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The NSF-Fiji Terrestrial Arthropod Survey: Overview[1,2]

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Abstract: A summary and overview of the NSF-funded project surveying the terrestrial arthropods of Fiji is presented.

BACKGROUND

Despite its central position amid the island groups of the southwest Pacific, the Fijian Archipelago is one of the most faunally unusual areas in the entire Pacific region. For although generally considered to be of Pacific geological origin, the Fiji group harbors New World lizards and African flies, elements that strongly suggest past continental associations for portions of the fauna.

In terms of proximity to other island groups, the Fijian Archipelago lies 1209 km from the Samoan Archipelago, 850 km from Tonga, 369 km from Vanuatu, and 1254 km from New Caledonia. This relatively close juxtaposition to other major Pacific island groups would suggest that the affinities of the Fijian arthropod fauna would be similar to those of the surrounding region. In fact, they are in many cases quite distinct. Critical assessment of this biogeographic anomaly and its origins has been hindered, however, by the absence of comprehensive surveys of the Fijian arthropod biota. Despite successive voyages of exploration and scientific expeditions to Fiji since its first European sighting in 1643 by Abel Tasman, very little has been published specifically in regard to the Fijian arthropod fauna and only a few surveys focusing specifically on arthropods have taken place. The current project will provide a more complete knowledge of the Fijian arthropod fauna, leading to a better understanding of the endemic components in this biota and their phylogenetic and geographic relationships.

Geography and Environment

The Fiji Islands in the eastern Melanesian region of the Central Pacific consist of over 500 named islands and occupy an ocean area of some 650,000 km^2 (Fig. 1) of which the land area is less than 3 percent. There are two large islands: Viti Levu (10,388 km^2) and Vanua Levu (5,535 km^2), two mid-sized islands: Taveuni (434 km^2) and Kadavu (408 km^2), and numerous smaller islands. The highest elevations are 1,323 m (Tomaniivi [= Mt. Victoria])

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2. Contribution No. 2005-003 to the Pacific Biological Survey.

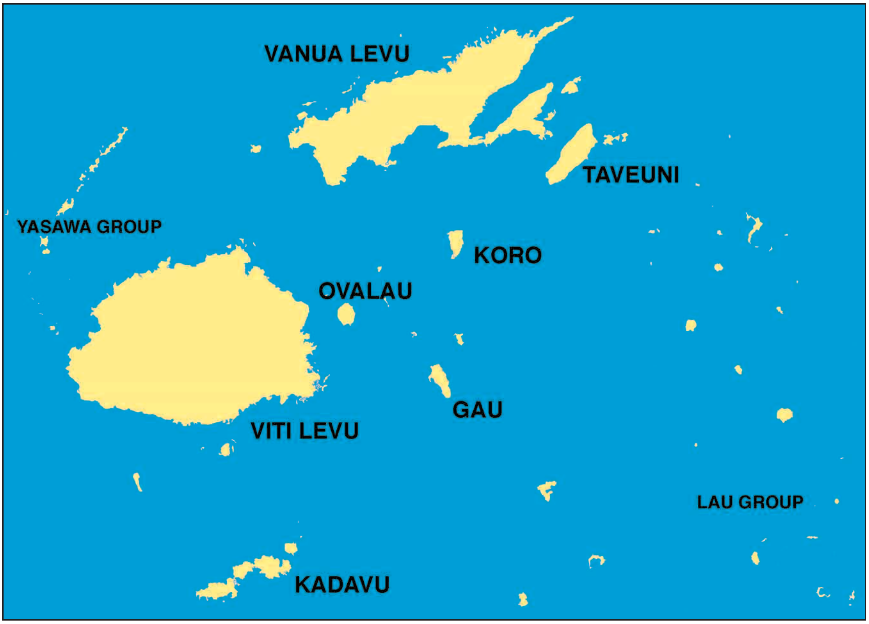

Figure 1. Map of the Fiji Islands showing some of the main islands where collecting stations are located.

on Viti Levu, 1,241 m (Mt. Uluiqala) on Taveuni, and 1,032 m (Mt. Batini) on Vanua Levu. The major islands are rugged, and landforms include volcanic plugs, eroded calderas, deep gorges, and ravines carved by mountain streams, flat-bottomed valleys with extensive flood plains, and mangrove dominated deltas. Although some of the Fijian Islands are true atolls, most of the low islands are composed of bedded limestone overlying volcanics.

Fiji has a warm, humid tropical maritime climate. There are few extremes in temperature, with mean monthly temperatures from 22 °C in July to 26 °C in January. The South East Trades predominate, bringing moisture-laden winds onto the land. On the larger islands, the orographic effect of the mountains is pronounced, with abundant cloud cover and rainfall on wet windward sides, and a marked rainshadow with diminished rainfall on the dry western or leeward sides. Because Fiji is subequatorial, there is weak seasonality, with widespread rainfall between November and April, with greatly diminished precipitation between May and October, especially on the low islands and the leeward sides of the large islands. Strong cyclonic depressions with high winds and rain occur infrequently from November through April. Average annual rainfall in the “dry zone” of the larger islands is between 165–229 cm, while in the lowland wet zone, 305–345 cm. Upland areas often receive 500+ cm, while certain localities in upland Taveuni receive almost 1000 cm of rainfall per year (Ash 1988). Fiji encounters between 10–15 cyclones per decade; 2–4 of these cause severe damage.

Vegetation

Rainfall is the most variable climatic factor in Fiji. It accounts for much of the variation in vegetation and, hence, the biota in general (documented for the Lepidoptera, Robinson 1975). Three generalized forest types occur on Fiji that correlate with rainfall: wet zone, dry zone, and coastal forests. Within these zones, local environmental factors further shape the composition of the forest communities (Mueller-Dombois & Fosberg 1998; Parham 1972; Smith 1979).

Wet Zone Vegetation. Moist tropical forest occurs as lowland rain forest, montane rain forest, and cloud forest. Elevations in Fiji are not high enough to break the continuity of the rainforest, and many species have a range extending from near sea level to the highest elevations. Montane rainforests (Fig. 2) are found in wind-exposed areas above 600 m where annual mean temperatures are 4–6 °C lower than in the lowland forests. Cloud forest occurs on ridges and peaks above 600 m on Fiji's largest islands. The Fijian rainforest has a comparatively large number of species in diverse families but lacks dominant floral indicator species. It supports many lianas, ferns, and epiphytes including orchids.

*Dry Zone Vegetation***.** The dry zones of Fiji, formerly covered with distinctive sclerophyllous forests and scrublands, occur on the leeward coasts and extend upward from sea level to about 450 m. On Viti Levu and to a lesser degree on Vanua Levu, the dry zone vegetation, after years of repeated burning, has been degraded to a flora dominated by grass and fern with many introduced invasive elements. The dry zone upland areas are of unusual interest, being well forested yet separated from the wet zone uplands by intervening tracts of grassland. They have been isolated sufficiently long for floristic endemism to have developed (Thaman 1996). On both Viti Levu and Vanua Levu, much of the area once covered by dry zone forest is now in sugar cane.

*Coastal Vegetation***.** The Fijian littoral and strand vegetation is part of the widely dispersed tropical Pacific coastal flora (Figs. 5, 6). Fiji also has considerable mangrove swamps, with the largest formations found in deltas of the large rivers or where the coastline is protected by barrier reefs. In the drier leeward areas with high seasonal evaporation, hyper-saline mudflats occur, a feature virtually absent in the wetter, windward mangroves.

Geology

In addition to its close proximity to other island groups, the geologic history of Fiji also provides some intriguing hypotheses as to faunal origins. Fiji is located along the tectonically active boundary zone between the Australian and Pacific Plates. The bedrock is a complex of volcanics, pyroclastic sediments, and limestone reef deposits developed since the early Cenozoic, some 40–50 Mya. In addition, uplift and erosion have exposed plutonic and low-grade regional metamorphic rocks of greater age. Limestones, often of great thickness, occur on Viti Levu. Overall, repeated volcanism and tectonic activity, combined with uplift and erosion have resulted in a complicated geology. The oldest exposed land surfaces on Fiji probably date from 5–20 Mya. Most soils are derived from underlying volcanics and uplifted coralline reefs, and alluvial soils are found along the floodplains of large rivers.

Figures 2–4. Selected habitats in Fiji. **2**. Mossy rainforest on the high plateau near Mount Tomanivi on Viti Levu. Photo N. Evenhuis. **3**. Waterfall near Colo-i-Suva on Viti Levu. **4**. Sigatoka sand dunes on leeward Viti Levu. Photos D.A. Polhemus.

Figures 5–6. Selected habitats in Fiji. **5**. Coastal mangrove habitat near Naqara Island along the south shore of Viti Levu with gymnosperm-dominated rainforest on background slopes. **6**. Volcanic rocks and shallow tidal area along shore on leeward Viti Levu. Photos D.A. Polhemus.

Theories on the origin of Fiji are contradictory and have evolved over the last few decades. For many years, Fiji was thought to have originated as a fragment of continental crust near the northeastern edge of the Indo-Australian Plate, where a subduction zone, indicated by the Vitaz Trench, is formed as the Pacific Plate subducts beneath a continental margin (Chase 1971; Green & Cullen 1973). The oldest rocks found in Fiji are from western Viti Levu and date from 34 Mya (Nunn 1998). Earlier authors (e.g., Green & Cullen 1973) hypothesized that Fiji emerged about 50 Mya (Eocene) as part of a volcanic arc, resulting in emplacement of a mixture of ophiolites (oceanic plate mantle) and intermixed with continental plate material. In this scenario, Fiji was part of an island arc system (the Vanuatu-Fiji-Lau-Tonga Ridge) that migrated eastward. Throughout this migration, Vanuatu was thought to be close to Fiji until the mid-Miocene (ca. 20 Mya). By contrast, Yan and Kroenke (1993) provided evidence to suggest that Fiji originated between 48 and 40 Mya on the Pacific Plate at the eastern edge of the outer island arc system, south of the Ontong Java Plateau. This island arc system was far east of the rifted continental sliver containing Norfolk and Lord Howe Islands, thus Fiji and Vanuatu were considered to be oceanic islands. This hypothesis indicates that Fiji and the older islands of Vanuatu emerged only in the last 10 Mya, shifting southward to their present position in relation to the New Hebrides Trench, which separates Vanuatu from New Caledonia.

It is difficult to find explicit statements as to when Fiji became subaerial, although Thornton (1981) believed that the Fiji archipelago was not emergent until the Miocene-Pliocene boundary (ca. 5 Mya). This hypothesis of recent emergence is at odds, however, with the presence of certain anomalous and poorly dispersive elements in the biota. The possibility that Fiji was part of an older migrating island arc system is more compatible with the high levels of endemism in seen in certain arthropod groups, because island arcs are persistent geologic features and their constituent islands are normally large and topographically complex (Polhemus 1996). Indeed, geological evidence suggests that as part of the Melanesian Arc, an ancestral Fiji was positioned much further west some 40 my, close to what is now the Solomon Islands (Hall, 2002)

A further complicating factor in relation to the islands' geologic history and geophysical features is the hypothesis that during the last glacial period [18,000 years B.P.—given an assumed $^{-}$120 m sea level change (Gibbons 1985)]—the islands of Viti Levu and Vanua Levu were in extremely close proximity, and separated by only a few kilometers. This distance could theoretically have permitted the exchange of many taxa between the two islands, and there is limited evidence from various arthropod groups to suggest that these large islands harbor discrete suites of endemic taxa.

In summary, Fiji's uncertain geological history, age, and proximity to other major Pacific island groups, coupled with the geographical complexity of the current islands in the Fijian archipelago, provide an excellent opportunity to utilize biotic data from arthropod groups as an independent means of testing competing geological and palaeogeographic hypotheses.

Biogeography

Fiji's position in the general biogeography of the southwestern Pacific has been reviewed by Keast (1996), Miller (1996), Gressitt (1961), Smith (1979), Mueller-Dombois &

Figure 7. Laboratory facility at the Ministry of Forestry in Colo-i-Suva serving as the center for sorting of arthropods and deposition of voucher collections. Photo D.A. Polhemus.

Fosberg (1998), and various authors in Keast & Miller (1996). The Fijian arthropod fauna shows the following affinities:

1. Papuan/Western Pacific source. This is the overall dominant pattern for the Fijian biota. For example, the Fijian flora shares 90% of its vascular plant genera with New Guinea (Ash 1992). Among the arthropods, macrolepidoptera (Robinson 1975), cicadas (Boer & Duffels 1996), dolichopodid flies (Bickel 1996); and some beetle families (Gressitt 1961) show this pattern as well.

2. Gondwanan source. The breakup of the Gondwanan supercontinent and the resultant drift and isolation of the component landmasses have produced vicariant patterns among the biota. In the SW Pacific, Gondwanan biotas are characteristic of the southern temperate regions. For a Fijian taxon to be Gondwanan, it would need to have direct phylogenetic links to a decidedly Gondwanan taxon from Australia, New Caledonia, or New Zealand—not indirectly via the Melanesian Archipelago. Some taxa, such as the endemic primitive family Degeneriaceae caused earlier speculation that Fiji might be a Gondwanan fragment, or that it arose near Australia (e.g., Raven & Axelrod 1972). However, geological evidence argues strongly against a direct connection, except for the possible accretion of the ‘Eua Ridge, which Kroenke (1996) suggested may have broken away from New Caledonia and drifted toward present-day Tonga, perhaps introducing a depauperate Gondwanan biota into Fiji some 6 Mya. Ash (1992) regards the Degeneriaceae in Fiji as a relict of a wide earlier Malesian distribution and not necessarily Gondwanan.

3. Widespread tramp species and/or accidental introductions. Many species have been accidentally introduced around the World with both prehistoric and recent human traffic.

In addition, there are many species, which are naturally widely dispersed. Such “tramp” species are often adapted to disturbed lowlands where they have an increased chance of both natural dispersal and accidental human transport.
4. *New World source*. The Fijian iguana genera (one extant, *Brachylophus*, and one fossil genus) are phylogenetically nested within the New World iguanas, strongly suggesting long distance dispersal from the Americas, probably by rafting and island hopping (Pregill & Steadman 2004). Some Fijian dipteran taxa may also show similar New World origins (some sciapodine Dolichopodidae; examples found from recent surveys include Mythicomyiidae).

Biogeographical Processes

1. Dispersal. Inter-island dispersal from a western Australasian source (and possibly also the Orient and Neotropics) is considered to be the principal source of derivation for much of the Fijian biota. The transoceanic dispersal capability of arthropods is well established, and many small-sized taxa are easily carried by wind (e.g., records in Holzapfel & Harrell 1968; Peck 1994a) or on oceanic flotsam (e.g., Peck 1994b).

2. Vicariance. In light of Fiji’s purported relatively young age, vicariant relationships with distant landmasses seem unlikely. However, the history of the Fiji and the Melanesian arc terrains is not well understood, and the possibility exists that that a component of the current biota has arisen through vicariance, mediated by tectonic rafting of small continental fragments from the Australian Plate. In addition, Pleistocene variations in sea level may have produced more recent vicariance events within the existing archipelago. Craig *et al*. (2001) suggested a combination of dispersal and vicariance to account for the distribution of the black fly subgenus *Inselliellum* (Simuliidae) in the western Pacific but also emphasized the importance of suitable habitat in determining the potential of colonization and subsequent radiation.

Biogeographical Potential

The Fijian biota has great potential to illuminate the biogeographical patterns and processes noted above. Although the terrestrial arthropod fauna is known only in outline, intriguing biogeographical links have been discovered, all of which require further investigation. A central Pacific-New World pattern in the dolichopodid flies is evident in the *Chrysosoma lacteimicans* group, known from the Samoan and Cook Islands, Micronesia, Fiji, and Vanuatu. Some of these species display marked similarities with the Neotropical *Amblypsilopus maculatus* group, but this is not clearly supported by strong synapomorphies, and indeed the generic placement of these two groups is equivocal (Bickel 1994). Further New World-Fijian links are suggested by newly discovered mythicomiid bee flies from the high rainforests of Taveuni, otherwise known from the more arid North and South American cordillera; and simuliid black flies from Taveuni, which are not the expected western Pacific subgenus *Hebridosimulium*, but a South American subgenus (D. Craig, pers. comm.). A link between Fiji and the Afrotropical fauna is suggested by agapophytine therevid snipe flies collected on the Sigatoka Sand Dunes, Viti Levu (Fig. 4) (M. Irwin, pers. comm.) and an undescribed genus of mythicomyiid fly found on Taveuni.

However, the geographic source or affinity of insular taxa may not be clear. Many genera or generic groups are widely distributed or cosmopolitan. Taxonomic literature is often fragmentary, and few groups have been analyzed so biogeographic provenance can be associated with unique synapomorphies (if indeed that is always possible). Fiji is likely to have many genera that are pantropical. If insect taxa arrived in Fiji through long distance dispersal from a presumed Papuan source or even the Neotropics, then it is desirable that the ancestral provenance be unequivocally demonstrated. For many insect genera this is impossible. This proposed project undoubtedly will produce many instances where the "dispersed" Fijian taxon becomes better known than that of any potential source area.

Previous Surveys

Early voyagers and explorers paid scant attention to the Fijian Islands and conducted few biological explorations. The Dutch explorer, Abel Tasman in 1643 was the first European to sight the Fijian Islands. He made no landfall, but sailed through the northern Lau group trying to avoid an oncoming hurricane and find safety in deeper waters. William Bligh in 1789, after the famous mutiny on the H.M.S. *Bounty*, passed between Viti Levu and Vanua Levu but, being unarmed, did not land. He returned in 1792 to map the islands.

Zoological exploration in Fiji began almost concurrently with expeditions by the French (*Astrolabe-Zélée* expedition, 1837–1840) and Americans (*U.S. Exploring Expedition*, 1838–1842). These expeditions resulted in only a few new taxa of arthropods being described. Scientific expeditions continued to be made to various of the Fijian islands and new taxa described based primarily on general collecting. In the 1860s, Eduard Graeffe, founder of the Godeffroy Museum in Hamburg, made one of the first biological explorations into the interior of Viti Levu (see Graeffe 1986 for an English translation of his personal travelogue), which resulted in some spectacular collections of walking sticks (*Graeffea* spp.), a huge cerambycid (*Xixuthrus heros*—114 mm long), and some buprestids. However, it was not until the American Museum of Natural History's *Whitney South Seas Expedition* in 1924 that significant and extensive collections of arthropods and associated observations were made (primarily by E.H. Bryan, Jr.), specimens of which are currently deposited in BPBM (as well as Bryan's journals and notes). The *Whitney* expedition visited Viti Levu, but was better known for collecting on almost all of the islands in the Lau Group and for the coining of Kadavu as "a collector's paradise" (Bryan 1924).

Subsequently, a few other scientific expeditions and other smaller visits were made to various of the Fijian islands in search of insects and other arthropods. In 1933, the *Zaca Expedition* (better known as the *Templeton-Crocker Expedition*) stopped in Fiji, with entomologist T.D.A. Cockerell and his wife making a rather cursory collection of arthropods. In 1938, the *Henry G. Lapham Expedition* with Bishop Museum entomologist Elwood C. Zimmerman on board made extensive collections of arthropods on the islands of Viti Levu, Ovalau, and Vanua Levu. Finally, from 1941–1981, Noel H.N. Krauss, Hawaii State exploratory entomologist, made several trips to Fiji in search of insects and other arthropods to be used in biological control of agricultural pests in Hawai'i.

Table 1. Comparison of Diptera Faunas of Selected Pacific Island Groups

Island Group	Size (km^2)	Families	Genera	Species
Fiji	18,376	57	296	493
Hawaiian Islands	16,640	58	342	1545
Samoan Archipelago	2,935	42	210	472

Current State of Knowledge of the Fijian Arthropod Fauna

There is little current comprehensive information published on the arthropod fauna of Fiji. Data available is found in scattered references dating as far back as the middle of the 19th century. Few complete treatments of major arthropod groups have been made and are, for the most part, more than 50 years old and in dire need of revision: Hemiptera (Kirkaldy 1908), orthopteroids *s. lat*. (Bruner 1916), Hymenoptera (Turner 1919), ants (Mann 1921), dragonflies (Tillyard 1924), Diptera Brachycera (Bezzi 1928), long-horned beetles (Dillon & Dillon 1943), Thysanoptera (Moulton 1944), and aculeate wasps (Williams 1947). More recent studies include: Psocoptera (Thornton 1981), cicadas (Duffels 1988), damselflies of the genus *Nesobasis* (Donnelly, 1990), and macrolepidoptera (Robinson 1975).

The arthropod composition of Fiji is only known for a few groups. However, based on recent checklists from Hawaii (Nishida 2002) and the Samoan Islands (Kami & Miller 1998) comparisons can be made for some groups. Table 1 shows the comparative levels of diversity for a few selected orders of insects in Fiji, Hawaii, and the Samoan Islands. To use Diptera as one example, Evenhuis (1989) is the most recent to catalog the entire Pacific Diptera. From this catalog and updated published and unpublished information, there are currently some 493 species of Diptera in 296 genera and subgenera in 57 families known from Fiji. This is in an interesting comparison to the 1545 species in 342 genera in 58 families found in Hawai‘i (Nishida 2002), which has a slightly smaller total land area (16,640 km^2) as compared to Fiji (18,376 km^2) and is roughly comparable to the numbers of species (472), genera (210) and families (42) of Diptera found in the much smaller land area of the Samoan Islands (2,935 km^2) (Kami & Miller 1998). Based on these comparisons, those in the table above, and specimens housed in Bishop Museum, we believe Fiji has many hundreds of undiscovered and undescribed arthropods.

NEEDS AND OPPORTUNITIES

Endemism and Biodiversity

The geographical placement of Fiji adjacent to other island groups of both volcanic and continental origin will allow us to make useful comparisons regarding the degree of endemism observed in the arthropod groups selected for this study with those groups elsewhere in the Pacific. These data can then be used to assess biogeographic hypotheses about origins of the Fijian fauna as well as its relationships to other neighboring faunal elements in the Central and South Pacific. Determining levels of endemism in Fijian arthropods, when placed in conjunction with distributional data, can also assist resource managers in determining potential areas in need of urgent natural resource conservation. Knowing the fauna of Fiji will also enable Fijians to attract more ecotourists. Indeed, the giant Fijian longhorned beetle, regarded as the second largest beetle in the world, has become a flagship for Fijian biodiversity (Yanega *et al*. 2004).

The Fijian government has been implementing a National Biodiversity Strategy and Action Plan for the conservation and sustainable use of the country's biological diversity and this proposed arthropod survey fits into many of the recommended actions (Fiji Department of the Environment 1997, 1999). However, accessible and meaningful knowledge about the Fijian biota is limited. One goal of this survey is to define areas of arthropod endemism and species richness throughout the Fijian archipelago.

Checklists and Literature Databasing

The Hawaii Biological Survey (HBS) was established by the Hawaii State government to inventory the plants and animals of the State of Hawaii and make this information available to the widest user community possible. Since its inception in 1992, the HBS 6-stage methodology (Allison & Miller 2000) has been used as a successful and cost-efficient model for the inventorying of the biota of discrete areas in various parts of the world (e.g., Africa, Indonesia, Papua New Guinea, Bermuda). We trust that by initiating the HBS approach to inventorying the arthropod fauna of Fiji, this project will lead to future Fijian government support of a Fiji Biological Survey that will fully inventory the country's plants and animals and make the information from those surveys available to a wide array of users such as students, scientists, land managers, public information officers, farmers, and others.

URGENCY

Loss of habitat

The population of Fiji (ca. 773,000 as of the most recent [1996] census) is largely confined to the two largest islands: Viti Levu (76%) and Vanua Levu (18%). While the population levels are not alarmingly high for a land area the size of Fiji, an annual 2–3% increase in population (Chandra & Chandra 1998) has resulted in a progressive increase in resource consumption and energy harnessing, resulting in environmental degradation (e.g., building of dams and new houses, logging, clear-cutting for increased agriculture use). Habitat loss (effectively forest loss) remains the most serious threat to the endemic fauna and flora of the Pacific islands. Deforestation in Fiji is moderate but continuing. Virtually all the lowland areas have seen deforestation of some kind and only small pockets of native fauna and flora remain in these protected areas (e.g., Sigatoka dunes). Since the mid 1960s an estimated 90,000–140,000 ha (11–16%) of the nation's forests have been converted to non-forest land use (Watling & Chape 1992), but conservation measures have been initiated in the last few years to reduce the logging of native forests—the number of hectares per year of native forest loss has been decreasing over the past 5 years. As a result, Fiji is one of the best remaining areas in the central Pacific to inventory the native upland fauna before more deforestation takes place making such an inventory an otherwise impossibility. These upland forested areas harbor the greatest diversity of native arthropod species and consequently these areas and their constituent native species are most vulnerable to perturbations and possible resulting reductions in populations and even extinctions. Freshwater drainages have also seen impacts to their native aquatic biota from habitat disturbance (e.g., Haynes 1994) and they have experienced silt and chemical pollution as well as the introduction of exotic plants and animals such as the water hyacinth (*Eichhornia* sp.) and cichlid fishes (e.g., *Oreochromis mossambicus*) (Ryan 2000). Heavy competition for resources by introduced species in aquatic ecosystems for resources inevitably results in a decline of native aquatic invertebrates (Cushing & Allen 2001).

Already, Fiji has witnessed the extinction of a number of its native species. Some of this has undoubtedly come as a result of human disturbance or intervention, but additionally, the introduction of alien invertebrate pests such as ants and vertebrate predators such as the cane toad and mongoose have been directly or indirectly responsible for the demise of many native invertebrates (Ryan 2000) as they have on other Pacific islands (Eldredge 2000; Nishida & Evenhuis 2000).

Biogeographic Link

Previous assessments of Fiji's fauna show an interesting array of affinities to adjacent areas. Preliminary assessments of invertebrate affinities have shown that Fiji is the easternmost Melanesian outpost of some lineages and is a gateway to other lineages occurring further east into French Polynesia. Previous or current arthropod surveys have or are being conducted in Samoa, French Polynesia, New Caledonia, New Guinea, and Australia. It is only logical to fill the gap in these island and nearby continental surveys with an intense arthropod survey of Fiji. By doing so, the results can be added to and integrated with ongoing research into the hypotheses of faunal origins throughout the Melanesian region as well as Fiji's history as a possible source area to further eastern and younger volcanic island faunas.

OBJECTIVES

There are three major objectives:

1. ***Diversity Assessment and Faunal Origins***. For each selected terrestrial arthropod group, numbers of native and endemic species will be assessed along with nonindigenous species. New taxa will be described and summaries of taxa will be made concurrent with comparisons of like arthropods on other nearby islands and continental land masses to hypothesize faunal sources of the Fijian taxa.

2. ***Capacity-Building of In-Country Taxonomic Expertise***. Working with the Wildlife Conservation Society, the University of the South Pacific, the Fiji Ministry of Fishoeries and Forestry (MAFF), and the Pacific loop of BioNET (PACINET), we will assist in providing training workshops for local people in Fiji participating in the project to learn how to collect, sort, and identify major arthropod groups. Information about our project will be disseminated to villagers via community meetings. Once this project is completed, it is hoped that these participants will continue to monitor the arthropod fauna within Fiji through support from various Pacific partners and funding agencies.

3. ***Checklists and Bibliography***. Checklists of identified taxa of selected focus groups as well as a full list of known (= published) arthropod taxa from Fiji and associated bibliography will be made and posted on the web. We will incorporate environmental data and host-plant data where applicable to give as complete an environmental picture as possible. This information will be made available on the web with the Hawaii Biological Survey website (est. 1.5 million user hits per year) used as a successful model.

PROJECT MANAGEMENT PLAN

Collecting Sites

This project essentially will continue and expand the Fiji Bioinventory of Arthropods (FBA) project, funded by the Schlinger Foundation between September 2002 and May 2004. Over $100,000 has been allocated to fund collectors, parataxonomists, supplies, and project oversight. That project's collecting sites will be continued in this study.

Collecting arthropods in Fiji will follow a two-tiered approach. 1) we propose to assist with the taxonomic portion of the PABITRA project (Pacific-Asia Biodiversity Transect), the collecting of which will be conducted concurrently and in collaboration with with our project. PABITRA has proposed to set up a trapping and collecting transect encompassing a number of different ecosystems in eastern Viti Levu between Mt. Tomaniivi and the Rewa delta on the southeastern coast; 2) we will complement the PABITRA project by using the Schlinger Foundation collecting sites, which are currently in 7 different ecosystems on different islands which provide as complete a coverage of the environment as possible. Various trapping and collecting methods will be employed in and around where the Malaise traps are placed by the NSF team and parataxonomists in Fiji.

Due to logistics constraints, rigorous collecting with Malaise and other trapping devices is currently concentrated primarily on Viti Levu, Taveuni, Vanua Levu, and Kadavu. There are many low islands and atolls, and collecting on the smaller outlying islands is also planned to take place during the project in order to duplicate the collecting of previous explorers and entomologists thereby providing a set of collections that can be used to compare with the older collections for any changes that may have taken place in the intervening years.

Collecting Protocol

In general we will follow the PABITRA collecting protocol (Allison & Englund 2005) which is a modification of the DIPWA methodology (Toda & Kitching 2002). All collecting sites will be located geographically using GPS and will be plotted on GIS and georeferenced to MaNIS standards (http://elib.cs.berkeley.edu/manis/GeorefGuide.html). We will specifically use the following collecting techniques for assessing diversity of arthropods within each collecting site:

1. Malaise traps (Fig. 8).— 2–5 Townes-style Malaise traps will be set up at each site and left for 12 days prior to collection. They will be activated every other week throughout the first year, so that the material collected is not expunged from the site and the quantity obtained does not overwhelm the sorting team. Malaise traps are among the most productive samplers in terms of species richness and number of specimens captured. A Malaise trap intercepts flying insects and takes advantage of their natural propensity to

Figures 8–10. Selected collecting techniques used in the survey. **8.** Malaise trap in mesic forest on Vanua Levu. Photo L. Brorstrom. **9**. Aerial sweep netting riparian arthropods at Wainidruku Creek on Viti Levu. **10**. Sticky trap on tree at Colo-i-Suva.Photos D.A. Polhemus.

climb or fly upward toward light after encountering the trap's central mesh panel. They are funneled into the collecting head of the trap, which is filled with 95% ethanol and are killed by drowning. Traps will be placed along known flight pathways such as small creeks and will intercept insects flying up to a meter above ground level, in or above surface vegetation.

2. Water pan traps.— Shallow plastic pans are placed on the ground or in trees to sample arthropods. The pans are filled with water and a surfactant (soap solution) to allow trapped specimens to sink to the bottom of the pan and drown. Salt will be added to prevent mold from accumulating in humid environments. Yellow, white. or blue colored pans have shown to be most productive in collections of arthropods. They are attractive to flying insects in both open areas and forest canopy. Pan traps will be left for 1 week at each site prior to collection.

3. Pitfall traps.— These consist of small plastic cups placed into the ground with the rim level with the surface. A series of unbaited pitfall traps containing ethylene glycol, and baited pitfall traps will be placed at each site and left for 1 week prior to collection.

4. Aerial nets (Fig. 9).— Aerial sweep nets with a fine mesh to collect smaller Diptera and Hymenoptera will be used to sample arthropods on vegetation, leaf litter, littoral habitats, beaches, and rocky intertidal reefs.

5. Aquatic sampling.— Aside from trapping with Malaise, pan traps, and aerial nets, an aquatic net will be used to specifically sample the stream fauna. In addition, benthic samples will be taken where feasible to collect and identify aquatic larvae, especially those of the selected focus groups.

6. Hand collecting.— Hand collecting, with or without the use of an aspirator, will be used for collecting arthropods on specific species of plants and to collect arthropods that are difficult to collect using other techniques—such as those on craggy rock faces, in small holes and crevices or on muddy substrates.

7. *Sticky traps* (Fig. 10).— Yellow sticky traps will be placed on tree trunks and other suitable vertical surfaces to collect arthropods that orient on vertical surfaces. Collecting in Australia (Bickel & Tasker 2004) has shown a impressive diversity of insects that are collected in this fashion that otherwise are not collected with other trapping methods. Sticky traps will be left for 1 week at each site prior to collection.

8. *Baiting*.— Baits with a mixture of sugar water, yeasted fruits or other vegetable or animal matter will be used to attract flies such as drosophilids, tephritids, platystomatids, tachinids, and beetles, etc. Mammal feces will be used for attracting endemic arthropods associated with this medium. McPhail traps may be used for longer term bait trapping as these can be left in the field for a week. Collecting will then be done either by aerial nets or hand collecting. Baits will be checked periodically after placement and specimens collected immediately following such checks.

9. *Pyrethrin fogging*.— The use of small aerosol room foggers containing pyrethrins has proven successful in the field in collecting cryptic arthropods or those otherwise difficult to access using the techniques described above. Spraying tree trunks, moss, low growing vegetation, etc. with the aerosol and gathering the results of knockdown onto white sheets placed beneath such areas being collected results in collections of arthropods sometimes not collected using other techniques.

Table 2. Target Taxa for Project

Order	Family	#sp.	#new	Specialist
Coleoptera	Buprestidae	43	10–15	C. Bellamy, CDFA
Coleoptera	Chrysomelidae	155	50–75	A. Samuelson, BPBM; C. Reid, AMS
Coleoptera	Cerambycidae	122	10–15	S. Lingafelter, USDA-SEL
Diptera	Dolichopodidae	19	50–60	D. Bickel, AMS; N.L. Evenhuis, BPBM
Diptera	Drosophilidae	20	40–60	D. Grimaldi, AMNH
Diptera	Lauxaniidae	21	40–50	S. Gaimari, CDFA
Diptera	Pipunculidae	1	20–25	J. Skevington, CNC
Diptera	Sphaeroceridae	1	100	S. Marshall, Univ. Guelph
Diptera	Stratiomyidae	21	20–25	N.E. Woodley, USDA-SEL
Diptera	Syrphidae	12	12	F.C. Thompson, USDA-SEL
Heteroptera	aquatic	15	15–20	D.A. Polhemus, SI
Hymenoptera	Ichneumonidae	57	100	A. Bennett, CNC
Hymenoptera	aculeates	40	15–20	F. Parker, retired; J. Pitts, USU
Hymenoptera	Formicidae	70	20–30	E. Sarnat, UC Davis
Spiders	Tetragnathidae	4	15	R. Gillespie, UCB
Spiders	Theridiidae	4	15	R. Gillespie, UCB
Spiders	Araneidae	6	22	R. Gillespie, UCB

10. *Winkler funnel extractions*.— Leaf litter samples will be taken at collection sites mainly for ants and spiders. These samples will be placed in Winkler funnels for extraction of leaf litter invertebrates into alcohol.

11. *Beating sheets*.—Beating sheets (a small canvas in a portable frame) will be used to extract small arthropods from vegetation that otherwise could be missed in other collecting methods such as fogging and aerial sweeping. This method will be used mainly for coleopterans.

Taxonomic Scope and Participants

The focus groups (Table 2) have been selected for comprehensive collecting and systematic description and analysis. These groups are currently known through existing Fijian collections to have a high degree of biodiversity in Fiji and also will act as excellent subjects in testing levels of endemism and in comparisons with other oceanic island groups. In addition, their known faunal constituency in other nearby areas will allow testing of hypotheses concerning origins of the Fijian fauna.

Specimen Processing/Deposition

Specimens collected will be sorted and processed by local parataxonomists in Fiji associated with this project (Fig. 11) and specimens of selected taxonomic focus groups will be sent to specialists for identification and description. A two-week intensive training workshop will be conducted by project specialists to enable parataxonomists to quickly identify selected focus groups being studied in this project. This workshop will include pictorial keys and other identification aids as well as specific techniques needed to collect, process, and curate specimens of each focus group before sending them to Bishop Mu-

Figure 11. Sorting center at Ministry of Forestry laboratory facility, Colo-i-Suva, Fiji. Photo N.L. Evenhuis.

seum where they will be collated by focal taxon and sent to specialists. All specimens will be processed at the Fijian Ministry of Fisheries and Forestry's Forestry Institute in Colo-i-Suva on Viti Levu (MAFF) (Fig. 7). Preservation of specimens will primarily be in alcohol and long-term storage of any remaining trapping residues after sorting focal groups will be at the Bishop Museum. Vouchers of selected specimens will be transferred immediately upon collection to 95% ETOH and frozen for any future molecular studies. Molecular workers will be identified before collection so that shipment to these persons of preserved specimens can be made immediately upon collection. Types of new species will be returned to Fiji once a suitable facility is in place to permanently house type specimens. Identified material will be in the Bishop Museum, Honolulu, with voucher material deposited at MAFF and other museums.

Data Management

All specimens sorted and identified will be databased using Mandala 5.3 (Kampmeier 2002), currently the standard database for processing data and specimens for the NSF-funded therevid PEET project (Mike Irwin, PI). The database team will attend a hands-on week-long training session, conducted by the database coordinator (Kampmeier), the trained collections and database manager, and one other member of the NSF-team. The databasers will enter locality, specimen, and taxon names (identifications only to focal taxon) data. The collections and database manager will ensure consistency and integrity of the data entered into the database. A special feature of this project is that a web interface will be built to allow specialists around the world access to the database. The collaborating specialists can easily enter definitive identifications, sexes of the specimens, data on dissections and molecular analyses of given specimens, and depository information directly into the database via the secure web interface, thus increasing the accuracy of the input data and reducing the time and cost of this input process. This will also allow collaborating specialists direct, immediate access to the entire database. Versions of the Fijian arthropod database also will be accessible to the general public on the World Wide Web during the course of the project.

Checklist and Bibliography

Following the protocol for island biotic surveys standardized by the Hawaii Biological Survey, a database of published records of taxa occurring on Fiji will be compiled from all available literature pertaining to the terrestrial arthropod fauna of Fiji. Most of this literature is currently available in the Bishop Museum, thus this work will be centralized there. This draft information will be made available on the World Wide Web for review and reference for project personnel. From this template of information, project specialists and other scientists will then be able to assess current knowledge of the fauna and make additions and corrections to the current checklist. A final checklist and bibliography will be made available in both hard copy and electronically with the database posted publicly on the World Wide Web following the same procedure as has been done previously for Hawai‘i (Nishida 2002) and Samoa (Kami & Miller 1998).

Publication of Results

New taxa of focal groups found during this survey and via the PABITRA project collecting will be described throughout the project. Publication will be through *Fiji Arthropods*, which is a peer-reviewed journal with quick turn-around time from submission to publication (usually less than one month). Access to these publications will be made available to the general public via pdf file download from the World Wide Web. Non-focal group taxa will be sent to specialists who have indicated interest in working up this material as part of their ongoing revisionary work on those groups.

EXPECTED RESULTS

Database/Bibliographies/Checklists

Specimen Database/Checklist/Bibliography. A complete checklist of the terrestrial arthropods based on the literature and the current project will be made available as hard copy and on the World Wide Web. Concurrently, an associated bibliography of Fijian arthropods will be published and also made available on the World Wide Web.

Refereed Publications. Publications of new taxa resulting from this study will be made throughout the term of the project, primarily being published in the peer-reviewed series *Fiji Arthropods*, published by Bishop Museum Press.

Web-Access to information All information resulting from this project will be made available on the World Wide Web so as to disseminate information to the widest user community possible. This will include descriptions and associated images, checklists, bibliographies, etc.

PROJECT SIGNIFICANCE

Increased Knowledge and Understanding of Areas of Endemism

The Pacific Ocean contains numerous island archipelagoes with a wide range of physical attributes and habitats. Fiji is the largest and most diverse island group in western Polynesia. The rather limited data on the Fijian arthropod fauna suggest that it is both a center of endemicity and a biotic source area for eastern Polynesia and much of Micronesia. Detailed systematic study of the chosen arthropod taxa will facilitate our understanding of Fijian fauna and its role in the biogeography of the central Pacific.

Comparison of Levels of Biodiversity on Islands

We have a good understanding of the arthropod fauna of some Pacific island groups (e.g., Hawai‘i, Samoa, New Zealand). This allows us to make comparisons and predictions using the Fijian fauna, incorporating such parameters such as area, climate, elevation, geological age and proximity to source areas. Knowledge of major components of the Fijian arthropod fauna will thereby provide a basis for further investigation and testing of the theory of island biogeography. We expect that the geocoded locality data we will be obtaining via GPS at each site and associated with taxa can be used as as a potential GIS layer for future analysis.

Native Peoples Embracing Their Natural Heritage

Native Pacific Islanders are an under-represented and under-funded group in the sciences. We see this project as a unique opportunity to allow the growth and development of native Pacific Islanders in a training and educational program that will help them understand better the natural resources surrounding them. The educational/training aspects of this project will be conducted in a fashion that is sensitive to the needs and traditions of the native Fijian peoples. By involving the local people in this project, educating them via training and community meetings while also listening to their stories of the environment, they have the opportunity to be empowered with the potential for decision-making with regard to their natural resources. By doing so we hope that they will embrace their natural heritage and provide for a sustained environment for their future generations.

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