Paniai Lakes and Lake Kutubu (Table 2).

Aquatic insects

Although much additional work remains to be done, reliable distributional data is now emerging for certain groups of aquatic insects in New Guinea, including dragonflies and damselflies (order Odonata, suborders Anisoptera and Zygoptera respectively), whirlygig beetles (order Coleoptera, family Gyrinidae) and water bugs (order Heteroptera). Information for Zygoptera was extracted from the publications of Lieftinck (1932, 1933, 1935, 1937, 1938, 1949a, 1949b, 1955a, 1955b, 1956a, 1956b, 1957, 1958, 1959a, 1959b, 1960, 1963), information for Gyrinidae from the works of Brinck (1976, 1981, 1983, 1984), and information for Heteroptera primarily from the works of Andersen (1975, 1989a, 1989b), Lansbury (1966, 1968a, 1972, 1973, 1993, 1996), Polhemus & Polhemus (1985, 1986a, 1986b, 1987, 1993, 1994a, 1994b, 1995, 1996, 1989, 1997, 2000a. 2000b, 2000c), and Todd (1959).

Species ranges were plotted for taxa in many genera within the above groups, searching for patterns of congruent circumscribed distribution. An attempt was made to include genera from as many different families as possible, so as to compare patterns among many lineages with separate evolutionary histories. On the basis of these range plots, areas of endemism were then defined that were at a minimum supported by species in several genera. The species occurring within these areas of endemism are listed in Tables 2 and 3.

Certain areas on New Guinea and nearby islands have not been treated within the context of this analysis due to lack of information; these include Long Island, Karkar Island, the Trobriand Islands, and Numfoor Island.

RESULTS

Areas of freshwater endemism in New Guinea and surrounding islands

Previous workers who have discussed the biogeography of aquatic organisms within New Guinea have identified four large endemic regions: Vogelkop, the North Coast Ranges, the Central Highlands, and the Southern Lowlands (Lieftinck, 1938, 1949; Allen, 1991). These areas generally correspond to the broad scale physiographic divisions within New Guinea as a whole and are relatively self-evident. The present study indicates that these four divisions are indeed valid, but contain many other smaller areas of endemism within them. These smaller areas are depicted in Maps 1 and 2, outlined in Tables 1–3, and discussed in further detail below. The numbers in the following discussion match those assigned to units on Maps 1 and 2; the area names reflect characteristic geographical or geomorphological features found within them.

In the central section of New Guinea there is a clear altitudinal segregation of biota, and this has been accommodated by defining large lowland, foreland, and mountain faunal units. The general elevational ranges for these units are: lowland = 0–50 m; foreland = 50–1200 m; highland = 1200 m upward. Although similar elevational segregation is also frequently seen in many of the smaller units defined herein for the New Guinea north coast ranges and offshore islands, such smaller mapping units have not been altitudinally subdivided for the sake of utility in the context of the current report .

Region 1 - Raja Ampat Islands

Area 1. **Waigeo** - The large island of Waigeo, lying on the Papuan shallow water platform northwest of the Vogelkop, represents an ophiolite exposure and supports endemic taxa in nearly all groups examined.

Area 2. **Batanta** - A small, narrow, but high island separated from Salawati along a narrow strait formed by the submarine trace of the Sorong Fault. It supports endemic taxa in several genera of aquatic Heteroptera. The mountains of northern Salawati island may also be assignable to this unit.

Area 3. **Misool** - The island of Misool lies on the Papuan continental shelf, and is primarily composed of upwardly deformed continental shelf limestones correlative to those of the Fakfak and Kumafa mountains on mainland New Guinea. Endemic taxa occur here in certain groups, while in other cases species are shared with the Vogelkop Lowlands to the east or with the central Moluccas (Ambon, Ceram, Buru) to the west.

Region 2 - Vogelkop and Bomberai Peninsulas

Area 4. **Vogelkop Lowlands** - The southern coastal lowlands of the Vogelkop Peninsula from Salawati Island southeastward to Etna Bay, including the low central portion of the Bomberai Peninsula. This is an area of endemism for Zygoptera and certain aquatic Heteroptera (Hydrometridae, Veliidae). Most of southern Salawati Island also falls within this unit; the Wagon Mountains of extreme northern Salawati appear, on the basis of limited aquatic insect surveys, to be provisionally allied to Batanta (Area 2), but are left unclassified in the current analysis.

Area 5. **Vogelkop Highlands** - This area is defined as including both the Arfak and Tamrau Mountains in the northern half of the Vogelkop Peninsula. The Tamrau Mountains contain a core of Paleozoic basement and represent a detached fragment of the Australian craton. Endemic taxa occur in many groups in this highland area.

Area 6. **Vogelkop Anticlines** - The limestone anticlines of the “Birds Neck” from the Jakati River southeastward to Etna Bay. These anticlines are steeply folded, forming sharp ridges with much karst terrain and poor integration of drainage. Several large and seasonally fluctuating lakes occur in the area behind Kaimana. These uplands form a transitional corridor between the Vogelkop Highlands and the mountains in the main body of New Guinea, and support numerous endemic fish species. The Wandamman Peninsula has also been included in this unit for the present, but this mountainous sliver of Australian craton will likely prove to be yet another discrete area of aquatic endemism once adequate faunal surveys are conducted.

Area 7. **Fakfak and Kumafa Mountains** - These ranges are large limestone anticlines of upwardly deformed continental shelf limestone along the western margin of the Bomberai Peninsula. Both ranges are no older than Pliocene, and represent recently uplifted montane islands that have developed a limited assemblage of endemic aquatic insect species.

Region 3 - North Coast Ranges and Valleys, and associated offshore islands

Area 8. **Biak-Supiori** - This nearly connected island pair lies off the Papuan continental platform, and was not connected to the main body of the island during the Pleistocene. Biak is mostly covered by Quaternary reef limestones, but Supiori, with greater elevation, contains exposures of andesitic island arc volcanics. Sampling for aquatic insects here has been relatively poor, but the presence of endemic species is known among the aquatic Heteroptera in the Gerridae and Notonectidae.

Area 9. **Yapen** - This island is a fault sliver rifted from the Van Rees Mountains on the main body of New Guinea. Its fauna is allied to the northern coastal ranges of Irian Jaya, but supports endemic species of Zygoptera and fishes.

Area 10. **Northwest Papuan Lowlands** - The Korime and Tami River basins at elevations below 400 meters appear on the basis of present sampling to be an area of faunal endemism. Future surveys are likely to reveal that this is an artificial picture created by a preponderance of sampling in the Jayapura area, and that the fauna characteristic of this area is in fact more widespread throughout the northern coastal lowlands of Irian Jaya.

Area 11. **Van Rees and Foja Mountains** - The northern coastal ranges of Irian Jaya, north of the Mamberamo Basin. This area is quite poorly explored and very little collecting of its fishes or aquatic insects has been accomplished, but the few samples at hand indicate that the area supports endemic species in some groups, and is allied to the Bewani, Torricelli and Prince Alexander Mountains further to the east. This unit is bisected by the deep north-to-south gorge of the Mamberamo River, which may warrant its subsequent subdivision into two separate units. The unit as defined here includes the hill country south of Lake Sentani; this is the only part of the unit that has been surveyed to any degree. Certain regional endemics in this latter area are also shared with the Mamberamo Foreland (Area 17).

Area 12. **Cyclops Mountains** - An extremely steep sided mountain range immediately west of Jayapura, representing an accreted ophiolite terrane. Endemic species are known in many groups, including Hemiptera (Gerridae, Naucoridae) and Zygoptera. This is the only area in New Guinea from which Plecoptera have been collected.

Area 13. **Bewani, Torricelli and Prince Alexander Mountains** - The northern coastal mountain block lying between the Papua New Guinea (PNG) border and the mouth of the Sepik River. This is a portion of an accreted island arc, and contains endemic species of Hemiptera in the families Naucoridae and Gerridae. As defined in this report, this unit also contains the Bougainville Mountains of the PNG-Indonesia border region.

Area 14. **Adelbert, Finisterre and Saruwaged Mountains (Huon Peninsula)** - This northern coastal mountain block running from east of the Sepik River delta to the tip of the Huon Peninsula corresponds to the Adelbert-Finisterre Terrane of tectonic geologists, and is considered to be an accreted sector of a formerly separate island that was sutured to New Guinea in the Late Miocene to Pliocene (Hill & Hall, 2003). As a result of their history as a separate landmass, these ranges contain many endemic species of Odonata and Heteroptera.

Area 15. **Mamberamo Basin** - The large structural basin drained by the Rouffer and Idenberg Rivers, which are the upper branches of the Mamberamo. This area is very poorly surveyed for aquatic biota, but is known to support certain endemic fishes and damselflies.

Area 16. **Sepik-Ramu-Markham Basins** - These large structural basins lie behind the north coastal ranges in PNG, and are drained by the Sepik, Ramu and Markham Rivers. The lowland fauna of this region includes endemic trepobatine Gerridae.

Region 4 - Central Mountain Ranges

Area 17. **Mamberamo Foreland** - The northern foothills of the central mountains at elevations between 50 and 1200 meters, from the Wamma River in the west to the Sepik-Mamberamo divide in the east. Many apparently endemic Zygoptera are known from this region due to collections made by the Third Archbold Expedition in 1939.

Area 18. **Sepik-Ramu Foreland** - The northern foothills of the central mountains at elevations between 50 and 1200 meters, from the Sepik-Mamberamo divide in the west to the rim of the Bulolo River basin in the east. This area has been surprisingly poorly surveyed for aquatic biota, but is known to harbor an endemic fish species.

Area 19. **Weyland Mountains** - A small, rugged mountain range lying slightly to the northwest of the western terminus of the central mountain ranges in Indonesian New Guinea, and having a separate geological origin. Limited surveys indicate that the aquatic insect biota of this range is different from that of the geographically proximate central ranges.

Area 20. **West Papuan Central Highlands** - The Central Dividing Range from the Wapoga River basin in the west to the headwaters of the Fly River in the east, at elevations above 1200 meters. The boundary between this unit and the Vogelkop Anticlines has been plotted southward along the Wamma River and then across to Etna Bay. In the northwest the boundary between this unit and the Foja and Van Rees Mountains has been plotted along the upper course of the Owa River, but should be considered extremely uncertain, as this is basically unexplored terrain. This unit contains the highest mountains in New Guinea, and has extensive exposures of karst terrain. The continuous area of extremely high elevation running east to west down the center of the range may represent still another area of freshwater endemism, but present surveys are inadequate to establish this. Numerous scientific expeditions have traversed various parts of this unit, demonstrating marked endemism in Zygoptera and aquatic Heteroptera (Naucoridae, Corixidae, Veliidae).

Area 21. **East Papuan Central Highlands** - The Central Dividing Range between the upper Sepik and Fly rivers in the west and the Bulolo River in the east, containing the headwaters of the Kikori and Purari Rivers at elevations above 1200 meters. This is a complex uplift, with several well separated areas of extremely high terrain centered around peaks such as Mt. Wilhelm and Mt. Giluwe, and contains an extensive exposure of uplifted Paleozoic basement in the Kubor Anticline. Despite its topographic and geological diversity, the present surveys of aquatic insects indicate that it forms a single area of faunal endemism, and it is thus treated as an undivided unit in the current report. Survey work has been extensive in this region, perhaps accounting for the apparently widespread distribution of its fauna, which includes endemic Naucoridae and Veliidae.

Area 22. **Morobe Highlands** - The mountains east of the Bulolo River where the central ranges abut the western terminus of the Owen Stanley Range, including the headwaters of the Wampit and Watut Rivers. This unit has also had extensive survey work due to the presence of the Wau Ecology Institute. Its aquatic insect fauna shows notable differences from that of the East Papuan Central Highlands (Area 21), with endemic Gerridae and Naucoridae. As currently defined, this unit also includes the Herzog and Bowutu Mountains, which are of disparate geological origin. Future survey work may show that this unit should be subdivided to accommodate endemism in these tectonic terranes.

Area 23. **Arafura Foreland** - The southern foothills of the central mountains at elevations between 50 and 1200 meters, between the Uta River in the west and the Lorentz River in the east. This unit, which is strongly indicated on the basis of both freshwater fish and aquatic insect data, includes the middle reaches of the Ajkwa and Lorentz Rivers, which have been subject to detailed biological surveys.

Area 24. **Trans-Fly Foreland** - The basins of the Digul, Fly, Aramia, and Turama rivers at elevations between 50 and 1200 meters. Most surveys have concentrated in the vicinity of Kiunga, on the Fly, and have revealed a diverse aquatic biota with a different species composition from that seen in the Kikori and Purari basins to the east or the Arafura Foreland to the west.

Area 25. **Papuan Gulf Foreland** - The basins of the Kikori, Purari, Vailala and Lakekamu rivers at elevations between 50 and 1200 meters. This unit includes the elevated karst terrain of the Papuan Plateau, lying to the west of the Kikori River. Recent intensive surveys of this remote area have revealed a rich and distinctive fauna, with many endemic Hemiptera species in the families Gerridae and Veliidae. This unit also includes Lake Kutubu, with its diverse assemblage of endemic fishes.

Region 5 - Southern Coastal Lowlands and associated Continental Shelf islands

Area 26. **Arafura Coastal Lowlands** - The southern coastal lowlands between Uta and the mouth of the Mappi River at elevations below 50 meters, which corresponds roughly to the head of tidal influence in these systems (the actual upper limit of tidal influence in fact often lies somewhat lower, but the 50 m. contour was chosen for practicality in mapping based on available charts). This area contains more areas of swamp than the slightly elevated Trans-Fly lowlands to the east, and on the basis of limited aquatic insect surveys appears to support a slightly different fauna. The eastern boundary of this unit has been set just west of the Mappi River, but this is a hypothetical alignment based on the mapped extent of palustrine habitats in the region.

Area 27. **Trans-Fly Coastal Lowlands** - The extensive lowland basins of the Digul, Fly, Aramia and Turama rivers lying between sea level and 50 meters. The eastern boundary of this unit is formed by the abrupt scarp of the Darai limestone plateau lying between the Turama and Kikori Rivers. The western boundary is poorly constrained, but has been mapped along the margin of the extensive palustrine habitats occurring immediately west of the Mappi River, which shares a common terminus with the Digul. This area of large, low gradient rivers and creeks supports a diverse and distinctive aquatic biota, including endemic fishes, crayfishes, and aquatic insects.

Area 28. **Papuan Gulf Coastal Lowlands** - The southern coastal lowlands from delta of the Kikori River eastward to Kerema. This boundaries of this unit are basically defined along the 50-m contour in the lower Fly, Kikori, and Purari river basins, near the heads of the river deltas (see comments under Area 26). The area supports endemic species of Veliidae, Hydrometridae, and trepobatine Gerridae.

Area 29. **Aru** - A set of low limestone islands lying on the Papuan continental platform. The fauna supports a few endemic species, but also shows strong alliances to the Asmat Lowlands and Vogelkop Lowlands. Further collections in all these areas may show that the Aru biota is merely an isolated segregate of that occurring in the Arafura Coastal Lowlands (Area 26).

Region 6 - Papuan Peninsula and associated offshore islands

Area 30. **South Papuan Peninsula Foreland** - The premontane foreland from Karima to Milne Bay. This area supports endemic Zygoptera and Naucoridae. It corresponds to the southern sector of the formerly separate East Papua Composite Terrane, which was sutured to the main body of New Guinea in the Oligocene (Davies et al., 1997).

Area 31. **Owen Stanley Range** - The central mountain chain of the Papuan Peninsula, comprised of uplifted ophiolites and subduction mélange. An area of rich endemism for aquatic insects, with many endemic species in all groups.

Area 32. **Popondetta Foreland** - The large area of premontane foreland north of the Owen Stanley Range, from Cape Vogel to Manau. Limited collections indicate endemic Zygoptera and Naucoridae.

Area 33. **Cape Nelson Peninsula** - This area of Late Tertiary volcanic peaks separated from the main body of the Owen Stanley Range by extensive lowlands is characterized by a distinctive suite of endemic aquatic Heteroptera.

Area 34. **Cloudy Mountains** - This unit, as defined by a suite of endemic aquatic Heteroptera and Odonata, includes the Cloudy Mountains, the extreme eastern extension of the Owen Stanley range that forms the East Cape peninsula, and Normanby Island in the D'Entrecasteaux group. It roughly corresponds to the geological Kutu Terrane of Pigram & Davies (1987).

Area 35. **D'Entrecasteaux Islands** - A chain of high islands with predominantly metamorphic geology, lying immediately north of the eastern Papuan Peninsula. Recent collections have demonstrated the presence of endemic Heteroptera and Zygoptera, but have also shown that this endemism is confined to Goodenough and Fergusson islands, with Normanby Island forming part of the Cloudy Mountains area of endemism instead.

Area 36. **Basilaki Island** - A small, hilly, heavily forested island lying at the eastern terminus of the chain of islands that extends eastward from the China Strait. Recent surveys have demonstrated the presence of endemic aquatic Heteroptera.

Area 37. **Misima Island** - A narrow island composed of a low limestone plateau on its eastern half and a very precipitous set of mountains formed from metamorphic rocks ringed by limestone terraces on its western half. The island harbors endemic species of aquatic Heteroptera and Odonata.

Area 38. **Tagula Island** - The largest island in the Louisiade Archipelago, hilly throughout with gentle slopes underlain by metamorphic bedrock. The island supports many endemic species of aquatic Heteroptera and Odonata.

Area 39. **Rossel Island** - A rugged, heavily forested island composed of metamorphic rocks similar to those of the Owen Stanley range on New Guinea. The island supports a rich assemblage of endemic aquatic Heteroptera, and shares other regional endemics with Tagula.

Area 40. **Woodlark Island** - An isolated island composed primarily of an elevated limestone surface with scattered higher ranges of hills formed from emergent metamorphic bedrock. No endemic fishes are known from the island, but it does support endemic species of aquatic Heteroptera and Odonata.

Native freshwater snail (Neritidae) in stream near Tufi

Macrobrachium lar from streams on Sideia Island

Table 1. Summary Listing of Areas of Freshwater Endemism in the New Guinea Region, as defined by freshwater fishes, crayfish, and selected aquatic insect groups

Region 1: RAJA AMPAT ISLANDS

- Area 1. Waigeo
- Area 2. Batanta
- Area 3. Misool

Region 2: VOGELKOP AND BOMBERAI PENINSULAS

- Area 4. Vogelkop Lowlands
- Area 5. Vogelkop Highlands
- Area 6. Vogelkop Anticlines
- Area 7. Fakfak and Kumafa Mountains

Region 3: NORTH COAST RANGES AND VALLEYS, AND ASSOCIATED OFFSHORE ISLANDS

- Area 8. Biak-Supiori
- Area 9. Yapen
- Area 10. Northwest Papuan Coastal Lowlands
- Area 11. Van Rees and Foja Mountains
- Area 12. Cyclops Mountains
- Area 13. Bewani, Torricelli and Prince Alexander Mountains
- Area 14. Adelbert, Finisterre and Saruwaged Mountains
- Area 15. Mamberamo Basin
- Area 16. Sepik-Ramu-Markham Basin

Region 4: CENTRAL MOUNTAIN RANGES

- Area 17. Mamberamo Foreland
- Area 18. Sepik-Ramu Foreland
- Area 19. Weyland Mountains
- Area 20. West Papuan Central Highlands
- Area 21. East Papuan Central Highlands
- Area 22. Morobe Highlands
- Area 23. Arafura Foreland
- Area 24. Trans-Fly Foreland
- Area 25. Papuan Gulf Foreland

Region 5: SOUTHERN COASTAL LOWLANDS, AND ASSOCIATED ISLANDS

- Area 26. Arafura Coastal Lowlands
- Area 27. Trans-Fly Coastal Lowlands
- Area 28. Papuan Gulf Coastal Lowlands
- Area 29. Aru

Table 1. (cont.). Summary Listing of Areas of Freshwater Endemism in the New Guinea Region.

Region 6: PAPUAN PENINSULA AND ASSOCIATED OFFSHORE ISLANDS

Area 30. South Papuan Peninsula Foreland

Area 31. Owen Stanley Mountains

Area 32. Popondetta Foreland

Area 33. Cape Nelson Peninsula

Area 34. Cloudy Mountains

Area 35. D'Entrecasteaux Islands

Area 36. Basilaki Island

Area 37. Misima Island

Area 38. Tagula Island

Area 39. Rossel Island

Area 40. Woodlark Island

Sampling near Tufi

Sicyopus nr. *zoesterophorum*, Basilaki Island

Melanotaenia sp., Gumini River near Alotau

Table 2. Lacustrine Subunits

The lacustrine subunits listed below are lakes or lake complexes that lie within various of the larger areas of endemism outlined in Table 1 above, but are worthy of individual recognition due to their distinctive assemblages of endemic fishes and crayfishes (although most are not currently known to contain endemic aquatic insect species). Each lake represents a unique ecosystem, and all are priority conservation areas.

Species endemic to single lakes or lake groups in New Guinea

Anggi Lakes
(Area 5, Vogelkop Highlands)

Insects
Ischnura rhodosoma

Lake Holmes (Danau Bira) 02° 29' S, 138° 00' E
(Area 11, Van Rees and Foja Mountains)

Fishes
Chilatherina bleheri
Melanotaenia maylandi (occurs in nearby creeks)

Lake Sentani 02° 42' S, 140° 30' E
(Area 10, North Irian Coastal Lowlands)

Fishes
Chilatherina sentaniensis
Glossolepis incisus
Glossogobius sp. 10

Ajamaru Lakes 01° 17' S, 132° 06' E
(Area 5, Vogelkop Highlands)

Fishes
Melanotaenia ajamaruensis
Melanotaenia boesmani
Glossogobius hoesei
Pseudomugil reticulatus (previous records of this species from elsewhere in New Guinea are in error)

Lake Kurumoi 02° 10' S, 134° 5' E
(Area 6, Vogelkop Anticlines)
Fishes
Melanotaenia parva

Lake Yamur 03° 39' S, 134° 58' E
(Area 6, Vogelkop Anticlines)
Fishes
Carcharinus leucas (Bull Shark)[1]
Variichthys jamoerensis

Notes: [1]A remarkably isolated inland population of this otherwise predominantly marine and estuarine species

Table 2. (cont.). Lacustrine Subunits

Lake Laamora 03° 41' S, 134° 17' E
(Area 6, Vogelkop Anticlines)

Fishes
Melanotaenia lakamora
Mogurnda magna

Lake Aiwaso 03° 39' S, 134° 16' E
(Area 6, Vogelkop Anticlines)

Fishes
Melanotaenia lakamora
Mogurnda aiwasoensis

Lake Kamaka 03° 43' S, 134° 11' E
(Area 6, Vogelkop Anticlines)

Fishes
Melanotaenia kamaka
Melanotaenia pierucciae (occurs in nearby creeks)
Craterocephalus fistularis

Panaiai Lakes 03° 55' S, 136° 20' E
(Area 20, West Papuan Central Highlands)

Insects
Ischnura ariel
Archiboldargia mirifica

Paniai Lake
Crayfishes
Charax boschmai
Charax buitenijkae
Charax communis
Charax murido
Charax pallidus
Charax paniaicus

Tage Lake 03° 57' S, 136° 15' E
Fishes
Oxelyotris wisselensis

Tigi Lake 04° 02' S, 136° 13' E
Fishes
Oxelyotris wisselensis
Crayfishes
Charax communis
Charax longipes
Charax solus

Lake Wanam (PNG) 06° 39' S, 146° 46' E
(Area 16, Sepik-Ramu-Markham Basin)

Fishes
Mogurnda maccuneae

Table 2. (cont.). Lacustrine Subunits

Mogurnda mosa
Glossolepis wanamensis

Lake Kutubu (PNG) 06° 25' S, 143° 19' E
(Area 25, Papuan Gulf Foreland)
Fishes
Glossogobius new sp. 8
Glossogobius new sp. 12
Hephaestus adamsoni
Mogurnda furva
Mogurnda spilota
Mogurnda variegata
Mogurnda vitta
Melanotaenia lacustris
Oloplotosus torobo
Crayfishes
Charax papuanus

Lake Tebera (PNG) 06° 45' S, 144° 40' E
(Area 25, Papuan Gulf Foreland)

Fishes
Melanotaenia herbertaxelrodi
Glossogobius new sp. 13

Table 3. Taxa Defining Areas of Endemism

Species occurring only in lacustrine subunits are marked with an asterisk (*)

Region 1: **RAJA AMPAT ISLANDS**

Area 1. **Waigeo/Gam**
Heteroptera
Gerridae
Ciliometra waigeo
Ptilomera waigeo
Stygiobates rajana
Notonectidae
Enithares digitata
Veliidae
Neusterensifer gamensis
Odonata
Coenagrionidae
Teinobasis prothoracica
Platycnemididae
Idiocnemis fissidens
Protoneuridae
Nososticta atrocyana
Nososticta evelynae
Nososticta erythroprocta
Coenagrionidae
Palaiargia nasisterna
Megapodagrionidae

Table 3. (cont.). Taxa Defining Areas of Endemism

            Argiolestes coartans
            Argiolestes ochrostomus
    Perciformes
        Melanotaeniidae
            Melanotaenia catherinae

Area 2. **Batanta**
    Heteroptera
        Veliidae
            Aegilipsicola insularis
            Neusterensifer batantana
            Tarsovelia rajana

Area 3. **Misool**
    Heteroptera
        Gerridae
            Ptilomera misoolensis
        Veliidae
            Neusterensifer misoolicus
    Odonata
        Protoneuridae
            Nososticta pyroprocta
        Coenagrionidae
            Palaiargia micropsitta
        Megapodagrionidae
            Argiolestes pyroprocta
    Perciformes
        Melanotaeniidae
            Melanotaenia misoolensis

Region 2: **VOGELKOP AND BOMBERAI PENINSULAS**

Area 4. **Vogelkop Lowlands**
    Heteroptera
        Gerridae
            Iobates salawati
        Notonectidae
            Enithares n. sp. 1
    Odonata
        Coenagrionidae
            Palaiargia eos
            Teinobasis micans
        Platystictidae
            Drepanosticta classeni
        Protoneuridae
            Nososticta xanthe
        Megapodagrionidae
            Argiolestes connectens
            Argiolestes fontinalis
    Perciformes
        Hemiramphidae
            Zenarchopterus ornithocephala
        Melanotaeniidae
            Melanotaenia irianjaya
        Terapontidae

Table 3. (cont.). Taxa Defining Areas of Endemism

Hephaestus lineatus

Area 5. **Vogelkop Highlands**

- Heteroptera
  - Gerridae
    - *Ptilomera arfak*
  - Veliidae
    - *Tarsovelia arfak*
  - Notonectidae
    - *Enithares* n. sp. 2
- Odonata
  - Platycnemididae
    - *Idiocnemis inornata*
  - Protoneuridae
    - *Nososticta dorsonigra*
  - Coenagrionidae
    - *Ischnura rhodosoma**
    - *Palaiargia arses*
    - *Palaiargia flavovittata*
  - Megapodagrionidae
    - *Argiolestes convergens*
    - *Argiolestes ornatus*
    - *Argiolestes pallidistylus*
    - *Argiolestes postnodalis*
  - Platystictidae
    - *Drepanosticta auriculata*
    - *Drepanosticta inversa*
- Coleoptera
  - Gyrinidae
    - *Dineutes* (*Rhombodineutes*) *pectoralis avicularis*
    - *Dineutes* (*Rhombodineutes*) *pectoralis pectoralis*
- Perciformes
  - Gobiidae
    - *Glossogobius hoesei**
  - Melanotaeniidae
    - *Melanotaenia ajamaruensis**
    - *Melanotaenia arfakensis*
    - *Melanotaenia boesemani**
    - *Melanotaenia fredericki*
    - *Pseudomugil reticulatus**

Area 6. **Vogelkop Anticlines**

- Heteroptera
  - Veliidae
    - *Neusterensifer etna*
- Odonata
  - Coenagrionidae
    - *Palaiargia starreanum*
  - Protoneuridae
    - *Nososticta lorentzi*
    - *Nososticta silvicola*
- Coleoptera
  - Gyrinidae
    - *Dineutes* (*Rhombodineutes*) *silenus*

Table 3. (cont.). Taxa Defining Areas of Endemism

Perciformes
Eleotridae
*Mogurnda aiwasoensis**
Mogurnda kaifayama
*Mogurnda magna**
Mogurnda mbuta
Melanotaeniidae
Melanotaenia angfa
*Melanotaenia parva**
*Melanotaenia pierucciae**
*Melanotaenia lakamora**
Pelangia mbutaensis
Terapontidae
*Variichthys jamoerensis**

Area 7. **Fakfak and Kumafa Mountains**
Odonata
Coenagrionidae
Palaiargia stellata
Papuagrion flavipedum

Region 3: **NORTH COAST RANGES AND VALLEYS, AND ASSOCIATED OFFSHORE ISLANDS**

Area 8. **Biak-Supiori**
Coleoptera
Gyrinidae
Dineutes (*Rhombodineutes*) *pectoralis biakensis*
Heteroptera
Gerridae
Metrobatopsis insularis
Notonectidae
Enithares vulgaris
Odonata
Coenagrionidae
Papuagrion insulare

Area 9. **Yapen**
Heteroptera
Gerridae
Ptilomera yapenana
Odonata
Protoneuridae
Nososticta wallacii
Perciformes
Eleotridae
Allomogurnda sampricei
Melanotaeniidae
Melanotaenia japenensis

Area 10. **Northwest Papuan Coastal Lowlands**
Odonata
Coenagrionidae
Teinobasis debeauforti
Protoneuridae
Nososticta callisphaena

Table 3. (cont.). Taxa Defining Areas of Endemism

Nososticta cyaneura
Nososticta rosea cruentata
Perciformes
Melanotaeniidae
*Chilatherina sentaniensis**
Glossolepis dorityi
*Glossolepis incisus**
Glossolepis pseudoincisus
Melanotaenia corona

Area 11. **Van Rees and Foja Mountains** (including Sentani Hills)
Odonata
Coenagrionidae
Aciagrion tonsillare
Palaiargia halcyon
Papuagrion corruptum
Papuagrion degeneratum
Papuagrion laminatum
Papuargia stuberi
Teinobasis stigmatizans
Platycnemididae
Arrhenocnemis sinuatipennis
Perciformes
Melanotaeniidae
*Chilatherina bleheri**
Melanotaenia maylandi

Area 12. **Cyclops Mountains**
Heteroptera
Gerridae
Ptilomera cheesmanae
Naucoridae
Cavocoris bisulcus
Veliidae
Neusterensifer cyclops
Odonata
Coenagrionidae
Palaiargia charmosyna cyclopica
Papuagrion fraterculum
Papuagrion rectangulare
Papuagrion rufipedum
Papuagrion spinicaudum
Megapodagrionidae
Argiolestes tristis
Platycnemididae
Idiocnemis nigriventris
Coleoptera
Gyrinidae
Dineutes (*Rhombodineutes*) *helleri stueberi*

Area 13. **Bewani**, **Torricelli and Prince Alexander Mountains**
Heteroptera
Gerridae
Metrobatoides genitalis

Table 3. (cont.). Taxa Defining Areas of Endemism

Ptilomera wewak
Veliidae
Neusterensifer cyclops
Rhagovelia thysanotos
Odonata
Coenagrionidae
Teinobasis luciae
Platycnemididae
Idiocnemis chloropleura
Coleoptera
Gyrinidae
Dineutes (*Rhombodineutes*) *helleri helleri*
Perciformes
Eleotridae
Mogurnda "n. sp. 5"
Melanotaeniidae
Chilatherina axelrodi
Terapontidae
Hephaestus obtusifrons

Area 14. **Adelbert, Finisterre and Saruwaged Mountains**
Heteroptera
Gerridae
Ptilomera biroi
Veliidae
Neusterensifer acuminata
Odonata
Platycnemididae
Idiocnemis adelbertensis
Idiocnemis huonensis
Protoneuridae
Nososticta astrolabica
Coenagrionidae
Palaiargia humida
Teinobasis dolobrata
Megapodagrionidae
Argiolestes kirbyi
Argiolestes montivagans
Platystictidae
Drepanosticta dendrolagina
Coleoptera
Gyrinidae
Dineutes (*Rhombodineutes*) *pectoralis mesosternalis*
Dineutes (*Rhombodineutes*) *tetracanthus buergersi*

Area 15. **Mamberamo Basin (Meervlakte)**
Odonata
Coenagrionidae
Teinobasis argiocnemis
Teinobasis olthofi
Perciformes
Gobiidae
Eugnathogobius tigrellus
Melanotaeniidae

Table 3. (cont.). Taxa Defining Areas of Endemism

Melanotaenia vanhuerni

Area 16. **Sepik-Ramu-Markham Basin**
- Heteroptera
  - Gerridae
    - *Ciliometra sepik*
- Perciformes
  - Melanotaeniidae
    - *Chilatherina bulolo*
    - *Glossolepis maculosus*
    - *Glossolepis wanamensis*
    - *Glossolepis wanamensis*
  - Gobiidae
    - *Glossogobius coatesi*
    - *Glossogobius* sp. 14

Region 4: **CENTRAL MOUNTAIN RANGES**

Area 17. **Mamberamo Foreland**
- Heteroptera
  - Gerridae
    - *Metrobatoides bifurcatus*
- Odonata
  - Coenagrionidae
    - *Palaiargia alcedo*
    - *Palaiargia charmosyna miniata*
    - *Palaiargia ceyx ceyx*
  - Megapodagrionidae
    - *Argiolestes amphistylus*
    - *Argiolestes aulicus*
    - *Argiolestes lamprostomus*
    - *Argiolestes simplex*
    - *Argiolestes sponsus*
    - *Podopteryx casuarina*
  - Platycnemididae
    - *Arrhenocnemis amphidactylus*
    - *Cyanocnemis aureofrons*
    - *Lochmaeocnems malacodora*
  - Platystictidae
    - *Drepanosticta eucera*
    - *Drepanosticta lepyricollis*
  - Protoneuridae
    - *Selysioneura ranatra*
- Coleoptera
  - Gyrinidae
    - *Dineutes* (*Rhombodineutes*) *heurni*
    - *Dineutes* (*Rhombodineutes*) *sinuaticollis*
    - *Dineutes* (*Rhombodineutes*) *tetracanthus tetracanthus*
- Perciformes
  - Melanotaeniidae
    - *Melanotaenia praecox*

Area 18. **Sepik-Ramu Foreland**
- Perciformes

Table 3. (cont.). Taxa Defining Areas of Endemism

Terapontidae
Hephaestus transmontanus

Area 19. **Weyland Mountains**
Heteroptera
Gerridae
Ptilomera nabire
Veliidae
Neusterensifer gladius
Neusterensifer nabire
Perciformes
Melanotaeniidae
Glossolepis leggetti
Melanotaenia rubripennis

Area 20. **West Papuan Central Highlands**
Heteroptera
Gelastocoridae
Nerthra improcera
Nerthra infecta
Nerthra monticola
Nerthra petila
Veliidae
Aegilipsicola iriana
Neusterensifer iriana
Tarsovelia reclusa
Odonata
Coenagrionidae
Archiboldargia gloriosa
Archiboldargia mirifica
Ischnura ariel
Ischnura isoetes
Oreagrion armeniacum
Oreagrion oreadum
Oreagrion xanthocyane
Palaiargia ceyx flammula
Palaiargia eclecta
Palaiargia myzomela
Papuagrion digitiferum
Papuagrion ekari
Papuagrion pandanicolum
Papuagrion pesechem pesechem
Papuagrion pesechem corniculatum
Megapodagrionidae
Argiolestes pectitus
Platycnemididae
Torrenticnemis filicornis
Platystictidae
Drepanosticta dorcadion
Coleoptera
Gyrinidae
Dineutes (*Merodineutes*) *archiboldianus*
Dineutes (*Rhombodineutes*) *pectoralis occidentalis*

Table 3. (cont.). Taxa Defining Areas of Endemism

Perciformes
Eleotridae
*Oxelyotris wisselensis**
Decapoda
Parastacidae
*Charax boschmai**
*Charax buitenijkae**
*Charax communis**
*Charax longipes**
*Charax murido**
*Charax pallidus**
*Charax paniaicus**
*Charax solus**

Area 21. **East Papuan Central Highlands**
Heteroptera
Gerridae
Ptilomera jimi
Notonectidae
Enithares n. sp. 3
Odonata
Coenagrionidae
Ischnura acuticauda
Platycnemididae
Paramecocnemis stilla-cruoris
Coleoptera
Gyrinidae
Dineutes (*Merodineutes*) *jocosus*
Dineutes (*Merodineutes*) *priscus*
Dineutes (*Rhombodineutes*) *pectoralis alticola*
Perciformes
Eleotridae
Allomogurnda hoesei

Area 22. **Morobe Highlands**
Heteroptera
Gelastocoridae
Nerthra robusta
Nerthra stevensi
Gerridae
Ptilomera morobe
Naucoridae
Cavocoris minor
Cavocoris rotundatus
Tanycricos froeschneri
Veliidae
Aegilipsicola rapida
Neusterensifer bowutu
Rhagovelia herzogensis
Tanyvelia missim
Coleoptera
Gyrinidae
Dineutes (*Merodineutes*) *wauensis*
Dineutes (*Rhombodineutes*) *pectoralis centralis*

Table 3. (cont.). Taxa Defining Areas of Endemism

Perciformes
Eleotridae
Allomogurnda flavimarginata

Area 23. **Arafura Foreland**

Heteroptera
Gerridae
Calyptobates kamoro
Calyptobates kopi
Ptilomera timika
Stygiobates iweka
Perciformes
Atherinidae
Craterocephalus nouhuysi
Eleotridae
Bostrichthys strigogenys
Mogurnda cingulata
Melanotaeniidae
Melanotaenia ogilbyi
Plotosidae
Oloplotosus mariae
Pseudomugilidae
Pseudomguil ivantsoffi
Pseudomguil paskai
Pseudomguil pellucidus
Terapontidae
Hephaestus habbemai

Area 24. **Trans-Fly Foreland**
Heteroptera
Gerridae
Calyptobates simplex
Ptilomera kiunga
Veliidae
Neusterensifer pseudocyclops
Perciformes
Melanotaeniidae
Melanotaenia oktediensis
Melanotaenia sexlineata

Area 25. **Papuan Gulf Foreland**
Heteroptera
Gerridae
Ptilomera kutubu
Ptilomera omo
Stygiobates mubi
Veliidae
Neusterensifer lubu
Tarsovelia kikori
Odonata
Coenagrionidae
Teinobasis debeauxi
Coleoptera
Gyrinidae

Table 3. (cont.). Taxa Defining Areas of Endemism

Dineutes (*Rhombodineutes*) *pectoralis papuanus*

Perciformes

Eleotridae

Allomogurnda flavomarginata
Allomogurnda landfordi
*Mogurnda furva**
Mogurnda kutubuensis
*Mogurnda spilota**
*Mogurnda variegata**
*Mogurnda vitta**
Oxyeleotris caeca

Melanotaeniidae

*Melanotaenia herbertaxelrodi**
Melanotaenia iris
*Melanotaenia lacustris**
Melanotaenia monticola
Melanotaenia mubiensis
Melanotaenia pimaensis

Plotosidae

*Oloplotosis torobo**

Terapontidae

*Hephaestus adamsoni**
Hephaestus fulginosis

Decapoda

Parastacidae

*Charax papuanus**

Region 5: **SOUTHERN COASTAL LOWLANDS, AND ASSOCIATED CONTINENTAL SHELF ISLANDS**

Area 26. **Arafura Coastal Lowlands**

Heteroptera

Gerridae

Ciliometra minajerwi

Odonata

Coenagrionidae

Papuagrion perameles
Plagulibasis ciliata
Teinobasis fulgens
Teinobasis nitescens

Perciformes

Apogonidae

Glossamia timika

Ariidae

Tetranesodon conorhynchus

Eleotridae

Oxyeleotris stagnicola

Terapontidae

Hephaestus roemeri

Area 27. **Trans-Fly Coastal Lowlands**

Heteroptera

Gerridae

Ciliometra kiunga

Mesoveliidae

Table 3. (cont.). Taxa Defining Areas of Endemism

Mesovelia stysi
Veliidae
Phoreticovelia rotunda
Odonata
Coenagrionidae
Austroagrion exclamationalis
Perciformes
Ariidae
Arius taylori
Eleotridae
Mogurnda mogurnda
Melanotaeniidae
Iriatherina werneri
Melanotaenia macullochi
Terapontidae
Hephaestus raymondi

Area 28. **Papuan Gulf Coastal Lowlands**
Coleoptera
Gyrinidae
Dineutes chalybeus
Heteroptera
Gerridae
Ciliometra setosa
Iobates ivimka
Perciformes
Eleotridae
Mogurnda pulchra
Area 29. **Aru**
Odonata
Coenagrionidae
Teinobasis buwaldi

Region 6: **PAPUAN PENINSULA AND ASSOCIATED OFFSHORE ISLANDS**

Area 30. **South Papuan Peninsula Foreland**
Heteroptera
Gerridae
Ciliometra femorata
Ptilomera breddini
Naucoridae
Aptinocoris fenneri
Aptinocoris sogeri
Cavocoris ismayi
Perciformes
Chandidae
Tentracentrum apagonoides
Melanotaeniidae
Melanotaenia papuae
Melanotaenia parkinsoni
Terapontidae
Hephaestus trimaculatus

Table 3. (cont.). Taxa Defining Areas of Endemism

Area 31. **Owen Stanley Mountains**
- Coleoptera
  - Gyrinidae
    - *Dineutes loriae*
    - *Dineutes macrochirus*
- Heteroptera
  - Veliidae
    - *Neusterensifer goilala*
    - *Rheovelia asymmetrica*
    - *Rheovelia truncata*
- Odonata
  - Megapodagrionidae
    - *Argiolestes epihippiatus*
    - *Argiolestes esuriens*
    - *Argiolestes luteipes*
    - *Argiolestes microstigma*
    - *Argiolestes prothoracicalis*
    - *Argiolestes saltator*
    - *Argiolestes saltuarius*
    - *Argiolestes tenuispina*

Area 32. **Popondetta Foreland**
- Heteroptera
  - Gerridae
    - *Ciliometra hirsuta*
  - Naucoridae
    - *Sagocoris asymmetricus*
  - Veliidae
    - *Rhagovelia aureospicata*
    - *Rhagovelia caesius*
    - *Rhagovelia hirsuta*
    - *Rhagovelia priori*
- Perciformes
  - Atherinidae
    - *Craterocephalus kailolae*
  - Chandidae
    - *Tentracentrum caudovittatus*
    - *Tentracentrum honessi*
  - Eleotridae
    - *Mogurnda lineata*
    - *Mogurnda orientalis*
  - Hemiramphidae
    - *Zenarchopterus robertsi*

Area 33. **Cape Nelson Peninsula**
- Heteroptera
  - Veliidae
    - *Brechyvelia tufi*
    - *Neusterensifer tufi*
    - *Rheovelia fonticola*

Area 34. **Cloudy Mountains**
- Heteroptera
  - Gerridae

Table 3. (cont.). Taxa Defining Areas of Endemism

Ciliometra priori
Veliidae
Aegilipsicola peninsularis
Neusterensifer femoralis
Neusterensifer sagarai
Rheovelia petrophila
Tanyvelia minima
Odonata
Protoneuridae
Selysioneura rangifera
Selysioneura rhaphia

Area 35. **D'Entrecasteaux Islands**
Heteroptera
Veliidae
Neusterensifer kula
Rheovelia robinae
Odonata
Megapodagrionidae
Argiolestes annulipes
Argiolestes armeniacus
Platycnemididae
Rhyacocnemis sufficiens
Protoneuridae
Selysioneura arboricola
Perciformes
Eleotridae
Allomogurnda insularis
Allomogurnda montana

Area 36. **Basilaki Island**
Heteroptera
Veliidae
Rheovelia basilaki
Odonata
Megapodagrionidae
Argiolestes n. sp. 1

Area 37. **Misima Island**
Heteroptera
Veliidae
Neusterensifer misima
Rheovelia anomala
Odonata
Protoneuridae
Selysioneura drymobia

Area 38. **Tagula Island**
Heteroptera
Veliidae
Neusterensifer sulcata
Tanyvelia tagulana
Odonata
Megapodagrionidae

Table 3. (cont.). Taxa Defining Areas of Endemism

Argiolestes n. sp. 2
Platycnemididae
Idiocnemis leonardi

Area 39. **Rossel Island**
Heteroptera
Veliidae
Neusterensifer yela
Odonata
Megapodagrionidae
Argiolestes n. sp. 3

Area 40. **Woodlark Island**
Heteroptera
Veliidae
Neusterensifer muyuw
Odonata
Protoneuridae
Selysioneura virgula

Water striders in the genus *Ptilomera* are a common component of stream biota in New Guinea, and have diversified into many regionally endemic species.

THREATS TO FRESHWATER BIOTA IN THE NEW GUINEA REGION

Although the overall condition of freshwater ecosystems in the New Guinea region is excellent, there are still obvious threats to the biota, which tend to manifest themselves on local rather than regional scales. These threats may be grouped into three general categories: 1.) physical alteration of habitat; 2.) use of biotic resources, and 3.) invasive species. Each of these threat categories is discussed separately below.

Physical Alteration of Habitat

Logging

Large-scale industrial logging, particularly by international timber companies such as the Malaysian Rimbunan Hijau, is a clear threat to watershed integrity throughout the New Guinea region. The obvious and disastrous effects of clear-cutting aside, even selective logging by such companies results in an extensive network of secondary roads that create widespread siltation and stream impoundment problems. Although tree-falls are a natural element of the New Guinea rainforest and the small impoundments resulting from them are encountered on nearly every forest stream in the region, particularly in the lowlands, logging tends to greatly increase the number of such channel obstructions, increasing pool habitat and decreasing riffles. Logging roads also tend to employ rudimentary bridges that subsequently collapse, creating further impoundments. Opening the forest canopy also increases insolation and thereby increases water temperature. The overall effect, then, is to create a stream that is warmer, more slowly flowing, and traps more sediment.

Much of the large scale logging in the New Guinea region is undertaken by foreign companies with poor environmental records. In PNG, for instance, Rimbunan Hijau and its associated companies are now estimated to control over 50 percent of the large scale commercial logging concessions and whole log exports; the company has also acquired control of *The National*, a widely read daily newspaper published in Port Moresby, through which it can rebut charges of environmental abuse. In Indonesian New Guinea, environmental and forestry regulations are even less stringently enforced than in PNG, leading to widespread illegal logging and consequent environmental degradation. In addition to large scale operations by Indonesian companies such as PTT Inhutani II and PT Astra, local military garrisons often set up illegal logging operations to subsidize their pay, usually with no consideration of environmental effects.

By contrast, the advent in PNG of small-scale logging utilizing “walkabout sawmills” appears to result in rather light and transient damage to streams and watersheds. Such operations leave a lighter environmental footprint because they usually target only particular tree species, such as rosewood, which are widely scattered in the forest; do not operate in one area for a long period of time; and do not require the creation of an extensive road network.

Shifting cultivation

The impacts of shifting cultivation are similar to those of clearcut logging, but on a far more localized scale. In traditional village settings, the effects of shifting cultivation were mitigated over time by the fact that such garden patches were relatively small in size and widely dispersed. In many cases, if all available garden areas had been used at least once, entire villages simply relocated to alternative sites, allowing the old gardens to go back to forest. As population has increased in many highland areas, however, the number of gardens has proliferated while the number of years they are allowed to lay fallow has decreased, and local governments have discouraged villages from changing location.

In general, shifting cultivation tends to have disproportionate impacts on first order streams (the smallest streams in a given drainage network), which are characteristic of the ridge slopes on which gardens are usually established. Creeks passing through newly cleared garden areas are usually exposed to intense sunlight and air high temperatures, and obstructed by massive tangles of vines and tree branches that in many cases make them nearly impossible to traverse. These ecosystem impacts produce significant faunal changes, with deep forest species that require cooling shade, particularly certain genera of Odonata, being absent in such areas. Provided that a patchwork of forest and garden plots remains intact, however, such forest biota will eventually recolonize streams in former garden areas once a canopy of native trees is re-established.

Oil palm plantations

Like logging, oil palm plantations result in wholesale ecosystem conversion that has broad impacts across entire stream catchments. The creation of a plantation requires initial land clearing equivalent to clear cut logging (which may in fact be the first step if the proposed plantation area is covered with primary forest), after which a new canopy structure of oil palms eventually becomes established. Nutrient inputs from such plantations into adjacent streams appear to be high, probably due to fertilizer and other agrochemical runoff, leading to a proliferation of algae and consequent impacts on the benthic biota. Because oil palm development is generally undertaken on relatively flat lowland sites, it disproportionately impacts the terminal reaches of streams via clearance of alluvial and swamp forests, with consequent impacts on diadromous biota similar to those described subsequently for mining.

Mining

Large scale mining operations have had obvious local impacts to certain river systems, notably the Ajkwa (Grasburg copper mine), Fly (Ok Tedi gold and copper mine and Porgera gold mine), and the Auga (Tolokuma gold mine). Reasonable attempts to mitigate these impacts, which include siltation, chemical contamination, and catchment dewatering for pipeline slurries, have been undertaken at Grasburg, Ok Tedi and Porgera, but few such measures appear to be in place at Tolokuma, which is severely contaminating the Auga system. The gold mines on the small islands of Lihir (near New Ireland) and Misima Island (in the Louisiade Archipelago) use submarine tailing disposal systems that have no impact on local streams. Both mines have had localized impacts to small streams due to road construction, but these are now abating on Misima with the pending closure of that operation.

Although large-scale mining produces dramatic local impacts that are highly visible, a more pernicious set of impacts often arises from small-scale gold mining efforts that are common throughout the New Guinea region, particularly in eastern PNG. As noted by Susupu and Crispin (2001): "Environmental issues do not seem to be a strong concern for members of the small-scale artisanal mining community. Issues such as damage to river beds, solids in water and destruction of riverbanks are not addressed." Placer and hydraulic mining has caused chronic disturbance to formerly pristine streams in the Wau/Bulolo area, and evidence of similar small-scale operations is frequently encountered in Milne Bay Province, which saw a major gold rush on Woodlark Island a century ago.

The most persistent impact to freshwater ecosystems from such small-scale mining arises not from physical disturbance to streambeds, however, but from the mercury used in the mining process. At present some 4.0 tons of mercury per year is sold to alluvial miners in PNG, based on wholesaler's records (Susupu and Crispin, 2001). This mercury is used to extract gold from black sand either in between the sluice-box compartments or via simple panning. In the Wau/Bulolo area, where dredge mining occurred from the late 1920s through the1960s, bulldozers still occasionally uncover large puddles of mercury, and similar situations are reported from long-term mining sites on Bougainville (Susupu and Crispin, 2001). In Indonesian New Guinea, local mercury pollution is now also occurring in the Timika area due to illicit gold refining operations being conducted by military units using barrels of concentrate stolen from Grasburg mine. Being non-soluble, mercury remains in river sediments indefinitely, and may be difficult to detect, since it is possible for river water to flow clear of mercury even when high levels of mercury are present in the river bed. Such mercury contamination, however, frequently enters the riverine food chain, where it is amplified through successive trophic levels, eventually posing severe risks to local human populations who consume fish and crustaceans.

In contrast to logging or oil palm plantations, which degrade entire catchments via wholesale landscape conversion, mining effluents generally impact only the main stem of any given catchment, leaving most tributaries undisturbed and available as potential reservoirs of biotic recolonization. The degradation of main stem rivers, however, particularly in the terminal reaches, can have serious impacts on certain diadromous faunal elements such as fish and prawns, preventing completion of the longitudinal migrations essential to their life cycles and thereby potentially extirpating them from certain river systems.

Petroleum

Petroleum development has relatively limited impact on inland waters, since the environmental disturbances associated with it tend to be small, scattered, and highly localized. Outside of the possibility of spills and pipeline leaks, which can obviously have serious short term local impacts, the major threat from petroleum development results from forest degradation or clearance adjacent to the network of service roads, which provide conduits into previously undisturbed tracts of forest. In certain cases, such as the development of a petroleum pipeline in the Kikori River basin of PNG, such access roads have been designed to be temporary, and to degrade over time once the initial construction phase is finished, with subsequent maintenance, if necessary, accomplished via helicopter. Local people are often loath to lose such roads, however, and conflicts have arisen over the practice of making them deliberately obsolescent. In general, due to the scattered nature of the operations and shifting well sites, the overall ecosystem impacts of petroleum development are in some aspects similar to those of selective logging or shifting cultivation. In addition, because petroleum operations are restricted to a only a few particular areas in New Guinea such as the Vogelkop Peninsula and Kirkori River basin, they do not appear to pose a broad scale threat to freshwater ecosystems in New Guinea on the same order as logging or even mining.

Dams

Dams and hydropower developments are sparse in the New Guinea region, and their impacts on freshwater systems are currently minimal. The Sirinumu hydro project, which supplies electricity for Port Moresby, greatly reduces the base flow of the Sogeri River at Rouna Falls in the dry season, with obvious negative consequences for the river's biota, but this is an exceptional and isolated case. Larger scale projects, such as the proposed reservoirs on the Mamberamo River in Indonesian New Guinea, or the Hathor Gorge of the Purari River in PNG, would clearly have significant basin-wide impacts were they to be constructed, but both are currently shelved. By contrast, small mini-hydros, which are commonly used in the mountains of PNG to provide electricity for local mission stations, have minimal biotic impact.

Ungulates

The impacts of introduced ungulates to New Guinea aquatic systems are underappreciated, but can be significant and extensive, particularly in upland areas. In the highlands of Central Province in PNG, for instance, cattle grazing has been observed to create widespread slope terracing and converts valley bottoms into muddy marshes, increasing river siltation and water turbidity. Feral pigs, although widespread in New Guinea, have not had the same disastrous impacts to native forests as observed on smaller islands in Polynesia, although significant loss of understory vegetation due to their activities was evident on some portions of Misima Island in the Louisiades, and local people on Sideia Island, east of China Strait in PNG's Milne Bay Province, complained that gardening was nearly impossible due to pig activity. Feral pigs are intensively hunted throughout the region, which probably serves to keep their numbers in check to some extent. It is unknown if they act as vectors of the water-borne disease leptospirosis, as they do in the Hawaiian Islands, but this seems likely.

Utilization of Biotic Resources

Live aquarium fish trade

With a single exception, there appears to be little impact on the native fauna due to the live aquarium fish trade. As far as we can determine there is very little commercial harvesting of wild fishes for the aquarium trade with the exception of the illegal trade for Saratoga or Bony Tongue (*Scleropages jardinii*: family Osteoglossidae), which occurs in the southern border area of PNG and the Indonesian province of Papua. Saratoga is popular in the aquarium trade, probably because of its similar appearance to the Asian Arowana (*S. formosus*), which is a much sought-after "good-luck" fish in eastern Asia, particularly China and Japan, where they are known as Dragonfish. The huge popularity of the Dragonfish has apparently resulted in a demand for other species of bony tongues.

Saratoga is a popular aquarium and sports-fish native to southern New Guinea and northern Australia. It breeds annually just prior to the wet season (September to November). After external fertilization the female orally incubates a brood of about 30–130 eggs until they hatch 1–2 weeks later (Allen *et al.* 2002). The female then guards the newly hatched young, which remain close to her mouth for the next 4–5 weeks. The young fingerlings are particularly vulnerable at this stage of the life cycle and are easily harvested. The species is protected by law in Indonesia, and subject to various regulations in Australia.

Beginning in the 1990s villagers in the Torassi or Bensbach River area, in the Western Province of PNG have been collecting and selling wild Saratoga fingerlings to merchants from Merauke across the nearby border in Papua (Hitchcock in press). These fish, as well as illegally captured fingerlings from Papua, are then exported to Asia, where they commanded considerable prices for several years. Australian fish breeders report that saturation of the market by Torassi Saratoga led to a collapse in prices and dramatic decline in demand for the species, which has negatively impacted upon the Australian export trade in wild-caught and captive-bred fingerlings. There is also evidence from local villagers living along the Bensbach River that seasonal harvesting of Saratoga over the past decade has resulted in a dramatic decline in population numbers. Therefore a critical need exists for more detailed study of this problem as well as a sound management plan that will insure the sustainability of the fishery. In addition, there needs to be effective policing of the illegal trade on the Papuan side of the border.

There is scant information on the harvest of other ornamental species. Rainbowfishes of the family Melanotaeniidae are the only New Guinea group that is regularly seen in the international aquarium trade. Most of the species were introduced to the trade by various foreign collectors, often operating illegally. Rainbowfishes spawn readily in captivity and there is now a large captive breeding pool that apparently satisfies most of the commercial demand, thus negating the need for wild-caught fish. However, there is probably limited capture of wild fish by Indonesian merchants in places such as Sorong and Jayapura, although reliable data is lacking.

At least one merchant was operating in Sorong as recently as six years ago. His trade revolved mainly around rainbowfishes, especially the brightly colored Boeseman's Rainbow (*Melanotaenia boesmani*), which is endemic to the Ayamaru Lakes region of the central Vogelkop Peninsula. The species was introduced to the aquarium hobby in 1983 by a German collector, and it has steadily increased in popularity. By 1989 Ayamaru villagers were catching so many live fish for the aquarium trade the species was on the brink of becoming endangered (Allen 1995). An estimated 60,000 male rainbows were captured each month for shipment to Jakarta exporters. Fortunately, the Indonesian government eventually placed controls on the industry.

Impact of food fish harvesting on native fishes

There is virtually no data on the harvest of native fishes for human consumption or the possible impact of this activity on native fishes in general. Compared to the considerable harvest of marine fishes, the amount of freshwater fishes seems relatively insignificant. Nevertheless, people living along the major river systems depend on freshwater fishes for a significant portion of their diet. Most of the larger villages have regular fish markets, which appear to be dominated by forktail catfishes, large gudgeons (*Eleotris* and *Oxyeleotris*), and various introduced fish, especially carp and tilapia. Forktail catfishes (family Ariidae) are represented in New Guinea fresh waters by 21 species and are probably the most important food fish in this habitat. Although they are heavily targeted by gill netting and traditional fishing methods their numbers do not appear to be declining, at least in the major rivers systems such as the Fly, Digul, Sepik, and Mamberamo.

A variety of fishing methods are employed including hook and line from canoes, homemade traps, and various nets ranging from simple one-person hoop nets to large seines and gill nets. Streams, some of considerable size, are sometimes diverted and the former channel containing isolated pools with dense fish concentrations are then netted or speared. Some villages also employ derris root to poison ponds, stagnant pools or slow flowing sections of creeks. In addition, local fishers are usually adept at catching gudgeons and other fishes that hide in crevices by hand.

Traditional fishing methods appear to have insignificant impact on the native fish fauna. After all, they have been used for centuries and continue to be sustainable. The problem lies with more modern techniques, especially when outboard motors have been introduced in combination with gill nets. It is our opinion that gill nets should be banned from areas of special biological significance, such as Lake Sentani and Lake Yamur in Papua Province, and Lake Kutubu in PNG. Gill netting has certainly played a major role in the demise of the Freshwater Shark (*Carcharinus leucas*) in Lake Yamur and the Giant Sawfish (*Pristis microdon*) in Lake Sentani.

Invasive Species

In relation to its overall size, the New Guinea region exhibits a remarkably low incidence of invasive freshwater species. This fortuitous situation appears to result from the fact that the region is lightly inhabited, has not experienced extensive colonization and settlement by foreign peoples (although this situation is changing in Indonesian New Guinea with a continuing influx of Malay settlers via government sponsored transmigration programs), and is still not well integrated into the global economy. The result is that freshwater ecosystems in many parts of the island and its proximal archipelagoes remain among the most pristine on earth.

New Guinea's general ecological integrity notwithstanding, freshwater fishes are an increasing problem throughout the island. Allen (1991) reported the presence of 22 species representing 19 genera, 11 families and all six continents. Since then at least six more introductions have been noted, and more can be expected, especially on the Indonesian side of the island. The main purpose of the present report will be to provide details of the more recent introductions as well as a general overview of the invasive problem.

Most of the introductions have had a negative impact, either by competing for space and limited food resources, or by feeding on natives species, including their eggs and fry. Tilapia (*Oreochromis mossambica*) has adversely affected the environment, creating turbid conditions in formerly clean lakes, and badly over-crowding the indigenous fauna due to its prolific breeding. Several species including tilapia, walking catfish, carp, and climbing perch appear to be undergoing rapid population increases and therefore pose a serious threat to native fishes.

The current distributional pattern of introduced fishes is closely tied to transmigration areas of Papua Province, the larger population centers such as Jayapura, Timika and Port Moresby, and certain areas that were targeted by the PNG government and FAO (e.g. Sepik-Ramu systems). The transmigration program of the Indonesian government is no doubt responsible for many of the introductions. Newly arrived settlers often bring their pets and fishpond stock from other parts of the archipelago. Thus, there is a major potential for further introductions.

Of primary concern is the relatively recent appearance of four invasive (tilapia, snakehead, climbing perch, and walking catfish) species in the Bensbach River system of southwestern PNG (Hitchcock 2002). At least some of these possibly entered the river via drainage ditches associated with the building of the Trans-Irian Highway, which in 1982 crossed the international border in two locations on the Upper Bensbach. Tilapia and walking catfish are more recent introductions, having been first noticed in the area in about 1995.

Of equal concern is the appearance of two South American fishes, *Prochilodus argenteus* (Prochilodontidae) and *Colossoma bidens* (Characidae), and *Barbonymus goniotus* (Cyprindiae) from western Indonesia in the Ramu system of PNG. The origin of these introductions remains a mystery, but they may have been species that were experimentally raised for potential introduction during an ill-conceived fish stock enhancement program sponsored by the Food and Agriculture Organization of the United Nations (FAO) in the 1980s.

Allen *et al*. (2002) noted that the Mamberamo River in Papua Province had the highest percentage (17.1) of introduced fishes of any major river system in New Guinea. The appearance of species such as tilapia, walking catfish, snakehead, and three species of cyprinids is particularly alarming, given the relative isolation of this system and lack of major population centers.

Another problem area is the Timika region of southern Papua Province. Prior to the opening of the Freeport gold and copper mine, there were no invasives in the region. But a huge influx of transmigrants has seen the introduction of tilapia, climbing perch, walking catfish, and snakehead (Allen *et al*. 2000). In addition, the Blue Panchax (Aplocheilidae) from southeast Asia was introduced in the 1990s, apparently for mosquito control.

Across New Guinea as a whole, invasive species appear more concentrated in lakes and wetlands, although lowland certain stream and river systems, particularly the Mamberamo and Sepik-Ramu basins, are badly contaminated. The amazingly intact character of New Guinea's wetland systems in a physical sense, particularly in the east, may in fact be limiting the spread of invasives, due to a lack of canals and periodically flooded agricultural field systems, coupled with natural seasonal drying. By contrast, the introductions of invasive fish into lotic (i.e., flowing water) environments is of great concern, since this enables highly vagile invasives such as tilapia, mosquitofish, or snakeheads to repeatedly penetrate both riverine and ephemeral riparian wetland habitats after seasonal flooding. Particularly problematic in this regard has been the introduction and continuing spread of snakeheads (*Channa* spp.) because of their ability to survive buried in the mud of ephemeral wetlands for months utilizing their accessory breathing organ. This predaceous invasive has the potential to spread throughout the entire coastal wetland zone of southern New Guinea, from Etna Bay eastward to at least the Lakekamu River.

Although the invasive fish species already present in New Guinea appear to be undergoing population expansions, thereby posing a grave threat to native species (Allen 1991), the specific impacts of such invasives on aquatic organisms endemic to New Guinea have for the most part not been determined. Similarly, little work has been undertaken regarding the identity or spread of other invasive freshwater animal species, particularly invertebrates.

The following section provides additional detail on many of the most significant invasive fishes documented from the New Guinea region, and their varying degrees of ecological impact as known to date:

Carp

Carp (*Cyprinus carpio*) are common in a few areas such as the upper Baliem River in Irian Jaya, Lake Kopiago, and the Lower and Middle Sepik and Ramu River systems (Allen 1991). Like many invasive fish species, carp modify their environment to conditions for which they are better suited to survive in than native fish species. Worldwide, carp are regarded as a pest fish because of their tendency to uproot and destroy aquatic vegetation that results in increased turbidity and a deterioration in habitats used by native species (Fuller *et al.* 1999). Carp have been found to not only impact native fish species directly through egg predation, but also negatively impact waterfowl by increasing turbidity causing a reduction in food availability needed by both birds and native fish (Fuller *et al.* 1999).

Tilapia

Tilapia (*Oreochromis* or *Sarotherodon* spp.) are perhaps one of the most adaptable and widespread species of fish in existence, and have been stocked throughout the world. These highly invasive fish species are now abundant in the Timika region (Allen *et al.* 2000), and lower Ramu and middle and lower Sepik rivers, and have become the most important food fish in the Sepik area (Allen 1991). Tilapia have ecological impacts similar to carp as they uproot aquatic plants, are known to feed on wetland taro, and reduce food supplies for native bird species (Englund and Eldredge 2001). In contrast to carp, tilapia are even more invasive in tropical areas because their ability to withstand saline and brackish-water environments (Englund and Eldredge 2001) allows them to spread along a coastline.

Snakeheads

Native to areas of Indonesia west of Weber's Line, snakeheads (*Channa striata*) currently are found on Waigeo Island off western Papua (Allen *et al*. 2000); in streams near Bintuni on the Vogelkop Peninsula (Allen 1991); and in the Timika region (Allen *et al*. 2000). Because migrants prefer eating this fish, it is commonly first found near migrant settlements (Allen *et al*. 2000) and would be expected to be spread throughout Irian Jaya by migrant communities. Species in the genus *Channa* are voracious and highly effective predators, and further establishment in New Guinea would have highly detrimental impacts to all freshwater biota. Snakeheads have been implicated in the extinction of at least 4 species of fish in Madagascar, and has displaced the formerly common native Cichlid genus *Paratilapia* from the central highlands and Lake Aloatra (Courtenay *et al*. 2004). Snakeheads appeared to have caused a general reduction of native fish numbers and diversity in areas where they are present (Allen *et al*. 2000).

Trout

Brown trout (*Salmo trutta*) were introduced in 1949 to the highland regions of PNG, and by 1952 had become established in this area (Werry 1998). In PNG, the effect of rainbow trout on the native ichthyofauna appears to be minimal because the trout have been stocked and only survive in high elevation (> 2000 m) areas lacking native fish (Allen 1991). Rainbow trout have also been documented to prey upon two species of endemic waterbugs, *Nesocricos mion* and *Tanycricos acumentum* in the highlands of PNG (Polhemus and Polhemus 1985, 1986). The impacts of this predation are unknown, however, and these insect species still remain common enough after the introduction of trout to be used as trout bait by highland tribesman (Polhemus and Polhemus 1985). In PNG, rainbow trout are thermally restricted to highland regions lacking native fish, and they appear to have low impacts on the native aquatic fauna (Allen 1991); whereas in Australia and New Zealand brown trout, and rainbow trout to a lesser extent, have been shown to adversely impact native fish species.

Livebearers (Family Poeciliidae)

At least three poeciliid species have been recorded from New Guinea; mosquitofish (*Gambusia affinis*), guppies (*Poecilia reticulata*), and green swordtails (*Xiphophorus helleri*). Mosquitofish are found in the Sepik and Ramu rivers, Lake Kutubu, and around Port Moresby (Allen 1991). Mosquitofish and the other two species of poeciliids have been introduced into New Guinea to control mosquitoes but their impact on mosquitoes has been minimal and they prey upon and they instead crowd out effective native predators of mosquitoes such as the native rainbowfishes (Allen 1991). Guppies are common in the Goldie River and in streams around Port Moresby and are often the only fish present. In 2004, surveys funded by Conservation International found guppies in the lower Gumini River, Milne Bay Province; these guppies were the only invasive fish species found in this stream. Green swordtails are found in the lower Ramu and middle and lower Sepik Rivers, and this species has the ability to penetrate streams far inland (Englund and Eldredge 2001).

It is imperative to conduct biodiversity surveys for aquatic fauna prior to the spread of highly invasive poeciliid fishes, because they have been documented to cause the local extirpation of native invertebrates, such as species in the spectacular endemic Hawaiian damselfly genus *Megalagrion* (Englund 1999). Additionally, international agency personnel need to be educated that native fish are often as good or better at controlling mosquito populations. Any introduction of poeciliids for mosquito control is highly misguided because of potential non-target impacts to native vertebrates and invertebrates, and because mosquitoes are generally found in puddle-type habitats not frequented by poeciliid fish.

Walking Catfish

Walking catfish (*Clarias batrachus*) have increased their numbers around the Timika region since 1997, and are now common in some areas there (Allen et al. 2000). This species was first introduced into New Guinea in the Lake Sentani region and is now also found in the Vogelkop Peninsula (Allen 1991). Similar to snakeheads, walking catfish have an accessory air-breathing organ allowing them to survive for long periods of time out of the water or in low-oxygen water. The impacts of this species on native biota are largely unknown (Fuller *et al.* 1999), but it does have excellent dispersal abilities once established because of its facultative air-breathing capabilities.

Blue Panchax

The blue panchax (*Aplocheilus panchax*) is an ornamental aquarium species apparently being introduced for mosquito control, and is now rapidly spreading in peat swamps and disturbed areas in the Timika region (Allen 2000). Similar to mosquitofish, this species can tolerate brackish water and may have similar impacts on native invertebrates. However, impacts to native biota are currently unknown.

Climbing Perch or Climbing Gouramies

Apparently first introduced into New Guinea in Irian Jaya (now Papua Province), climbing perch or climbing gouramies are one of the most widely distributed invasive fish species in New Guinea and are found from the Timika region of Indonesian New Guinea to the Morehead River area of PNG (Allen 2000). This species is one of the hardiest of fishes (Fuller *et al.* 1999) because its accessory air-breathing organ allows it to survive for up to six days out of water (Allen *et al.* 2000). The use of its strong fin spines allows it to traverse considerable distances on land, and it is found in fresh to brackish water (Fuller *et al.* 1999). The impacts of this fish on native biota in New Guinea are unknown.

Gouramies

Introduced primarily as a food fish, two families and three species of gourami are found in New Guinea. Two species in the family Belontiidae, the snakeskin gourami (*Trichogaster pectoralis*) and threespot gourami (*Trichogaster trichopterus*) have restricted ranges and do not appear to be highly invasive as the range of both of these species remains quite limited in New Guinea (Allen 1991). Werry (1998) states *T. pectoralis* is established in the southern lowland floodplain systems and certain areas around Port Moresby. The giant gourami (Family Osphronemidae), *Osphronemus goramy*, was introduced in 1957 but most introductions appear to have been unsuccessful and not in sufficient quantities to provide a fishery (Werry 1998). Impacts to native biota from gouramies are likely minimal because these species have not spread or even become successfully established except in a few instances.

URGENCY OF NEED TO ASSESS BIOTA

The foregoing analysis of endemism and threats clearly demonstrates that even though the rich aquatic biota of New Guinea is still largely intact, it faces increasing dangers on many fronts, a situation reflective of aquatic biotas across Melanesia as a whole. Although physical destruction of aquatic habitats by various means should by no means be dismissed, it is clear that the main threat facing this regional aquatic biota in the near term is invasive species.

For the invasive aquatic species already present, it is important to understand what effects they are having, and how quickly they are expanding their ranges. Such studies would make excellent research projects for local students at universities and secondary schools in the region. For instance, many of the invasive fish species now present in New Guinea have been documented to cause extinction or severe range reductions of native fish and invertebrate taxa in other areas of the world, but their specific impacts within the context of New Guinea ecosystems are at present conjectural. Similarly, the introduced cane toad (*Bufo marinus*) was observed to be spreading from the Milne Bay area of far eastern Papua New Guinea to offshore islands east of the China Strait in early 2004, but its effects on native aquatic biota have not yet been determined. The situation is even less clear in regard to invertebrates; it is not currently known whether any species of invasive freshwater insects, crustaceans or molluscs are having an impact on New Guinea freshwater systems. Given, however, that no evidence of such invasive invertebrate species was encountered during the recent faunal surveys that contributed to this report, we believe that most if not all of the current freshwater invasives on the island are fishes.

Given that invasive species problems are still at an early stage in New Guinea, and across Melanesia as a whole, it is imperative to expand the current freshwater biodiversity analysis of New Guinea to cover the entire region. In many areas, such as the Solomons and Vanuatu, this will require comprehensive field surveys of the aquatic biota, which should be conducted as soon as possible in order to have a proper frame of reference from which to judge future impacts invasive species. Of concern are continuing fish introductions promoted by the U.N. and its various agencies such as Food and Agriculture Organization to provide alternative protein sources and cash earning opportunities. Werry (1998) documented the introduction of six invasive fish species to New Guinea between 1991 and 1997 through FAO programs, and a similar government-sponsored introduction of *Tilapia* has also occurred in the Solomon Islands. These introductions, coupled with the importation of food fishes by migrants, threaten the unique vertebrate and invertebrate biodiversity found in the streams Melanesia. Only through a proper base of scientific knowledge can such impacts be mitigated or avoided, thereby conserving these remarkable freshwater communities for future generations.



Tubetube Island, Milne Bay: left to right, D. Polhemus, Smithsonian Institution, sampling Tubetube Island estuaries; *Teinobasis rufithorax* (female) collected in this area; Neil Lima of C.I. sampling

Stiphodon birdsong, Basilaki Island

Neil Lima, C.I., collecting samples Basilaki Island

Pristine mangrove estuary, Tufi

Microphis brachyurus, Sideia Island

Small streamlet, Normanby Island

REFERENCES

Allen, G. R. 1991. *Field guide to the freshwater fishes of New Guinea*. Publication No. 9, Christensen Research Institute. Calendar Print Pte. Ltd., Singapore. 268 pp.

Allen, G.R. 1995. *Rainbowfishes in nature and the aquarium*. Tetra Press, Melle, Germany. 180 pp.

Allen, G. A. 2003a. Unexplored islands of Papua New Guinea. *Fishes of Sahul*, 17 (2): 926–948.

Allen, G. R. 2003b. *Allomogurnda*, a new genus of gudgeon (Eleotridae) from fresh waters of New Guinea, with descriptions of 7 new species. *Fishes of Sahul* 17 (3–4): 978–997.

Allen, G. R., K. G. Hortle and S. J. Renyaan. 2000. *Freshwater Fishes of the Timika Region, New Guinea*. P. T. Freeport Indonesia, Timika. 175 pp.

Allen, G. R., Ohee, H., Boli, P., Bawole, R., and Warpur, M. 2002. Fishes of the Yongsu and Dabra areas, Papua, Indonesia. *In* Richards, S.J. and Suryadi, S. (eds.), A biodiversity assessment of Yongsu-Cyclops Mountains and the southern Mamberamo Basin, Papua, Indonesia. RAP Bulletin of Biological Assessment 25. Conservation International, Washington, DC.

Andersen, N. M. 1975. The *Limnogonus* and *Neogerris* of the Old World. *Entomologica Scandivanica*, *Suppl*. 7: 1-96.

Andersen, N. M. 1989a. The coral bugs, genus *Halovelia* Bergroth (Hemiptera, Veliidae). I. History, classification and taxonomy of species except the *H. malaya*-group. *Entomologica Scandivanica*, 20: 75–120.

Andersen, N. M. 1989b. The coral bugs, genus *Halovelia* Bergroth (Hemiptera, Veliidae). II. Taxonomy of the *H. malaya*-group, cladistics, ecology, biology and biogeography. *Entomologica Scandivanica*, 20: 179–227.

Bain, J. H. C., H. L. Davies, P. D. Hohnen, R. J. Ryburn, I. E. Smith, R. Grainger, R. J. Tingey and M. R. Moffat. 1972. Geology of Papua New Guinea. Bureau of Mineral Resources Australia, Canberra, Geology and Geophysics, Canberra. 1:1,000,000 scale map.

Brinck, P. 1976. The Gyrinidae of the Bismarck Archipelago and the Solomon Islands (Coleoptera: Gyrinidae). *Entomologica Scandivanica*, 7: 81–90.

Brinck, P. 1981. *Spinosodineutes* (Coleoptera: Gyrinidae) in New Guinea and adjacent islands. *Entomologica Scandinavica Suppl*. 15: 353–364.

Brinck, P. 1983. A revision of *Rhombodineutes* Ochs in New Guinea (Coleoptera: Gyrinidae). *Entomologica Scandinavica*, 14: 205–233.

Brinck, P. 1984. Evolutionary trends and specific differentiation in *Merodineutes* (Coleoptera: Gyrinidae). *International Journal of Entomology*, 26 (3): 175–189.

Brooks, G. T. 1951. A revision of the genus Anisops (Notonectidae, Hemiptera). *University of Kansas Science Bulletin* 34 (1) (8): 301–519.

Courtenay, W. R., Jr., J. D. Williams, R. Britz, M. N. Yamamoto, P. V. Loiselle. 2004. Identity of introduced snakeheads (Pisces, Channidae) in Hawai‘i and Madagascar, with comments on ecological concerns. *Bishop Museum Occasional Papers* 77: 1–13 pp.

Davies, H. L., Perembo, R. C. B., Winn, R. D., and K. Gemar, P. 1997. Terranes of the New Guinea orogen. Pp. 61–66 *in* Proceedings of the Geology Exploration and Mining Conference, Madang. Edited by G. Hancock. Australian Institute of Mining and Metallurgy, Melbourne.

Demoulin, G. 1954. Contribution à l'étude des Palingeniidae (Insecta, Ephemeroptera). *Nova Guinea (Zoology)* 33: 305–344, 8 figs.

Dow, D. B. 1977. A geological synthesis of Papua New Guinea. *Bulletin of the Bureau of Mineral Resources Australia* 201: 1–41.

Dow, D. B., G. P. Robinson, U. Hartono and N. Ratman. 1986. Geologic map of Irian Jaya, Indonesia. Geological Research and Development Centre, Ministry of Mines and Energy, Bandung. 1:1,000,000 scale map.

Englund, R. A. 1999. The impacts of introduced poeciliid fish and Odonata on endemic Megalagrion (Odonata) damselflies on Oahu Island, Hawaii. *Journal of Insect Conservation* 3: 225–243.

Englund, R.A. and L.G. Eldredge. 2001. Fishes. *In*: Hawaii's invasive species, a guide to invasive plants and animals in the Hawaiian Islands (eds. G. W. Staples and R. H. Cowie), p. 32–40. Mutual Publishing & Bishop Museum Press, Honolulu.

Förster, V. F. 1898. Odonaten aus Neu-Guinea. *Beiträge zur Kenntniss der indo-australischen Odonatenfauna*, Nr. 7: 271–302.

Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. *Nonindigenous fishes introduced into inland waters of the United States*. American Fisheries Society, Bethesda, Maryland. 613 p.

Gentili, E. 1980. The genus *Laccobius* in Melanesia (Coleoptera: Hydrophilidae). *Pacific Insects* 22 (3-4): 385–400.

Gentili, E. 1981. I *Laccobius* di Nuova Guinea conservati al Museo "G. Doria" di Genova. Ann. Museo Civico di Storia Naturale Genova, 83: 271–274.

Gentili, E. 1988. Verso una revisione del genere *Laccobius* (Coleoptera, Hydrophilidae). *Annuario Oss. Fis. Terr. Mus. Stoppani Semin. Arc. Milano* (n.s.) 9 (1986): 31–47.

Gentili, E. 1989. Alcune novitá sul genere *Laccobius* (Coleoptera, Hydrophilidae). *Annuario Oss. Fis. Terr. Mus. Stoppani Semin. Arc. Milano* (n.s.) 10 (1987): 32–39.

Grant, P. M. 1985. Systematic revision of the *Thraulus* group genera (Ephemeroptera: Leptophlebiidae: Atalophlebiinae) from the Eastern Hemisphere. Dissertation, Florida State University. 333 pp.

Hamilton, W. 1978. Tectonic map of the Indonesian region. U. S. Geol. Survey. Misc. Invest. Ser., Map 1-875-D. U. S. Gov. Printing Office, Washington, D. C. 1:5,000,000 scale map.

Hamilton, W. 1979. Tectonics of the Indonesian region. U. S. Geological Survey Professional Paper 1078. 345 pp.

Hill, K. C. and R. Hall. 2003. Mesozoic–Cenozoic evolution of Australia's New Guinea margin in a west Pacific context, pp. 265–290 *in* R. R. Hillis & R. D. Müller (eds.), Evolution and Dynamics of the Australian Plate. Geological Society of Australia Special Publication 22 and Geological Society of America Special Paper 372.

Hitchcock, G. 2002. Fish fauna of the Bensbach River, southwest Papua New Guinea. *Memoirs of the Queensland Museum* 48(1): 119-122.

Hitchcock, G. In press. Cross-border trade in Saratoga fingerlings from the Torassi or Bensbach River, southwest Papua New Guinea. *Traffic Bulletin of the IUCN*.

Holthuis, L. B. 1939. Decapoda Macrura, with a revision of the New Guinea Parastacidae. *Zoological Results of the Dutch New Guinea Expedition 1939*, 3: 289–328.

Holthuis, L. B. 1950. Results of the Archibold Expeditions. No. 63. The Crustacea Decapoda Macrura collected by the Archbold New Guinea Expeditions. *American Museum Novitates*, 1461: 1–17.

Holthuis, L. B. 1956. Contributions to New Guinea carcinology I. *Nova Guinea*, (n.s.) 7: 123–137.

Holthuis, L. B. 1958. Freshwater crayfish in the Netherlands New Guinea Mountains. *SPC Quarterly Bulletin*, 8: 36–39.

Holthuis, L. B. 1982. Freshwater Crustacea Decapoda of New Guinea, pp. 603–619, in J. L. Gressitt, (ed.), *Biogeography and Ecology of New Guinea*. Dr. W. Junk, The Hague.

Holthuis, L. B. 1986. The freshwater crayfish of New Guinea. *Freshwater Crayfish*, 6: 48–58.

Hungerford, H. H. and R. Matsuda. 1965. The genus *Ptilomera* Amyot and Serville (Gerridae: Hemiptera). *University of Kansas Science Bulletin*, 45: 397–515.

IUCN. 1991. *A Directory of Asian Wetlands*. IUCN Conservation Monitoring Centre, Cambridge. 1181 pp.

Kormilev, N. A. 1971. Ochteridae from the Oriental and Australian regions (Hemiptera-Heteroptera). *Pacific Insects*, 13: 429–444.

Lansbury, I. 1962. Notes on the genus *Anisops* in the Bishop Museum (Hem.: Notonectidae). *Pacific Insects*, 4 (1): 141–151.

Lansbury, I. 1963. Notes on water-bugs of Solomon Islands and New Hebrides. *Pacific Insects*, 5 (1): 5-10.

Lansbury, I. 1965. A new tribe and genus of Notonectidae (Heteroptera: Notonectidae) from Borneo. *Pacific Insects*, 7 (2): 327–332.

Lansbury, I. 1966. Notes on the genus *Aphelonecta* (Hemiptera-Heteroptera: Notonectidae). *Pacific Insects,* 8 (3): 629–632.

Lansbury, I. 1968a. The *Enithares* (Hemiptera-Heteroptera: Notonectidae) of the Oriental Region. *Pacific Insects*10 (2): 353–442.

Lansbury, I. 1968b. A revision of the genus *Paranisops* (Heteroptera: Notonectidae). *Proceedings of the Royal Entomological Society of London* (B) 33 (11–12):181–188.

Lansbury, I. 1968c. 50. Notonectidae (Hemiptera-Heteroptera) of Rennell Island. *The Natural History of Rennell Island, British Solomon Islands*, 5: 95–98.

Lansbury, I. 1969. The genus *Anisops* in Australia (Hemiptera-Heteroptera, Notonectidae). *Journal of Natural History*, 3: 433–458.

Lansbury, I. 1972. A review of the Oriental species of *Ranatra* Fabricius (Hemiptera-Heteroptera: Nepidae). *Transactions of the Royal Entomological Society of London*, 124 (3): 287–341, 262 figs.

Lansbury, I. 1973. A review of the genus *Cercotmetus* Amyot and Serville, 1843 (Hemiptera-Heteroptera: Nepidae). *Tijdschrift voor Entomologie*, 116 (5): 83–106, 91 figs.

Lansbury, I. 1974. Notes on the genus *Enithares* Spinola (Hem., Notonectidae). *Entomologist's Monthly Magazine*, 109: 226–231.

Lansbury, I. 1975. Notes on additions, changes and the distribution of the Australian water-bug fauna (Hemiptera-Heteroptera). *Memoirs of the National Museum of Victoria* 36: 17–24.

Lansbury, I. 1993. *Rhagovelia* of Papua New Guinea, Solomon Islands and Australia (Hemiptera-Veliidae). *Tijdschrift voor Entomologie*, 136: 23–54.

Lansbury, I. 1996. Two new species of *Ciliometra* Polhemus (Hem., Gerridae) from Papua New Guinea. *Entomologist's Monthly Magazine*, 132: 55–60.

Lieftinck, M. A. 1932. The dragonflies (Odonata) of New Guinea and neighboring islands. Part I. Descriptions of new genera and species of the families Lestidae and Agrionidae. *Nova Guinea 15, Zoology* 5: 485–602.

Lieftinck, M. A. 1933. The dragonflies (Odonata) of New Guinea and neighboring islands. Part II. Descriptions of a new genus and species of Playcneminae (Agrionidae) and of new Libellulidae. *Nova Guinea 17, Zoology* 1: 1–66.

Lieftinck, M. A. 1935. The dragonflies (Odonata) of New Guinea and neighboring islands. Part III. Descriptions of new and little known species of the families Megapodagrionidae, Agrionidae, and Libellulidae (genera *Podopteryx*, *Argiolestes*, *Papuagrion*, *Teinobasis*, *Huonia*, *Synthemis*, and *Protocordulia*). *Nova Guinea* 17, Zoology 203–300.

Lieftinck, M. A. 1937. The dragonflies (Odonata) of New Guinea and neighboring islands. Part IV. Descriptions of new and little known species of the families Agrionidae (sens. lat.), Libellulidae and Aeshnidae (genera *Idiocnemis*, *Notoneura*, *Papuagrion*, *Teinobasis*, *Aciagrion*, *Bironides*, *Agyrtacantha*, *Plattycantha* and *Oreaeschna*). *Nova Guinea*, (n.s), 1: 1–82.

Lieftinck, M. A. 1938. The dragonflies (Odonata) of New Guinea and neighboring islands. Part V. Descriptions of new and little known species of the families Libellaginidae, Megapodagrionidae, Agrionidae (sens. lat.) and Libellulidae (genera *Rhinocypha*, *Argiolestes*, *Drepanosticta*, *Notoneura*, *Palaiargia*, *Papuargia*, *Papuagrion*, *Teinobasis*, *Nannophlebia*, *Synthemis* and *Anacordulia*). *Nova Guinea*, (n.s.), 2: 47–128.

Lieftinck, M. A. 1949a. Synopsis of the Odonate fauna of the Bismarck Archipelago and the Solomon Islands. *Treubia*, 20, part 2: 319–374.

Lieftinck, M. A. 1949b. The dragonflies (Odonata) of New Guinea and neighboring islands. Part VII. Results of the Third Archibold Expedition 1938-1939 and of the Le Roux Expedition 1939 to Netherlands New Guinea (II. Zygoptera). *Nova Guinea* (n.s.), 1: 1–82.

Lieftinck, M. A. 1955a. Notes on Australasian species of *Neurobasis* Selys (Odonata, Argiidae). *Nova Guinea,* (n.s.), 6 (1): 155–166.

Lieftinck, M. A. 1955b. Notes on species of *Nannophlebia* Selys from the Moluccas and New Guinea (Odonata). *Zoologische Mededelingen*, 33 (29): 301–318.

Lieftinck, M. A. 1956a. Revision of the genus *Argiolestes* Selys (Odonata) in New Guinea and the Moluccas. *Nova Guinea,* (n.s.), 7 (1): 59–121.

Lieftinck, M. A. 1956b. Two new Platycnemididae (Odonata) from the Papuan region. *Nova Guinea,* (n.s.), 7 (2): 249–258.

Lieftinck, M. A. 1957. Notes on some argiine dragonflies (Odonata) with special reference to the genus *Palaiargia* Forster, and with descriptions of new species and larval forms. *Nova Guinea,* (n.s.), 8 (1): 41–80, 5 pls.

Lieftinck, M. A. 1958. A review of the genus *Idiocnemis* Selys in the Papuan region, with notes on some larval forms of the Platycnemididae. *Nova Guinea*, (n.s.), 9 (2): 253–292.

Lieftinck, M. A. 1959a. On the New Guinea species of *Ischnura* Charpentier and Oreagrion Ris, with special reference to the larval forms and notes on the species of adjacent regions (Odonata, Coenagrionidae). *Nova Guinea,* (n.s.), 10 (2): 213–240.

Lieftinck, M. A. 1959b. New and little known isostictine dragonflies from the Papuan region (Odonata, Protoneuridae). *Nova Guinea,* (n.s.), 10 (2): 279–302.

Lieftinck, M. A. 1960. Three new species of *Notoneura* Tillyard from western New Guinea. *Nova Guinea,* (n.s.), 10 (7): 117–126.

Lieftinck, M. A. 1963. New species and records of Libellulidae from the Papuan region. *Nova Guinea, Zoology*, 25: 751–780.

Nederlandsch Aardrijkskundig Genootschap, Amsterdam. 1938. *Atlas van tropisch Nederland* [Atlas of the Tropical Netherlands], uitgegeven door het Kononklijk nederlandsch aardrijkskundig genootschap in samenwerking met den Topographischen dienst in Nederlandsch-Indie. Reproductiebedrijf van den Topografischen dienst in Ned.-Indie [Topographic Section of the Netherlands East Indies], Batavia [Jakarta]. 9 pp., 31 maps. (In Dutch).

Ochs, G. 1925. Über papuanische Gyriniden. *Senckenbergiana*, 7 (5): 172–177.

Ochs, G. 1955. Die Gyriniden-fauna von Neuguinea nach dem derzeitigen stand unserer kenntnisse (Coleoptera: Gyrinidae). *Nova Guinea, New Series*, 6 (1): 87–154.

Ochs, G. 1960. Nachtrag zur Gyriniden-fauna von Neuguinea. *Opuscula Zoologica*, 53: 1–4.

Petocz, R. G. 1989. *Conservation and development in Irian Jaya*. A Strategy for Rational Resource Utilization. E. J. Brill, Leiden. xxii + 218 pp.

Pigram, C. J. and Davies, H. L. 1987. Terranes and the accretion history of the New Guinea orogen. Bureau of Mineral Resources, *Journal of Australian Geology and Geophysics*, 10: 193–211.

Polhemus, D. A., J. Maciolek and J. Ford. 1992. An ecosystem classification of inland waters for the tropical Pacific islands. *Micronesica*, 25 (2): 155–173.

Polhemus, D. A. 1994. Conservation of aquatic insects: worldwide crisis or localized threats? *American Zoologist*, 33: 588–598.

Polhemus, D. A. and J. T. Polhemus. 1985. Naucoridae of New Guinea, I. A review of the genus *Nesocricos* La Rivers (Hemiptera: Naucoridae) with descriptions of two new species. *International Journal of Entomology*, 27(3): 197–203.

Polhemus, D. A. and J. T. Polhemus. 1986a. Naucoridae of New Guinea, II. A review of the genus *Idiocarus* Montandon (Hemiptera: Naucoridae) with descriptions of three new species. *Journal of the New York Entomological Society*, 94(1): 39–50.

Polhemus, D. A. and J. T. Polhemus. 1986b. Naucoridae of New Guinea. III. A review of the genus *Tanycricos* with description of a new species. *Journal of the New York Entomological Society*, 94: 163–173.

Polhemus, D. A. and J. T. Polhemus. 1989a. Naucoridae (Heteroptera) of New Guinea. IV. A revision of the genus *Cavocoris* La Rivers, with descriptions of four new species. *Journal of the New York Entomological Society*, 97: 73–86.

Polhemus, D. A. and J. T. Polhemus. 1989b. The Aphelocheirinae of tropical Asia (Heteroptera: Naucoridae). *Raffles Bulletin of Zoology*, 36: 167–310.

Polhemus, D. A. and J. T. Polhemus. 1997. A review of the genus *Limnometra* Mayr in New Guinea, with the description of a very large new species (Heteroptera: Gerridae). *Journal of the New York Entomological Society*, 105: 24–39.

Polhemus, D. A. & J. T. Polhemus. 1998. Assembling New Guinea - 40 million years of island arc accretion as indicated by the distribution of aquatic Heteroptera (Insecta), pp. 327–340 *in* R. Hall and J. Holloway, (eds.), Biogeographical and Geological Evolution of SE Asia. Backhus Publishers, Leiden. 417 pp.

Polhemus, D. A. & J. T. Polhemus. 2000a. Naucoridae (Heteroptera) of New Guinea. 6. A revision of the genera *Sagocoris* and *Aptinocoris*, with descriptions of new species. *Journal of the New York Entomological Society*, 107 (4): 331–371.

Polhemus, D. A. and J. T. Polhemus. 2000b. Additional new genera and species of Microveliinae (Heteroptera: Veliidae) from New Guinea and adjacent regions. *Tijdschrift voor Entomologie*, 143: 91–123.

Polhemus, D. A. & J. T. Polhemus. 2000c. New species of Microveliinae (Heteroptera: Veliidae) from the Raja Ampat Islands. *Tijdschrift voor Entomologie*, 143: 279–289.

Polhemus, D. A. and J. T. Polhemus. 2000d. A biodiversity survey of aquatic insects in the Ajkwa River basin and adjacent areas, Irian Jaya, Indonesia. *Tropical Biodiversity*, 5: 197–216.

Polhemus, J. T. and D. A. Polhemus. 1987. The genus *Valleriola* Distant (Hemiptera: Leptopodidae) in Australia, New Caledonia, and Papua New Guinea with notes on zoogeography. *Journal of the Australian Entomological Society*, 26: 209–214.

Polhemus, J. T. and D. A. Polhemus. 1990. Aquatic Heteroptera of Celebes: regional relationships versus insular endemism, pp. 73–86 *in* Insects and the Rain Forests of South East Asia (W. J. Knight and J. D. Holloway, eds.). Royal Entomological Society of London, London. 343 pp.

Polhemus, J. T. and D. A. Polhemus. 1991. Three new species of marine water striders from the Australasian region, with notes on other species (Gerridae: Halobatinae, Trepobatinae). *Raffles Bulletin of Zoology*, 39 (1): 1–13.

Polhemus, J. T. and D. A. Polhemus. 1993. The Trepobatinae (Heteroptera: Gerridae) of New Guinea and surrounding regions, with a review of the world fauna. Part 1. Tribe Metrobatini. *Entomologica Scandivanica*, 24 (3): 241–284.

Polhemus, J. T. and D. A. Polhemus. 1994a. Four new genera of Microveliinae (Heteroptera) from New Guinea. *Tijdschrift voor Entomologie*, 137: 57–74.

Polhemus, J. T. and D. A. Polhemus. 1994b. The Trepobatinae (Heteroptera: Gerridae) of New Guinea and surrounding regions, with a review of the world fauna. Part 2. Tribe Naboandelini. *Entomologica Scandivanica*, 25: 333–359.

Polhemus, J. T. and D. A. Polhemus. 1995. The Trepobatinae (Heteroptera: Gerridae) of New Guinea and surrounding regions, with a review of the world fauna. Part 3. Tribe Trepobatini. *Entomologica Scandivanica*, 26: 97–117.

Polhemus, J. T. and D. A. Polhemus. 1996. The Trepobatinae (Heteroptera: Gerridae) of New Guinea and surrounding regions, with a review of the world fauna. Part 4. The marine tribe Stenobatini. *Entomologica Scandivanica*, 27: 279–346.

Polhemus, J. T. and D. A. Polhemus. 2000. The Trepobatinae (Heteroptera: Gerridae) of New Guinea and surrounding regions, with a review of the world fauna. Part 5. Taxonomic and distributional addenda. *Insect Systematics and Evolution*, 31: 291–316.

Susapu, B. and G. Crispin. 2001. Report on small-scale mining in Papua New Guinea. Mining, Minerals and Sustainable Development Project, International Institute for Environment and Development, (IIED), Rep. 81. 29 pp.

Todd, E. L. 1955. A taxonomic revision of the family Gelastocoridae (Hemiptera). *University of Kansas Science Bulletin*, 37 (11): 277–475.

Todd, E. L. 1959. The Gelastocoridae of Melanesia (Hemiptera). *Nova Guinea,* new series, 10: 61–94.

Werry, Lloyd P. 1998. A review of freshwater fish introductions in Papua New Guinea. *Science New Guinea* 24: 33–36.

Gerry Allen, Bishop Museum research affiliate, and Bena Sena of C.I. sampling a small stream on Tagula Island

Ron Englund, Bishop Museum, and Neil Lima of C.I. photographing damselflies onboard the *Marlin I*

APPENDIX: FRESHWATER BIOTA AND HABITAT PHOTOGRAPHS

Mortonagrion martini (Ris) found in lowland swamp forests near the coast, Sideia Island

Alluvial lowland swamp forests near Suloga Harbor, Woodlark Island, habitat of the very rare *Mortonagrion martini*

Teinobasis dolobrata Lieftinck found in coastal swamp forests draining the Huon Gulf, such as the Kofure River near Tufi

Argiolestes new sp. found during the present C.I. funded survey on waterfall faces and seeping banks at Sariba Island, pictured on the right.

Rhinocypha tincta, Sideia Island

Argiolestes annulipes, Sariba Island

Idiocnemus zebrina, male, Sariba Island

Idiocnemus zebrina, female, Sariba Island

Idiocnemus inaequidens, near Tufi

New species of amber-winged damselfly, Sideia Island

Nososticta salomonis, Sideia Island

Nososticta finisterre, Sariba Island

Tanymecosticta leptalea, Sariba Island

Pseudagrion silaceum, Gumini River, Alotau

Pseudagrion n. sp., Kofure Stream, Tufi

Selysneuria n. sp. 1, Gumini Stream, Alotau

Selysneuria raphia, Basilaki Island

Unknown damselfly, Basilaki Island

Drepansticta conica, Basilaki Island

Teinobasis rufithorax, male, Tubetube Island

Neritina turtoni, Sideia Island

Anisoptera sp. 1, male, Tubetube Island

Anisoptera sp. 1, female, Tubetube Island

Anisoptera sp. 2, Sariba Island

Anisoptera sp. 3, Sariba Island

Anisoptera sp. 4, Basilaki Island

Macrobrachium grandimanus, Sideia Island

Stiphodon sp., Sideia Island

Stiphodon sp., Basilaki Island

Eleotris sp., Basilaki Island

Ambassis sp., Sideia Island

Glossogobius hoesei, Vogelkop Highland lakes

Oxyeleotris caeca, a blind cave fish found in a limestone sinkhole near Kafka, Kikori River Basin, Papuan Gulf Foreland

Pseudomugil ivantsoffi, Arafura Foreland

Pseudomugil connieae, Popondetta area

Glossolepis dorityi, Northwest Papuan Coastal Lowlands

Melanotaenia catherinae, Raja Ampat Islands

Melanotaenia lacustris, Lake Kutubu

Melanotaenia praecox, Mamberamo Foreland

Mogurnda cingulata, Arafura Foreland

Hephaestus habbemai, Arafura Foreland

Glossogobius sp., Basilaki Island

Mogurnda sp., Sideia Island

Redigobius sp., Sideia Island

New *Lentipes* species, male, Goodenough Island

Awaetowa River Fergusson Island, D'Entrecasteaux Islands

Stream habitat Woodlark Island

Freshwater eel, *Gymnothorax polyuranodon*, Basilaki Island

Kolukolu Creek estuary, Tagula Island, Louisiade Archipelago

Dibuwa River, Normanby Island, D'Entrecasteaux Islands