Identifying Invertebrate Representation within Fiji's Future Network of Forest Reserves

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Dedication

I dedicate my thesis to the following people:

Rob Parry-Jones
Jane Rienks
David Olson
Marilyn Cornelius

I thank the above named persons for exposing and encouraging me to study entomological conservation. I also thank the above named persons and everyone else who in one way or another has been the encouragement for my perseverance. This thesis would not have been possible without their love and support. Thank you for being my strength.

Sunil Raj Prasad
January 2006.

Declaration

I, Sunil Rajesh Prasad, of the University of the South Pacific, student ID Number s99007386, declare that this thesis is my original work. This thesis has not previously been submitted in any other university and will not be submitted as assessed work in any other academic course. People who have contributed to this work and other people's work have been appropriately acknowledged in the acknowledgements and references.

…………………..

Sunil Raj Prasad

June 2006.

I, Dr. Craig G. Morley, being the principal supervisor for Sunil R. Prasad, student ID number s99007386, certify that this thesis titled "Identifying Invertebrate Representation within Fiji's Future Network of Forest Reserves" is complete for submission for assessment.

……………………

Dr. Craig G. Morley

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ABSTRACT

Fiji's biodiversity is rich with many species however many are threatened by loss of habitat and invasive species. In order to conserve its biodiversity Fiji needs to have a representative network of forest reserves. At present Fiji has 17 forest reserves and seven nature reserves totalling 319 km^2, which is 1.7% of Fiji's total land mass. According to Fiji's NBSAP (1999) at least 10 % of the total land area should be set aside for conservation as a long-term sustainable measure. Fiji fails to meet this. Most of the existing reserves in Fiji have been set up without any proper biodiversity study of the area.

This study focuses on using leaf litter invertebrates (weevil Curculionidae, harvestmen Opilione, Rove beetles Staphylinidae) as invertebrate biodiversity indicators in highlighting areas with high biodiversity conservation value. The leaf litter invertebrates were collected by sifting leaf litter from twenty $1m^2$ quadrats along a 100m transect. This was repeated three times at each site. The sites were standardised at 300m above sea level. The collected leaf litter was processed in Winkler bags for 48 hours after which the collected specimens were alpha sorted (separation of target taxa from other taxa and debris) followed by morphospecies sorting based on predetermined morphological characters. The morphospecies presence/absence and abundance data was used to subject the sites to Jaccard's nearest neighbour similarity test and MDS Decorana plot analysis. The dissimilar sites were mapped to produce an Important Invertebrates Areas (IIAs) map, which was assessed against other important taxa areas (palms, angiosperms, heritage trees and other invertebrates). A high degree of overlap between the IIAs and

other important taxa areas, and identification of important biodiversity areas within Fiji on a finer geographic scale suggested that the invertebrates used in this study were good biodiversity indicators.

Chapter 1 Introduction

1.1 Introduction

Fiji's biodiversity is unique and due to the immaculate island state contains a high degree of endemic flora and flora. This has lead to the inclusion of Fiji in the Polynesia-Micronesia hotspot (Allison and Eldredge 1999). Rapid habitat loss, deforestation and taxonomic strains are rapidly threatening this biodiversity. To overcome this there exists a handful of reserves that have been poorly selected to represent Fiji's biodiversity. These existing reserves are governed by an archaic set of laws that were part of the old colonial government (Anonymous 1998).

The future recommended areas for the network of reserves needs to be well assessed so that it is representative of local biodiversity. This can be easily done by using leaf litter invertebrates as they are easily sorted to morphospecies level. The morphospecies concept is important to conservation projects that use absence/presence data as morphospecies are closely correlated to taxonomic sorting.

When designing reserves usually umbrella species are used however for island states such as Fiji this becomes a problem as we do not have a lot of native mammals and the birds tend to cover large areas which fails to identify small biological areas (Wildlife Conservation Society 2004). Therefore, it is understood that usage of existing data together with invertebrate data should be used for highlighting areas with high conservation values. Buffering of these areas prevents harvesting and penetration of humans into the core conservation areas (Putney 2003). These isolated areas that are identified should be linked to provide refuge areas for animals which are known to migrate seasonally in search for food and mates.

1.2 Fiji's Biodiversity

Although invertebrates contribute immensely to the earth's biodiversity, it is estimated that a million insects have been catalogued worldwide but only 66-96 % have yet to be described (Cranston and Hillman 1992).

Wide geographic ranges and the thousands of isolated islands have led to an extremely high diversity of flora and fauna in the Pacific (Myers 1990). Unfortunately, the biodiversity of Polynesia-Micronesia is amongst the most endangered in the world due to habitat destruction and invasive species (Olson and Farley 2003). Polynesia-Micronesia is also one of the central regions of the present global extinction crisis (www.biodiversityhotspots.org). Fiji having a high level of endemic biodiversity, is part of the Polynesia-Micronesia hotspot (www.biodiversityhotspots.org). Fiji is also the eastern most limit of high biodiversity and endemism in the Pacific and rivals Hawai'i and New Caledonia in terms of its unique biodiversity (Caldecott 1996).

More than 3,000 species of plants are found in Fiji, and this number has been correlated to the patterns of rainfall (Stanley 2000). Almost half of Fiji's land area is covered with rainforest (Mueller-Dombois and Fosberg 1993). Fiji possesses two of endemic Degeneriaceae, which includes a single species, *Degeneria vitiensis* found on Viti Levu and Vanua Levu. This rare taxon, occurs only on Vanua Levu and Taveuni in small, scattered populations (Stanley 2000). This family is normally found on older islands associated with Gondwanaland. Another species of plant that exhibits endemism includes the Tagimoucia *Medenalia waterhousii*, which is only found in swampy lakes (Wildlife Conservation Society 2004). Fiji has a total of 893 of 1594, or so, species of plants (Stanley 2000).

Fiji's endemic plants are matched equally by its unique fauna. In terms of terrestrial vertebrates, the richest diversity is among birds and reptiles, while there are few mammals and amphibians (Smith 1954; Smith 1979; Pernetta and Watling 1978) (see Table 1.1 for a list of percent endemism of different taxonomic groups). Among the reptiles, two species of iguana, *Brachylophus fasciatus* and *Brachylophus vitiensis* may have originated from the Americas and these are threatened due to habitat destruction (Ryan 2000).

Although Fiji has high endemic biodiversity, the taxonomic group that has been largely ignored is the invertebrates, especially the terrestrial invertebrates. The invertebrates are expected to show a fine localized endemism pattern (see Table 1.2 for localized endemism of cicadas).

Table1.1 The percent endemism of different taxonomic groups in Fiji.

Taxonomic group	Species	Endemic Species	Percent Endemic	Reference
Plants	1594	893	56	Watling 2001
Birds	57	26	46	Watling 2001
Mammals	6	1	17	Watling 2001
Reptiles	27	8	30	Watling 2001
Amphibians	2	2	100	Watling 2001
Insecta-Cicadas	15	14	93	NBSAP 1999
Insecta-Stick insects	19	12	63	NBSAP 1999
Insecta-Odonata	33	22	67	NBSAP 1999
Marine-Insects	2	2	100	NBSAP 1999

Table 1.2 Some of the localized cicada endemics identified by Duffels and Ewart (1988).

Name	Range
Baeturia rotumae	Rotuma island
Aceropyga distans distans	Viti Levu
Aceropyga distans taveuniensis	Taveuni and Natewa peninsula
Aceropyga distans lineifera	Totoya and Moala
Aceropyga stuartii stuartii	Viti Levu
Aceropyga stuartii pallens	Vanua Levu and Taveuni
Aceropyga corynetus ungulata	Vanua Levu and Taveuni
Aceropyga corynetus corynetus	Viti Levu and Ovalau
Aceropyga corynetus monacantha	Kadavu
Aceropyga philorites macracantha	Lautoka (Mount Evans)
Aceropyga philorites acuta	Colo-I-Suva
Aceropyga philorites egmondae	Nausori (Nai-masimasi)
Aceropyga philorites pterophon	Nausori highlands
Aceropyga philorites philorites	Viti Levu
Aceropyga philorites huireka	Vanua Levu
Raiateana kuruduadua kuruduadua	Viti Levu
Raiateana kuruduadua bifasciata	Vanua Levu and Taveuni
Fijipsalta tympanistria	Rakiraki (Nakauvadra Range)

Another less studied but important invertebrate of Fiji, is the giant long-horned beetle (genus *Xixuthrus*) (Liebregts *et al.* 2001; Olson 2001). There was some confusion over its taxonomic status and species synonymy but recently it has been sorted. Five species of *Xixuthrus* beetles has been cited in the literature, however, it was concluded by Yanega *et al.* (2004) that there are only three taxonomically distinct species, *Xixuthrus heros* (Heer), *X. heyrovski* (Tippmann) *X. ganglbaueri* (Lameer), while *X. costatus* (Montrouz) and *X. terribilis* (Thomson) are the synonyms for the three. This shows that even the giant *Xixuthrus* beetles that have the potential of becoming a conservation and heritage icon have been poorly classified and rarely studied.

1.2.1 Ancient Lineage

Fiji has many species of Gondwanan origin and Olson and Farley (2003) consider that this has resulted from diversification of a mixture of the ancient lineages from Gondwanaland and recent arrivals. It is also believed that Fijian invertebrates might have had a similar origin. Duffels and Ewart (1988) believed that the ancestors of the *Aceropyga* species of cicada reached Fiji when Fiji-Vanuatu and Tonga were still connected in a single island arc.

1.3 Conservation threats of the Fijian Invertebrates.

Biodiversity conservation is one of the most important environmental issues both in Fiji (NBSAP 1999) and overseas (SPREP 2004; UNEP 1993). Most biodiversity conservation studies use abundance or species diversity indices of trees (especially angiosperms), vertebrates (birds), mammals, and to a lesser degree reptiles and amphibians (Cranston and Trueman 1997) for conservation planning. These taxa are often quite extensively studied, because they are charismatic and have international appeal. Conversely, the invertebrates which account for most species are hardly touched (Cranston and Trueman 1997, Crisp *e. al.* 1998). By overlooking invertebrates we are omitting the most numerous organisms that are partially responsible for maintaining Fiji's ecosystem processes and biodiversity.

1.3.1 Conservation bureaucracy

Many conservation projects are designed to protect charismatic taxa and in theory this also protects the invertebrates and the habitat within which they live. Detrimental processes, such as the loss of habitat and invasive species, push invertebrates to the brink of extinction, especially local endemics (Olson and Farley 2003). The lack of funds and time for conducting invertebrate research also hampers obtaining information on invertebrates. Therefore, one proposal is to change from species diversity to across-the-board species inventory studies, but this is very expensive and often time-consuming (Cranston and Trueman 1997). Therefore, we need to develop a system of indicators that can identify the hotspots and coldspots of biodiversity, endemism and rarity.

Several studies have shown that invertebrate biodiversity is positively related to the biodiversity of other important taxa (Armbrecht and Ulloa-Chacon 2003; Gardiner *et al*. 2003; Kati *et al*. 2003; Morrison and Porter 2003). Despite this, no one has been able to identify a set of invertebrates, which can be used as indicator of biodiversity (Cranston and Trueman 1997).

1.3.2 Habitat loss

Fiji's forest has some of the most threatened forest types in the Pacific region (such as the dry forest in the Western division of Fiji and the Sago palm (*Balaka spp*) swamp forests near Navua and Serua. Olson and Farley (2003) state that the presence of some intact forests from the mountain tops down to the coast line makes the conservation of Fiji's forest worthwhile as forests are fast disappearing. Good forests are diminishing. Therefore, wildlife which require large areas of intact forest (such as the giant long horned beetles) are fast becoming threatened from extinction (Wildlife Conservation Society 2004). Forest fragmentation can also lead to species extinction because less mobile species are separated into small patches leading to difficulty in the exchanging of genetic material that is essential for the survival of the species. Fragmentation can increase the number of remnant population and their isolation, which lead to increased rates of local extinction and decreased rates of recolonisation (Andren 1992; Harrison 1994). Loss of habitat for endemic invertebrate fauna is a major threat and can lead to their extinction.

1.3.3 Taxonomic strains

Cranston and Hillman (1992) state that areas with mega-diversity (such as that found in many developing countries) tend to have very little or no taxonomic expertise. The problem with getting expatriates to do the taxonomic work in developing countries without local expertise includes expensive research fees, travelling costs, and failure in the maintenance of local collections due to lack of local expertise (Cranston and Hillman 1992).

This gap in taxonomic strains can be overcome by the use of morphospecies as a first step in including the invertebrates in diversity and conservation assessment projects. The Australian draft Federal Biodiversity Policy (see http://www.deh.gov.au/biodiversity /publications/strategy/index.html) states the importance of morphospecies in taxonomic work (primary sorting of specimens) (Cranston and Hillman 1992).

1.4 Fiji's existing reserves

Currently, Fiji has about 5% of its forest protected under nature reserve (5, 719 ha), protected forest (a single protected forest at Batiwai) (15, 750 ha), and reserve forest (33, 200 ha) (Anonymous 1998). This unplanned system of protected forests encompasses different forest areas spread over the various islands within Fiji. Even though this seems like an acceptable proportion of protected forest, the very nature in which it was done was unplanned, and may not be representative of the natural biodiversity of Fiji's forest. Watling and Chape (1992) state that the present system is inadequate because the system has been "departmentalised" rather then being controlled by a national institution. Therefore, a biological inventory, of as many taxa as possible, needs to be carried out to ensure that the natural biodiversity of Fiji's forest is preserved before it is lost.

The present reserves chosen for protection were probably selected for ease of availability, because the land had no agricultural value, or for cultural and archaeological reasons (e.g.

Sigatoka Sand Dunes). However, these criteria are insufficient to conserve Fiji's biodiversity.

Table 1.3 List of all the protected terrestrial areas in Fiji (source Ministry of Forestry).

Island	Type	Name	Longitude	Latitude	Area (Ha)
Viti Levu	Forest reserve	Wabu Creek	178 º 02'06" E	17 º 36'59" S	1,176
		Garrick reserve	178°27′E	18°10′S	427
		Maranisaqa and Wainiveiota	178 º 28'00" E	18 º 02'54" S	77
		Suva and Namuka Harbour	178°27′E	18°10′S	3
		Vago	178 º 26'13" E	18 º 04'15" S	25
		Nadarivatu/Nadala	177 º 57'43" E	173 º 4'33" S	7,404
		Savura Creek	178 º 27'16" E	18 º 04'16" S	348
	Forest park	Colo-I-Suva	178 º 28'45" E	18 º 03'38" S	91
	Forest reserve	Colo-I-Suva	178 º 28'41" E	18 º 03'32" S	279
		Naboro	178 º 17'06" E	18 º 07'52" S	19
		Yarawa	177 º 57'27" E	17 º 14'17" S	160
		Vuo	178 º 23'49" E	18 º 07'15" S	1.2
		Draunibota and Labiko	178 º 23'20" E	18 º 07'44" S	2.2
		Draunibota and Labiko	178 º 23'20" E	18 º 07'44" S	2.2
		Naitasiri	178 º 29'01" E	18 º 03'14" S	30
		Qoya	178 º 23'04" E	18 º 06'02" S	67
		Nadarivatu	177 º 57'43" E	173 º 4'33" S	93
		Qaranibuluti	177º 59'38" E	173 º 4'47" S	279
		Savura Creek	178 º 27'16" E	18 º 04'06" S	100
	National park/Nature reserve	Tomaniivi	178 º 02'06" E	173 º 5'33" S	1,323
Vanua Levu	Forest reserve	Waisali reserve	179 º 15'79" E	6 º 49'86" S	120
		Buretolu	177 º 56'02" E	173 º 7'55' S	1198
		Korotari	179 º 22'01" E	18 º 31'01" S	1045
	Nature reserve	Vunimoli	179 º 27'28" E	18 º 32'16" S	20
		Ravilevi	179 º 58'34" W	18 º 53'02" S	4,018
	Protected forest	Batiwai	177 º 58''48" E	18 º 08' S	15,750

1.4.1 The Legislative Background on Fiji's Protected Area

Fiji's legislature on protected areas stems from the colonial days, and although archaic it is still legally binding. Therefore, understanding of the existing protected areas in Fiji and the inclusion of future areas needs to focus on these legal bindings. Given below is an account of this legislature.

Resolution IV (Forest management, silviculture and protection of the forest policy) (Legislative Council Fiji 1950) states that "the importance of forest protection cannot be over-emphasized". It also states that adequate legislation and efficient control services (fire control, preventative measures against insects and disease, etc) are essential. Statement number 5 of the same resolution proposes that shifting cultivation and grazing should be controlled and degraded land should be reforested to promote protection of the existing forest and to prevent loss of degraded land.

The Forest Policy of Fiji, guided by the British Empire Forestry Conference, states that "protection and development of natural vegetation is necessary for maintaining essential climatic conditions, conservation of soil and water for agriculture, ensuring adequate and continuous forest supplies, developing surplus timber products for exports, promoting the use of all species for timber (even the lesser known ones), and maintaining and improving soil fertility by extending forest cover if necessary" (Legislative Council Fiji 1950). However, the policy does not encompass preservation and protection of local biodiversity and other important ecological processes. It seems that the forest policy was drafted with a specific forestry (timber trade) and agricultural focus. In the section titled "forest reserves and dedication" it explicitly states that land not suitable for agriculture, mining, or any other purpose than forestry may be set aside as forest reserve. It is further elaborated that "this land may be kept under proper forest cover and at the same time may be used to provide a return to the owner and to the colony in the form of forest produce". The decree also gives the conservator of the forest the responsibility for controlling forestlands and forest operations including controlling of grazing, hunting, cultivation in forest reserves and for the preservation of forests, while the Minister for Forests is responsible for declaring any land to be a forest reserve, nature reserve, or de-reserved as appropriate (Anonymous 1992). The Decree states that forest reserves can be managed as permanent forest in order to extract the maximum benefits of protection and production on a permanent basis, while nature reserve are managed exclusively for the purpose of permanent preservation (conservation) of their environment including biodiversity, soil, and water. This shows that forest reserves have been set up for forestry needs and nature reserves have a biodiversity focus.

The 1992 Decree also prohibits the following activities in a forest reserve or a nature reserve unless possessing a license; "timber felling or extraction, extracting other forest produce, extracting peat, rock, sand, shell and soil other than minerals as defined in the Mining Act, clearing land, damaging or destroying vegetation (cutting, burning or uprooting), erecting buildings or livestock enclosures, allowing entry to domestic animals, planting any crops or trees, constructing or obstructing any roads, paths or waterways, setting any traps, snares or nets or using or being in possession of any guns, poison or explosive substances, and hunting or fishing". Under Part VII titled "Fires", the Forest Decree (Anonymous 1992) states that "no person should cause or light fires in any forest reserve or nature reserve". If being guilty of any of the offences listed above, the offender can be fined as much as $10, 000 or up to 12 months of imprisonment or both can be levied.

1.5 Leaf litter system and how does it function

The leaf litter system forms a complex microhabitat with potentially high structural diversity due to leaf sizes that form a continuous layer on the forest floor (Caldwell and Vitti 1999). Depending on the available surface layer, the leaves produce a complex habitat for the initial decomposers (fungi and other decomposers, arthropods and other invertebrates (Stork and Blackburn 1993). The decomposition of the litter forms part of the complex nutrient recycling process that is essential for the maintenance of a healthy forest system. The degradation process is brought about by organisms such as isopods, fungi and collembolans (Caldwell and Vitti 1999). The degraded material is then well mixed with the soil by the ploughing-in effect of the earthworms and other organisms that transit from the soil to the litter layer and *vice versa*.

The litter system is composed of many different types of organisms, some spend part of their life cycle in the litter (such as some beetles), some take refuge in the crevices of decaying leaves (such as weevils), while others are exclusively found in litter systems such as many Staphylinid larvae.

In a study of the invertebrates of the arboreal *Pandanus* litter against the adjacent ground litter it was found that the two litter systems had distinct communities, the ground litter had a higher proportion of soil arthropods while the arboreal litter had higher proportion of flying specimens (Reinks 2001 *pers. comm.*). This is logical as ground litter is easily colonized by the soil organisms, whereas, the arboreal litter acts as a refuge site for many arboreal species (Reinks 2001 *pers. comm.*). Some arthropods were common to both system and these were usually the species that have large ranges such as the termites, ants, centipedes and millipedes.

1.6 A Background Review of the Indicator Groups

1.6.1 Weevils (Coleoptera: Curculionidae)

Weevils may be distinguished from most other beetles by three features (a) the elongate rostrum formed at the front of the head, (b) the terminal three segments of the antennae fused into a club shape, and (c) the second segment arises subapically on the first segment, and the small palps are often concealed (Lyal 1993).

Weevils are normally nocturnal and during the day they find refuge in leaf litter. This makes leaf litter sifting and beating woody plants favourable methods of collection. Weevil larvae do not feed on the dead wood but are thought to feed on the fungi and bacteria growing on the dead wood (Lyal 1993).

If disturbed on vegetation most weevils will fold their head down so that the rostrum lies between the front legs, they will fall to the ground and remain immobile. The lack of any projection allows them to fall without getting caught on the plants, and to slip into crevices in the ground. I also made similar observations when extracting weevils from the leaf litter using Winkler sacks. The animals collected from the ethanol tend to be curled up and resemble pieces of dirt. Weevils tend to be very cryptic, so that they resemble seeds, broken twigs, and some ”that camouflage themselves as raindrops, glistening on leaves” (Clausen 2003).

Only six papers from Fiji on weevils were found by electronic search done on Google and the University of the South Pacific’s library catalogue (see Zimmerman 1936, 1937, 1939, 1942a, 1942b, and 1943, Table 1.3). Unfortunately, little distributional information is mentioned in the papers.

Table 1.4 Listed species of Fijian weevils in the literature (non agricultural species) (Zimmerman 1936, 1937, 1939, 1942a, 1942b, and 1943).

Subfamily	Genus	Species
Trachodinae	*Acicnemis*	*Acicnemis crassivsculus*
		Acicnemis crassiusculus
Anthonominae	*Amblycnemis*	*Amblycnemis fulgidus*
Crytorhynchinae	*Ampagia*	*Ampagia nigra*
	Deretiosus	*Deretiosus fasciculiceps*
		Deretiosus v-niger
		Deretiosus lectus
		Deretiosus variegatus
		Deretiosus apicalis
		Deretiosus exithiodes
		Deretiosus lateroalbus
		Deretiosus squamituber
	Orochlesis	*Orochlesis angulata*
		Orochlesis bella
		Orochlesis vitticollis
		Orochlesis bryani
		Orochlesis eluta
		Orochlesis nigra
		Orochlesis tessellata
	Deretiodes	*Deretiodes scutellaris*
		Deretiodes muticus
	Teleodactylus	*Teleodactylus invenustus*
		Teleodactylus purpureotinctus
		Teleodactylus angustus
		Teleodactylus parallelus
		Teleodactylus minutus
Rhynchorinae	*Rhabdocnemis*	*Rhabdocnemis abscura*
Brachyderinae	*Leacis*	*Leacis vitiensis*
	Nesogenocis	*Nesogenocis cucullus*
	Viticis	*Viticis bedentatus*
	Ottinychus	*Ottinychus comptus*
		Ottinychus gemmatus
Tenebrionidae	*Araucariola*	*Araucariola parallela*
		Araucariola compacta
		Araucariola simulans

1.6.2 Rove beetles (Coloeptera: Staphylinidae)

Rove beetles or Staphylinid beetles belong to suborder Polyphaga (Staphylinoidea: Staphylinidae) and are identified by a short elytra exposing several abdominal segments (Crowson 1981; Newton and Thayer 1992). They are slender with powerful abdominal muscles causing them to elongate when exposed to moist conditions and shorten when dried (Newton *et al.* 2000). Most are between 1-40 mm long (Newton 1990). There are over 45, 000 species known worldwide (Newton and Thayer 1992; Buse and Good 1993) and the oldest known fossils are more than 200 million years old from the Triassic period (Fraser *et al.* 1996). Species level identification always requires dissection of the genitalia (Newton 1990).

Staphylinid beetles are found in leaf litter, grasslands, and can concentrate in fallen decomposing fruits, space under loose bark of the fallen and decaying trees, dung and the nests of some vertebrates (Young 1998). Some are known to climb on plants and hunt for prey at night (Newton and Thayer 1992).

Complex interaction of Staphylinid beetles with other organisms have also been observed. *Euvira* (Aleocharinae) develops in communal nests of the *Eucheira socialis* butterfly (Ashe and Kistner 1989). Adults of some Aleocharinae oviposit into the syconia of *Ficus sp.* while the adults and larvae feed on the pollinating wasp (Agaonidae) of the *Ficus sp.* flowers (Frank and Thomas 1997).

Staphylinid beetles are also proving to be important biological control agents. Current attempts are being made to conserve *Tachyporus* (Tachyporinae) which are known predators of cereal aphids (Sunderland 1975).

To date there has been no published research papers on Staphylinids in Fiji.

1.6.3 Harvestmen or Daddy-long legs (Opilionae)

Harvestmen (daddy long legs) belong to the order Opiliones. They resemble spiders in having eight legs and are also grouped in Class Arachnida. Harvestmen have an oval shaped body, Opistosoma, which is a fused cephalothorax and abdomen (Carpenter 2000). Unlike the spiders Opiliones do not possess any silk glands. However, they do have chelicerae and padipalps (Nyfeler and Symondson 2001).

Opiliones are normally active during the night and are omnivorous, feeding on small insects, decaying animals, dung, plants and fungi (Carpentar 2000). Opiliones are found in moist, shady environments such as in caves, plant undergrowth, leaf litter, on the ground, and sometimes under and inside building (Carpenter 2000).

Opiliones have minimal interaction with other organisms however profound relationships have been observed with mites (Nyfeler and Symondson 2001). The mites are usually found attached to their bodies and it is not clear if this is a parasitic or phoretic relationship. Family Trogulidae and Ischyropsalididae (*Ischyropsalis hellwigi*) are specialised gastropod predators and can either smash open the shell or force their way in through shell apertures (Machado and Vasconelos 1998). Although aggregations are observed on plants and other materials, these are harmless to humans, plants and other animals (Carpenter 2000).

To date there has been no published research papers on Opiliones in Fiji.

1.7 Parataxonomy versus Taxonomy

There are many difficulties in positively identifying invertebrates, it is laborious, time consuming and requires a high level of entomological expertise (Oliver and Beattie 1996a; 1996 b; Danks 1997; Thomas and Cranston 1997; Derraik *et al.* 2002; Barrat *et al.* 2003a). In terms of species composition invertebrates contribute to the bulk of the world's biodiversity and it has been estimated that globally insects constitute 50% of all named species and 20% of these are the Coleoptera alone (Goldstein 1997; Barrat *et al.* 2003). Invertebrate biodiversity is often sampled with less effort than vertebrate and flowering plant inventories even though they may represent the bulk of the natural biodiversity present (Oliver and Beattie 1996a). On islands it is imperative to take account of the invertebrates in conservation assessment studies because they are the most numerous life forms. To overcome the lack of taxonomic expertise within islands, Oliver and Beattie (1996a; 1996b; 1997), and Beattie and Oliver (1994) argued that morphospecies ("taxa readily separated by morphological differences that are obvious to individuals without extensive taxonomic training") can be used to monitor and measure conservation research. Even though, the use of morphospecies has been suggested, the use of higher taxonomic level classification (phylum, class or even family) should never the less be sought after (Cranston and Trueman 1997).

Various groups of terrestrial invertebrates, predominantly insects, are easily sorted to morphospecies as they can have distinct physical (morphological) characteristics that can aid in the separation of the dissimilar invertebrates (Kremen *et al.* 1993; Olson 1994). Below are three case studies using the morphospecies method which also compares their findings with respect to the efficiency and error levels compared to a full taxonomic classification.

1.7.1 Case Study 1

Oliver and Beattie (1996a) sorted ants, spiders, and beetles to investigate morphospecies surrogacy for taxonomic species. These specimens were used as they are abundant and species rich on the forest floor and have many distinguishable characteristic traits. They obtained a high 1:1 (one morphospecies correctly sorted to one taxonomic species) ratio of sorting into categories for the specimens they examined (ants = 98.8%, beetles = 80% and spiders = 85%). Splitting and lumping error was the only noticeable error in the following beetle families Curculionidae, Pselaphidae, Scydmaenidae, and Staphylinidae. However, splitting and lumping errors can cancel each other out if the error is consistent throughout the sampling (Oliver and Beattie 1996b; Olson *pers. Comm.*). This consistency can be achieved if the same individual does the sorting. Oliver and Beattie (1996a) suggest that morphospecies can be used as a surrogate for other taxonomic species especially if comparing species richness temporally and spatially. Representativeness and complementarity of sites is also feasible as long as each different morphospecies is given a unique identification code or mark (Oliver and Beattie 1996a). This can be used to determine complementarity using multivariate analysis techniques. However, the authors caution the validity of this method for other taxa, as non-arthropod taxa requires an investigation of the internal anatomy. Lastly, this technique is useful for entomologists as the bulk of the alpha sorting and collection is achieved before it is sent away for verification by the taxonomists.

1.7.2 Case Study 2

Barratt *et al.* (2003) investigated morphospecies surrogacy for Coleoptera species and whether they could improve its accuracy. The authors state that the unavailability of taxonomic expertise, taxonomic revisions and incomplete keys in New Zealand impeded biodiversity investigations of the invertebrates. They asked three postgraduate students with different levels of basic entomology training to sort a range of Coleoptera based on the physical characteristics used in morphospecies identification which were later checked and corrected by specialists. All three students identified the Coloeptera to within 10% of that determined by the specialist. The authors found that the two experienced students tended to lump species less frequently. The most common error was with the Curculionidae where the students split the species, because they exhibited sexual dimorphic traits. The authors conclude that a partnership between parataxonomy and taxonomy can work well and this can be used to train and fast-track conservation biodiversity assessment studies, especially where little invertebrate knowledge and expertise exist.

1.7.3 Case Study 3

In another New Zealand case study, Derraik *et al.* (2002) tested the accuracy for three orders; Araneae, Coleoptera, and Lepidoptera. According to the authors, Curculionidae, the largest family in the Animal Kingdom, yielded the best results matching the morphospecies to taxonomic species 77.8% of the three. They concluded that morphospecies sorting had the potential to be used in conservation studies but the accuracy needed to be refined and double checked for particular arthropod groups.

The case studies above, clearly show that the error rate of sorting invertebrates using morphospecies techniques is minimal and in some cases negligible (Derraik *et al.* 2002, Ward and Stanley 2004 *unpublished*). Barratt *et al.* (2003) showed that with training morphospecies sorting increased the accuracy of sorting. Ward and Stanley (2004 *unpublished*) obtained similar results with morphospecies when compared to the taxonomic dataset.

1.8 Designing a biologically representative reserve

Some of the methods for identifying conservation reserves are through endemism hotspot identification, species richness, rarity or irreplaceability, and complementarity (Pressey *et al.* 1993). By using a combination of these approaches a more complete conservation plan will be produced than using a single approach. The resulting reserve will be more representative of all the biological elements and landscape features.

One method to conserve biodiversity is to set up a network of protected areas to preserve as many representative species as possible (Olson 1994; Kelly *et al.* 2002). Historically, most reserves in Fiji were set up before conservation practices were set in place and the purpose of those reserves was for hunting and recreational purposes and not for conserving species. Reserves were usually established to protect mammals and birds, usually because their taxonomy and distribution are better known and also because of their surrogacy, flag-ship and umbrella species values (Stattersfield 1998; Kelly *et al.* 2002).

1.8.1 Umbrella Species

Umbrella species conservation often involves conservation of wide-ranging animals and is assumed that by conserving these species all other species will also be conserved (Noss *et al.* 1996; and Berger 1997). When there is a lack of information on the biology and location of a particular umbrella species, a substitute approach is to allocate the largest remaining block of forest for conservation (Poiani *et al.* 2000). This method is useful in island ecosystems where there is a lack of wide-ranging animals. Large areas of intact forest act as refuge sites for viable populations, offer great resources and habitat diversity, support more than one ecological process, and provide large undisturbed core areas (Poiani *et al.* 2000). However, selection of small fragments for reservation can be a concern for serious long time ecological problems of competition and penetration of the core areas by invasive species, edge effects, lack of viable populations, bottle neck-effect, in-breeding, and over time degraded natural processes (Shafer 1997).

Invertebrates tend to be very localized often with very restricted ranges and high degrees of local endemism (Olson and Farley 2003). Small forest fragments may not be ideal refuges for more itinerant species (Peregrine falcons, Collared Lory's, and other Fijian birds) but they may harbour unique assemblages of invertebrates.

1.8.2 Linkage

Due to the patchy distribution of most invertebrates, the distribution and continuity of invertebrates and habitats become limiting when it comes to the designing of the reserves (Webb and Thomas 1994). Thomas (1984) showed that gaps of 1-10 km can be a barrier to butterfly dispersal for about 78% of the species studied. He estimated that forest patches within 200-500 m of a population could be colonized over several years and generations. However, the invertebrates used in this study have dispersal power less then that of the butterflies so their dispersal rate may be much lower and it could take them longer to colonize neighbouring habitat patches. For other invertebrates patch distribution can be even more challenging as smaller body size and lower mobility will make them more vulnerable to micro-climatic and other environmental effects.

Linkage provided by corridors is very important for migratory species in Fiji, which seasonally track fruiting trees at different elevations (Wildlife Conservation Society 2004). Therefore, it is important to maintain a connection between the few remaining large forest blocks such as Serua, Sovi, Waimanu, etc. Conserving the riparian vegetation along streams and rivers will also help maintain high water quality. The rivers and streams in Fiji harbour a unique assemblage of freshwater mussels, snails, gobies, prawns that are of great economic value and should also be conserved. This is the basic principal of landscape ecology and conservation, it is argued that the whole landscape has to be considered when reserves are designed to ensure that all the ecological processes are capture by the reserves (Wiens 2002).

1.9 Conclusion

Although Fiji has a unique assemblage of terrestrial arthropods, little conservation work has been carried. This is due to many of the Fijian terrestrial invertebrates having yet to be studied in detail and the lack of taxonomic work. Taxonomic work on terrestrial arthropods is lacking due to the absence of local entomologists, although the Ministry of

Agriculture has one local entomologist who deals with agricultural pests. This is not enough to meet the taxonomic demand needed to study the wild terrestrial arthropod assemblage.

Deficient conservation strategies and threats from habitat destruction and invasive species are further pushing the Fijian terrestrial invertebrates towards extinction. Therefore alternative procedures need to be adapted to fast track the evaluation of invertebrates in Fiji's reserves. Usage of the morphospecies concept, with sorting of taxa readily by morphological differences, has been extensively utilised in Australia and New Zealand. Although these countries have bulk of the regional taxonomists they still prefer use of this concept as this method prepares specimens for formal taxonomic classification which in turn fast tracks the taxonomic work. The morphospecies concept is also very reliable and effective (Oliver and Beattie 1996a; 1996 b; Derraik *et al*. 2002; Barrat *et al*. 2003).

Using the morphospecies concept and the internationally accepted protocols on reserve designs, terrestrial invertebrates can be used to design a representative network of forest reserves. Leaf litter invertebrates, especially the arthropods, can be easily sorted to morphospecies and presence/absence and abundance data can be reliably gathered. If the invertebrate assemblages on the different islands are different then the presence and absence data can be used for mapping areas that have dissimilar invertebrates. The areas obtained from the invertebrate surveys can be overlaid with areas important to other taxa. Overlapping areas can then be mapped to show areas with high conservation value.

These areas then should be linked using riparian and alternative vegetation to design an effective network of forest reserves for Fiji.

Chapter 2 Identifying High Conservation Areas in Fiji using leaf litter Invertebrates

2.1 Introduction

Biodiversity conservation is one of the most important biological issues around the world (UNEP 1993; IUCN 2000; SPREP 2004). The Convention on Biological Diversity (UNEP 1993) calls for signatory countries to perform intensive biodiversity assessments within two years to fight loss of biodiversity. To achieve this requires a rapid but accurate biodiversity assessment technique. Australia overcame the rapid species identification process by the use of Recognizable Taxonomic Units (RTU) (a method of sorting specimens into different groups e.g. morphospecies) while Conservation International (CI) employed teams of multidisciplinary experts (scientists train locals who are then responsible for conducting and continuing the field surveys). The Australian approach to rapid species identification was first introduced by Beattie and Oliver (1994) and is defined as “a range of methods that facilitate rapid field survey work and classification”. The fieldwork usually involves a multidisciplinary team including experienced field scientists and people with local knowledge, to survey faunal groups that are representative of the biological diversity. The scientists quantify the variety of organisms collected by classifying them into “Recognizable Taxonomic Units”.

Most conservation studies use abundance or species diversity to establish biodiversity indices. Trees (especially angiosperms), birds, mammals, and to a lesser degree reptiles and amphibians have until now been the most readily used taxa in these studies (Cranston and Trueman 1997). Although these taxa have been extensively studied and are charismatic with international appeal, invertebrates which are the most diverse group have often been overlooked (Cranston and Trueman 1997; Crisp *et al.* 1998). By excluding the invertebrates that are largely responsible for maintaining the essential ecosystems processes, we overlook a significant proportion of Fiji's biodiversity (Cranston and Trueman 1997). Globally, insects constitute 50% of all named species and 20% of these are the Coleoptera alone (Barrat *et al* 2003). Although in Fiji, only a few invertebrate surveys have been conducted in Fiji, it is estimated that majority of insect groups are endemic (Olson *pers. comm.*).

Although insects contribute immensely to the biodiversity of our planet, it is estimated that 66-96% are yet to be described and most are from developing countries like Fiji (Cranston and Hillman 1992). Invertebrate biodiversity is sampled with less effort than that gathered from vertebrate and flowering plant inventories (Oliver and Beattie 1996a; 1996 b). In island ecosystems, where the invertebrates account for the majority of the biodiversity, it is imperative to take into account the invertebrates in conservation assessment studies.

Leaf litter invertebrates are an essential part of a forest ecosystem. These invertebrates are responsible for the majority of the energy transfer, nutrient recycling, and trapping moisture (Levings and Windsor 1985; Longman and Jenik 1987). Three indicator groups, rove beetles (Staphylinidae), harvestmen (Opiliones), and weevils (Curculionidae) are used in this study to assess their representativeness in forest reserve design. These groups were chosen because of their low vagility (less movement) and the relative ease of being sampled and sorted to morphospecies (Olson 1994).

I examined the potential of using leaf litter invertebrates as indicator species to assess whether they are useful in designing forest reserves. The samples collected were tested for relatedness (both inter and intra islands) using morphospecies richness and abundance to determine if the leaf litter invertebrates were similar across all sites. Similarity was tested among all sites so that the sites with unique invertebrates could be isolated (as dissimilar sites have higher conservation priority than sites which are similar). The hypothesis being tested was that the leaf litter invertebrates were similar across all sites. If the leaf litter invertebrates were similar then there would be no distinction among the samples, suggesting that leaf litter invertebrates were not useful indicator species for designing forest reserves. However, if they were distinct according to site then it would be possible to use the data to highlight areas that have ‘unique’ assemblages and thus, have high conservation value. The areas discussed in this chapter will then be discussed in Chapter 3 to highlight the forest areas with high conservation value.

2.2 Methodology

2.2.1 Study sites

The sites chosen in this study were from the important sites profile listed in Olson and Farley (2003). These sites were selected after a workshop in which experts from Government, NGOs and conservation organisations prescribed a conservation value to a number of sites. The sites identified here as having high conservation value based on their dissimilarity from the MDS plot were grouped into biotic provinces. In total, 26 sites were chosen (see Table 2.1 for more information on the conservation significance of the sites and Fig 2.1 for location).

Table 2.1 Conservation significance of the sites used in the study (based on Olson and Farley 2003).

Site*	Location	Conservation significance
Nakobalevu	Viti Levu	Remote forest
Waivudawa		
Mount Korobaba		
Koroyanitu		Montane forest
Wainivalau		Intact lowland forest wilderness
Vatukalikali		Isolated and large block of forest
Nakauvadra		
Nabukavesi		
Naikorokoro		
Nakavu		
Naboutini		Largest block of remote forest and forest wilderness
Galoa		
Nabukelevu		
Lovoni	Ovalau	Forest and fauna
Nabukelevu (Kadavu)	Kadavu	Unique Kadavu flora and flora especially invertebrate fauna
Namara		
Gau	Gau	Montane forest and Cloud forest
Koro	Koro	Forest and Parrots
Momici	Taveuni	Remote forest Largest island without the small Indian mongoose *Herpestes javanicus*
Lavena		
Nakanakana	Natewa Peninsula Vanua Levu	Remote forest
Kasavu		
Saqani	Vanua Levu	Remote and large block of montane and transitional forest types, Sandalwood forest remnant and dry forest sites
Nakasa		
Dogotuki		
Uluivaya		

* All sites had primary forest with 75-100% canopy cover and insects were collected during fine weather (0mm rainfall for the last 24 hours), the substrate beneath leaf litter

was soil for all sites except Naikorokoro which had a rocky substrate type. All sampling was done between December 2003 and July 2004.

Key

	Site No	Island	Locality
1	V43	Viti Levu	Naboutini
2	V45	Viti Levu	Nabukelevu
3	V44	Viti Levu	Galoa
4	V39	Viti Levu	Nakavu
5	V36	Viti Levu	Nabukavesi
6	V38	Viti Levu	Naikorokoro
7	V10	Viti Levu	Waivudawa
8	V14	Viti Levu	Korobaba
9	V34	Viti Levu	Wainivalau
10	V4	Viti Levu	Nakobalevu
11	V30	Viti Levu	Koroyanitu
12	V42	Viti Levu	Nakauvadra
13	V37	Viti Levu	Vatukalikali
14	O33	Ovalau	Lovoni
15	G40	Gau	Gau
16	R27	Koro	Koro
17	N56	Vanua Levu	Uluivuya
18	N50	Vanua Levu	Nakasa
19	N49	Vanua Levu	Saqani
20	N54	Vanua Levu	Dogotuki
21	N48	Vanua Levu	Kasavu
22	N47	Vanua Levu	Nakanakana
23	T52	Taveuni	Momici
24	T53	Taveuni	Lavena
25	K46	Kadavu	Nabukelevu
26	K51	Kadavu	Namara

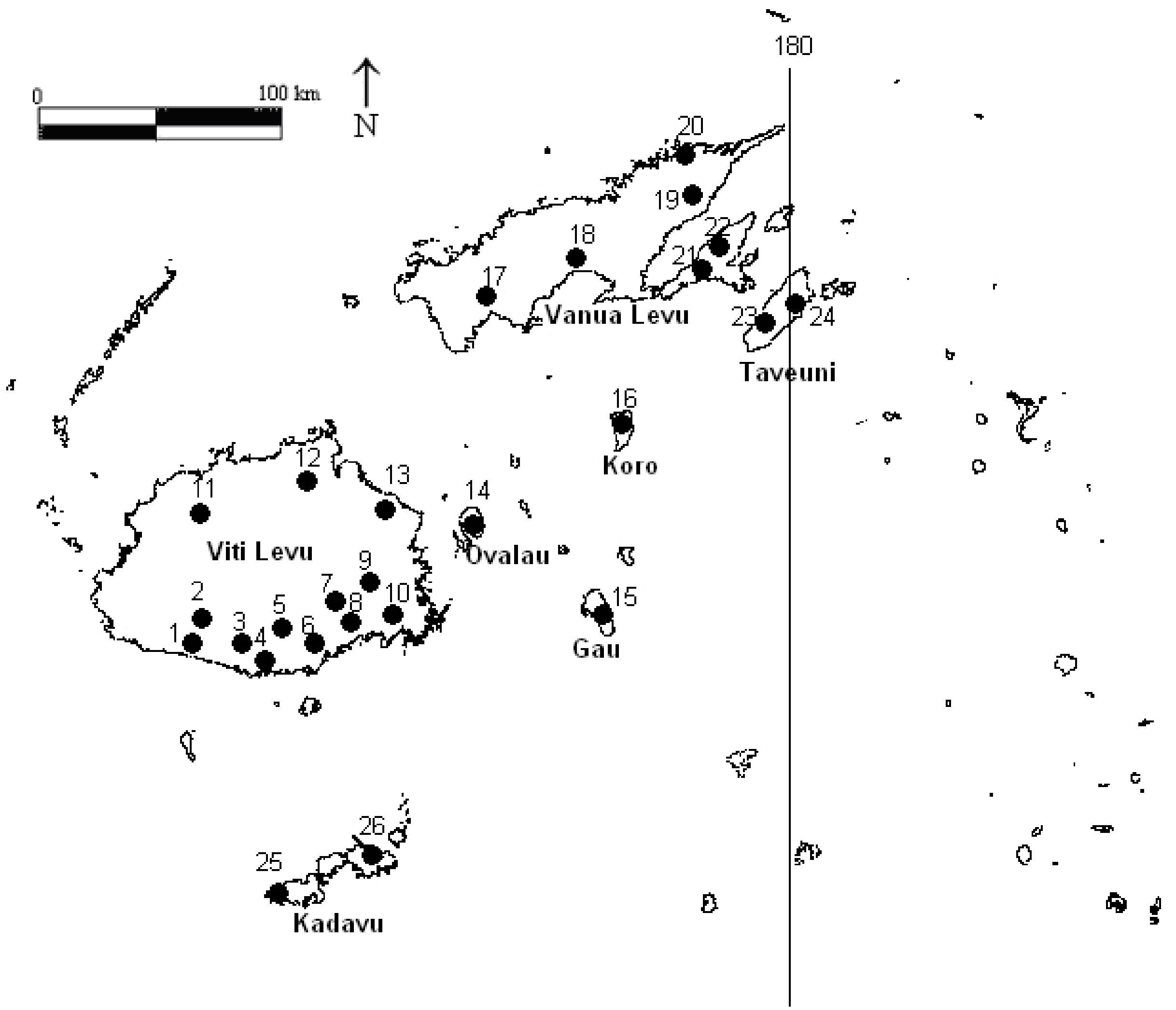


Figure 2.1 A map of Fiji showing the location of the litter sampling sites.

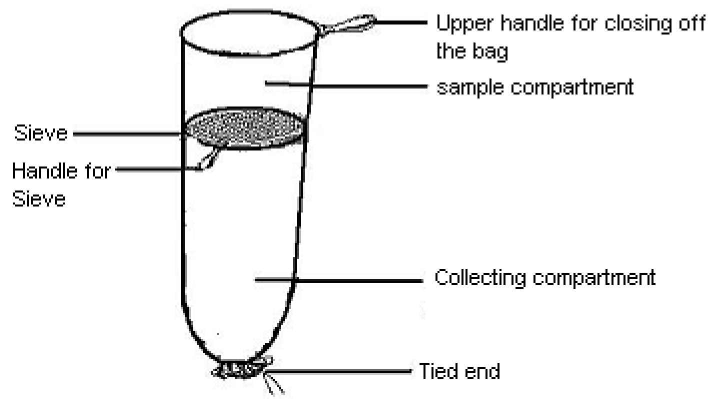
2.2.2 Sample size and survey design

The aim of this study was to compare leaf litter invertebrate morphospecies diversity and abundance between various sites in Fiji. Elevation was standardized at 300m and litter-processing time to 48 hours for each sample. 300m was chosen as this was an approximate mid elevation level for Fiji and it is known that diversity peaks at mid elevation (Olson 1991; Olson 1994, Fisher 1996, Fisher 1998). All samples were collected during fine weather to increase the number of leaf litter invertebrates because wet litter has a higher retention rate of the invertebrates (Olson *pers. comm.).*

There is quite a lot of variation in leaf litter sampling. For example, the area or volume of litter sampled can vary extensively. Some studies use volume while other ecological studies rely on litter area (see Olson 1991 for the efficacy of litter sifting). For this study, three 100m transects with twenty 1 m^2 plots at 5m intervals were used (20 shift sample). The leaf litter inside each 1 m^2 plot was collected, coalesced and sifted through a wire sieve, which was later transferred into a cotton bag until it was processed in the Winkler sacks (Figure 2.2). Three samples from each site were taken on one occasion.

2.2.3 Winkler extraction

After collection, the leaf litter was held in a small 0.5-cm^2 sack that was suspended in a large cotton Winkler bag with a beaker of 95% ethanol fixed at the bottom of the bag. The litter was held in the Winkler bags for 48 hours during which the invertebrates inside the sack worked their way out of the drying litter and fell into the ethanol.



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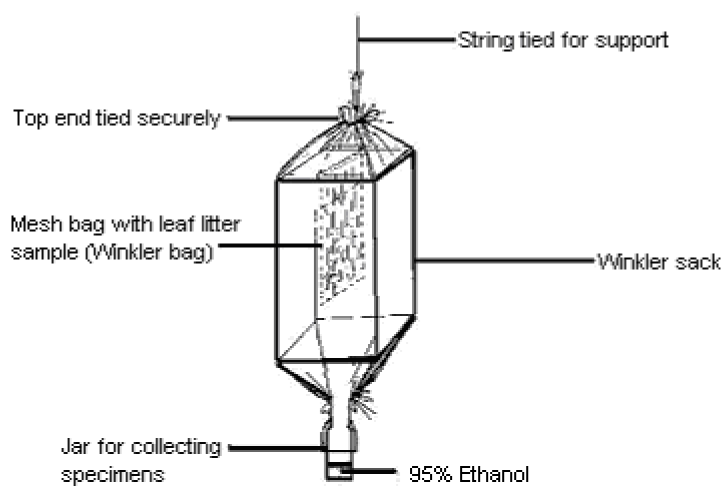

B

Figure 2.2 Leaf litter invertebrate extraction equipment A) Leaf litter sifter, B) Winkler Sack.

2.2.4 Sorting of samples

The samples retrieved by hand and from the Winkler extraction were Alpha sorted (separation of target taxa from the unwanted taxa and debris) under a dissecting microscope. The specimens were sorted into different morphospecies based on external characteristics predetermined from Newton (1990) and after consultation and training with specialists from the Wildlife Conservation Society (David M. Olson) and Landcare Research-New Zealand (Dr. Richard Leshlen and Darren Ward). The presence/absence and abundance was recorded. The use of the word “species” hereinafter refers to morphospecies.

2.2.5 Sampling and sorting bias

A common bias which arises during sorting is the lumping and/or splitting of species. This usually happens when dealing with cryptic species (lumping) or when there is extensive sexual dimorphism (splitting). However, lumping and splitting may cancel each other out if the samples are consistently sorted (Oliver and Beattie 1996 a; 1996 b).

2.2.6 Data analysis

Similarity of the samples was assessed using Jaccard's index (Krebs 1998; Longino 2000). The index is based on:

$$S_j = a / (a + b + c)$$

Where S_j = Jaccard's similarity coefficient

a = Number of species in sample 1 and 2

b = Number of species in sample 2 but not in sample 1

c = Number of species in sample 1 but not in sample 2

A Decorana analysis was used to separate the sites into different clusters based on their species composition. During a Decorana analysis, the computer-generated algorithm splits the sites along two axes and the similar sites appear close to each other near the center of the Decorana plot (McCune and Mefford 1999; McCune and Grace 2002). Species diversity was calculated using the Simpson's Diversity Index, D.

$$D = \Sigma n(n-1) / N(N-1)$$

Where n = total number of organisms of a particular species

N = total number of organisms of all species

2.3 Results

All the sites pooled together revealed a total of 317 morphospecies of the three indicator groups (255 Curculionidae, 48 Staphylinidae, 14 Opilionidae) with an average number of 22 morphospecies (Figure 2.3). Of the 26 sites 35% had high morphospecies diversity:high unique morphospecies (the term ‘unique’ is used in placed of the term endemic as endemic is usually associated with generic species), 27% had low morphospecies diversity:low unique morphospecies, 11% had low morphospecies diversity:high unique morphospecies, and 27% had high morphospecies diversity:low unique morphospecies (see appendix 2).

The invertebrates samples collected demonstrated a distinct assemblage from the main island communities and several overlaps occurring between the smaller outer laying islands and the main islands (Figure 2.4). The samples from Kadavu were close to those from Taveuni suggesting that the two islands have a similar leaf litter invertebrate community assemblages both in terms of composition and abundance (T52 and K46 cluster seem to be closer then T53 and K51 cluster). They are also very close to the Saqani sample (N49) which is the Northeastern part of Vanua Levu. Vanua Levu and Viti Levu have some close affinities (V30 and N47 on Decorana plot Figure 2.4). V34 is different from all the other sites and this might be a possible outlier at the origin 0,0 (Red box), this is the region where outliers usually show up. There are three areas on the plots where overlap clusters occur V43 withV4, V37 with V39, V44 with R27, and N48 with G 40. These three sets of sites were very similar to each other in terms of the leaf litter morphospecies presence/absence and abundance, thus having the same conservation value. Fig 2.5 shows the Simpson's Index values for each site, the mean Simpson Index value of 8.7 shows that sites are generally species diverse (D values above 13 would be considered too high and below 4 would be considered too low). Figures 2.6.A to F shows the Jaccard's dendrograms.

Figure 2.6 A shows that using the three indicator groups the Viti Levu samples split on the same branch while the other samples split gradually from each other. These samples, although made up of many islands are different from each other as they do not spilt under the same island branch. Figure 2.6 B shows that when the island samples are group as one, the islands spilt differently indicting that there is less similarity between island samples. Figure 2.6 C shows the splitting of the sub biotic provinces which coincides with the Decorana plot. Similar results are shown when the individual data sets are graphed (Figure 2.6d, 2.6 E and 2.6 F).

Also, see Appendix 3 for the abundance and absence/presence data respectively.

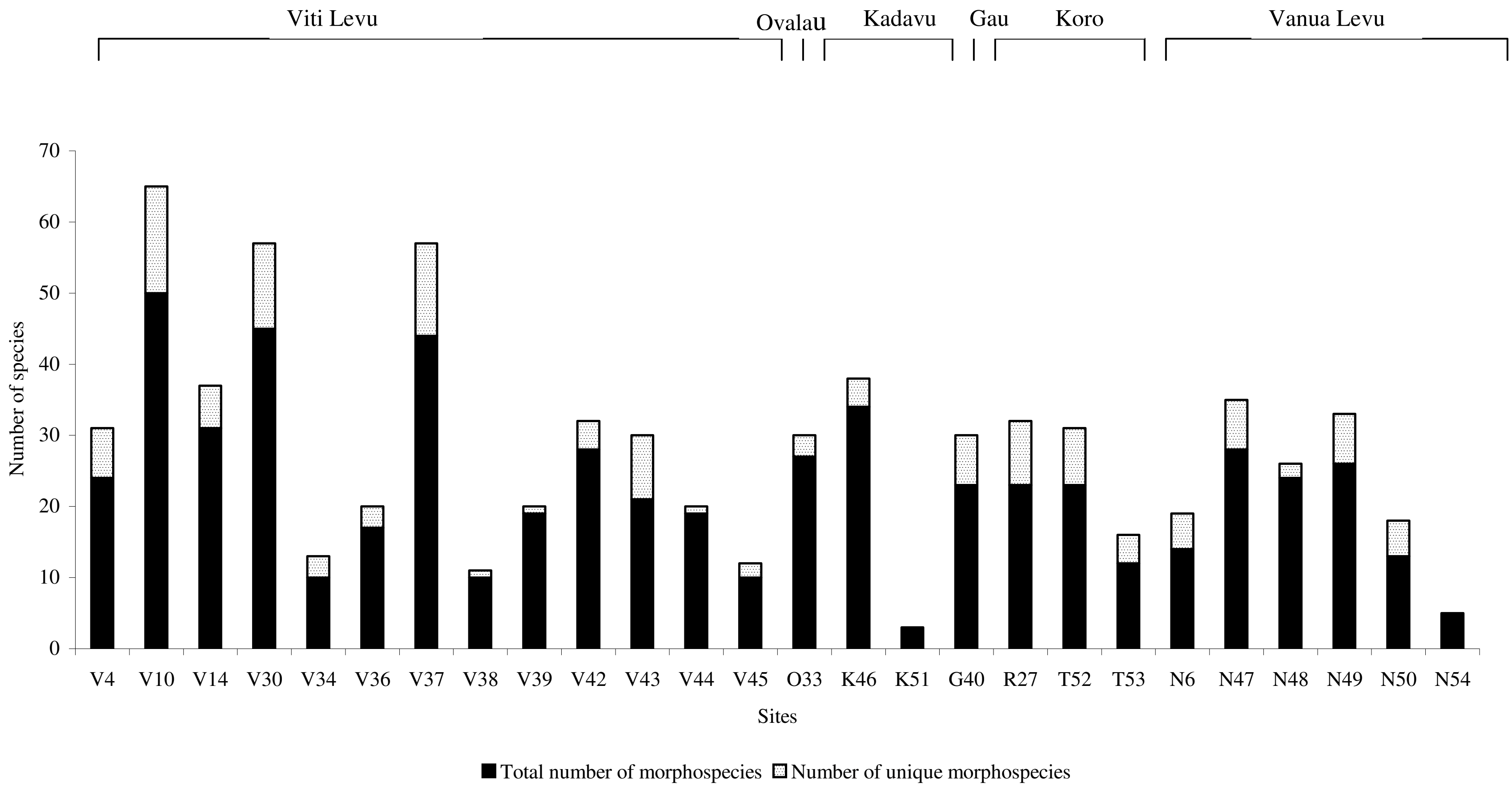

Figure 2.3 Total number of morphospecies collected from each site and the number of unique morphospecies.

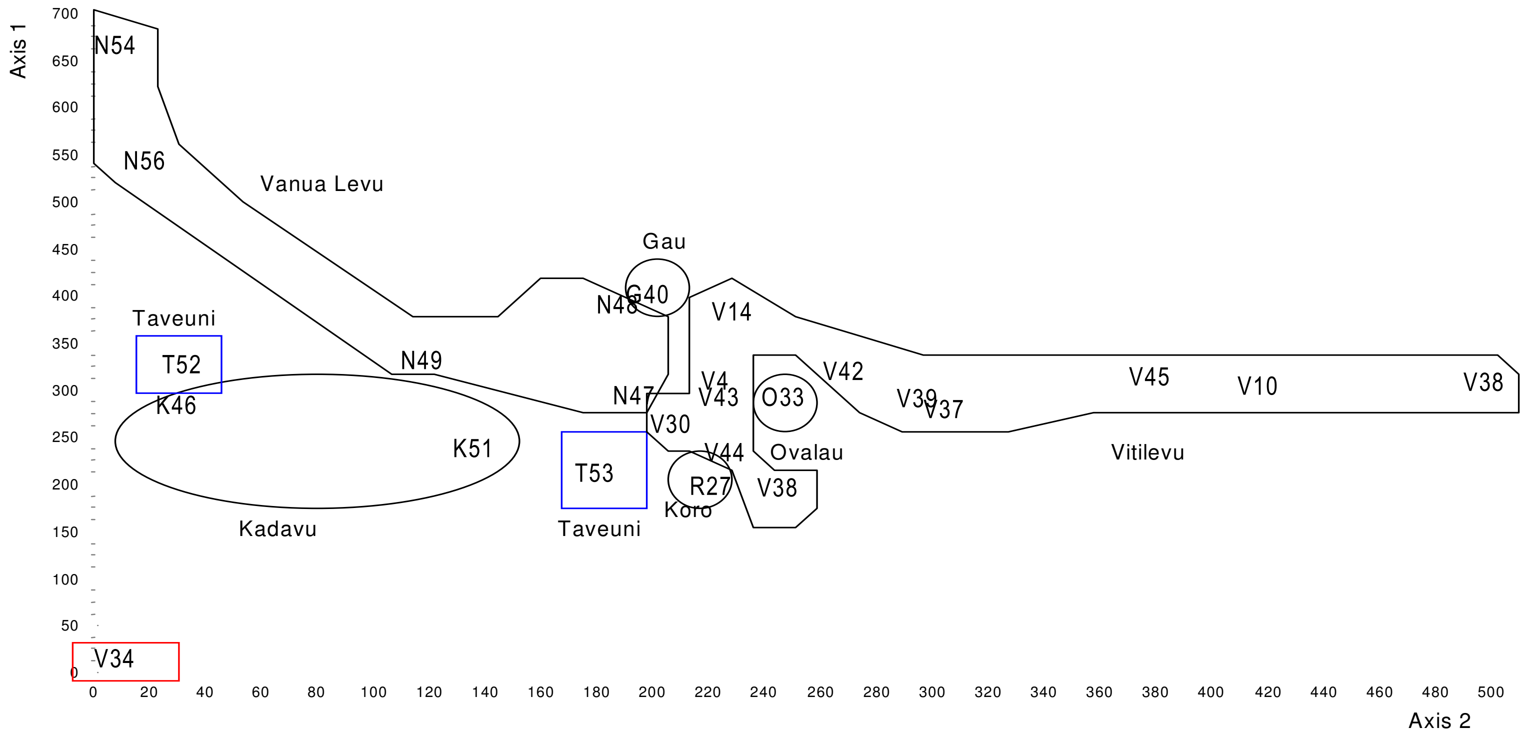

Figure 2.4 MDS Decorana plot of the 26 leaf litter sites based on morphospecies richness, abundance, and presence/absence data. The sites have been clustered based on these parameters along two arbitrary axes. Sites that have a similar species richness, abundance and morphospecies appear clustered towards the centre while sites with dissimilar species richness, abundance and morphospecies appear at the edges of the plot, Sites which overlap are most similar (V= Sample from Viti Levu, O=Ovalau, K=Kadavu, G=Gau, R=Koro, T=Taveuni (indicated by blue box) and N-Vanua Levu).

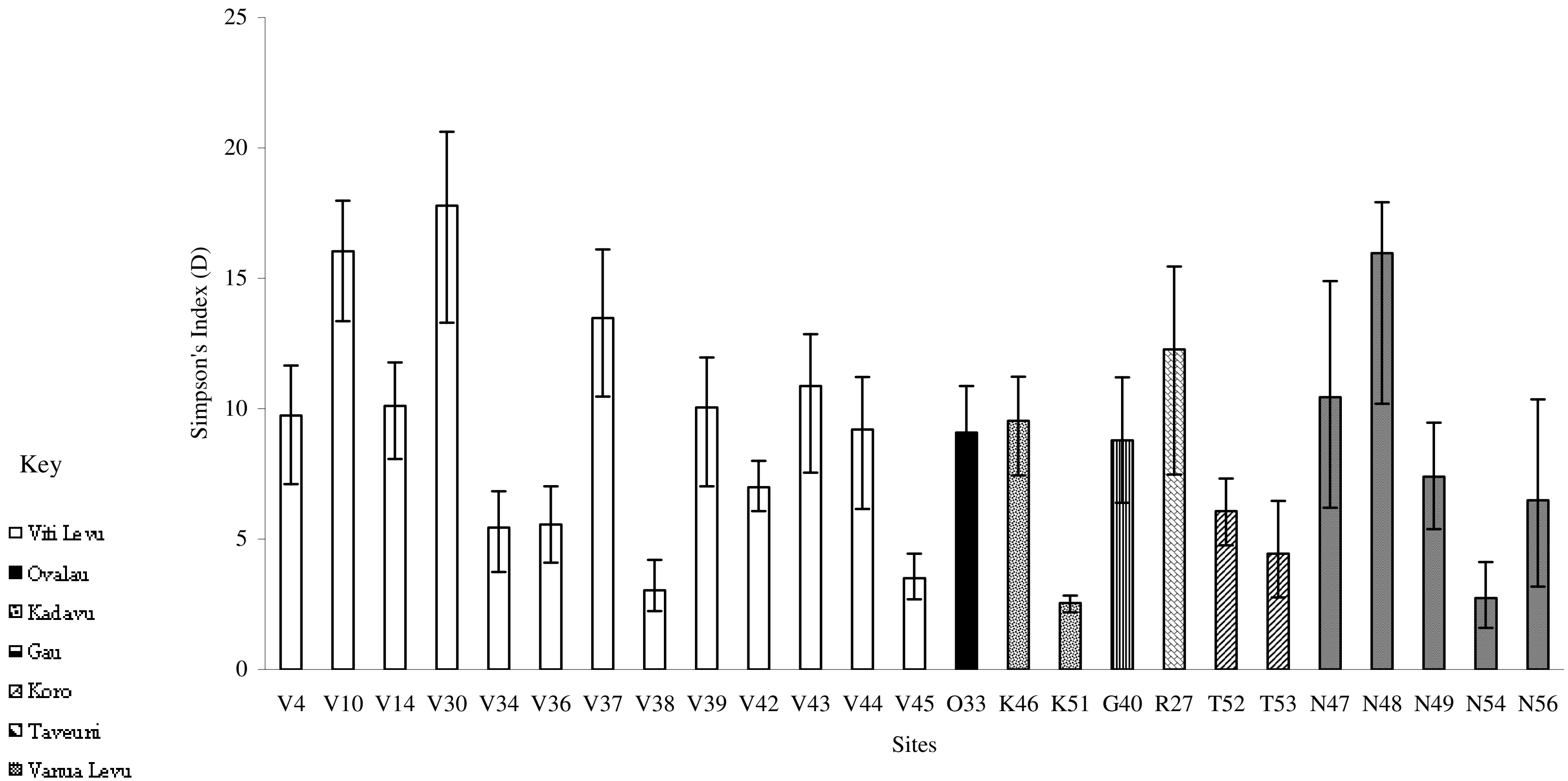

Figure 2.5 The Simpson's index value (D) for all species with bootstrapped 95% confidence intervals.

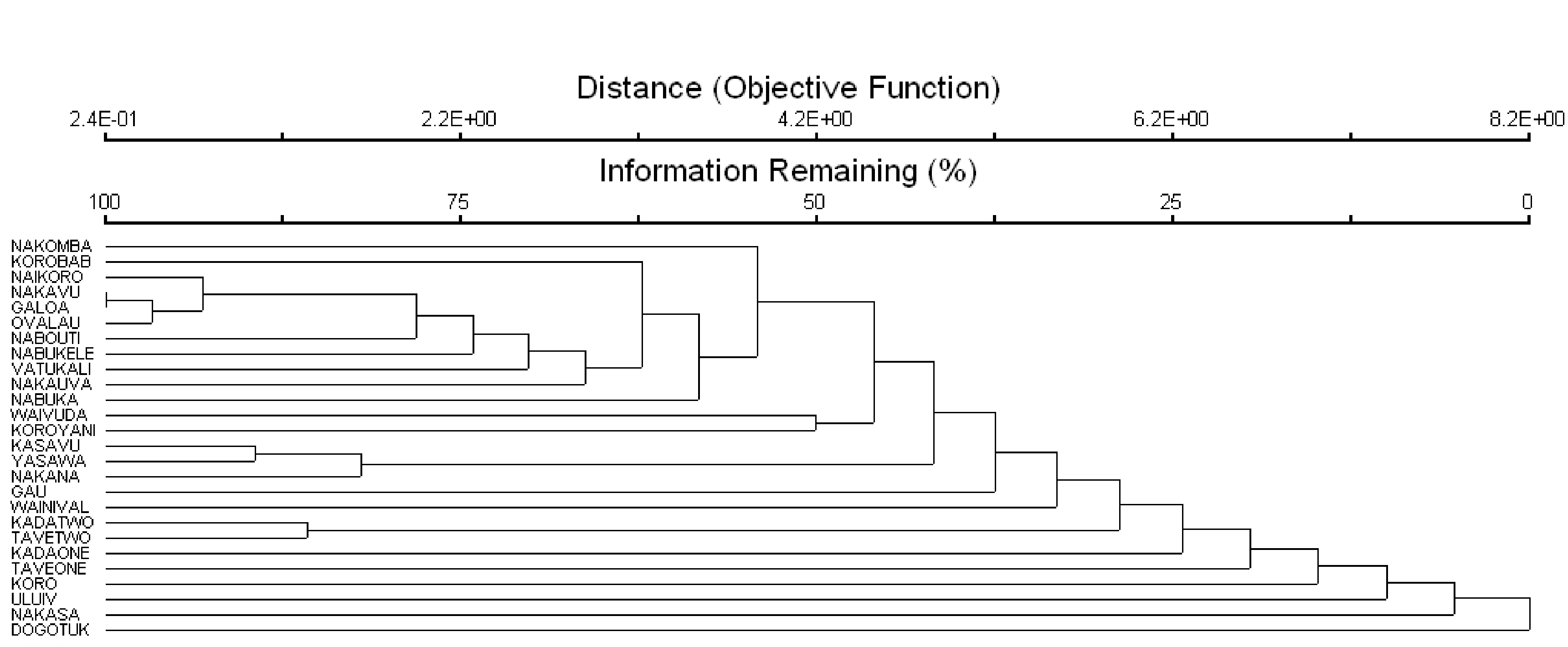

Figure 2.6.A Jaccards nearest neighbour analysis dendogram for the three indicator groups (Curculionidae, Opilionae and Staphylinidae).

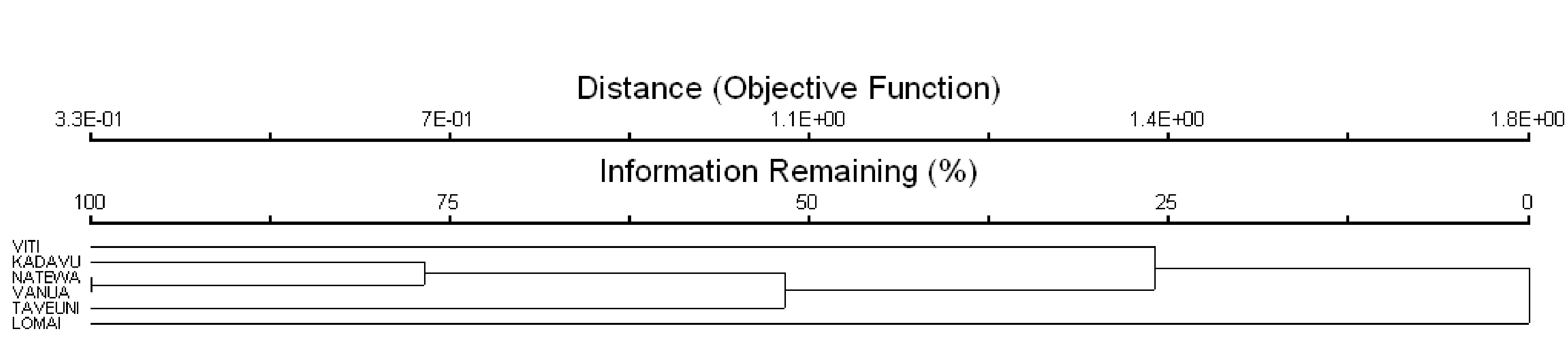

Figure 2.6.B Jaccards nearest neighbour analysis for the assigned invertebrate boundary (individual islands) deducted from the Jaccards dendograms and MDS decorana plots for the three indicator groups (Curculionidae, Opilionae, and Staphylinidae).

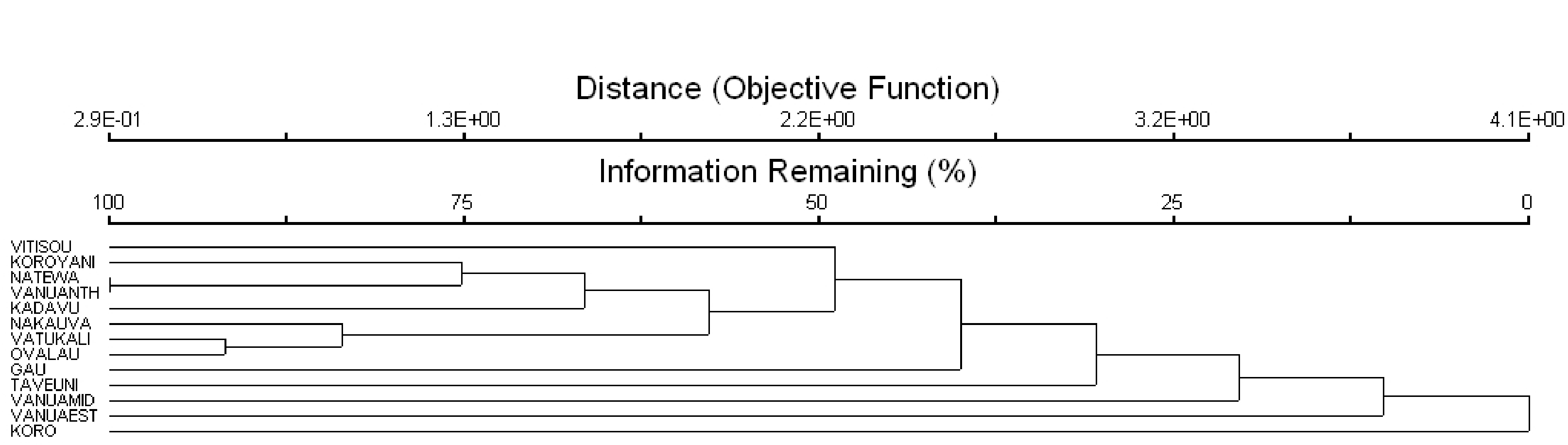

Figure 2.6.C Jaccards nearest neighbour analysis for the assigned sub biotic province (within island boundaries) deducted from the Jaccards dendograms and MDS decorana plots for the three indicator groups (Curculionidae, Opilionae, and Staphylinidae).

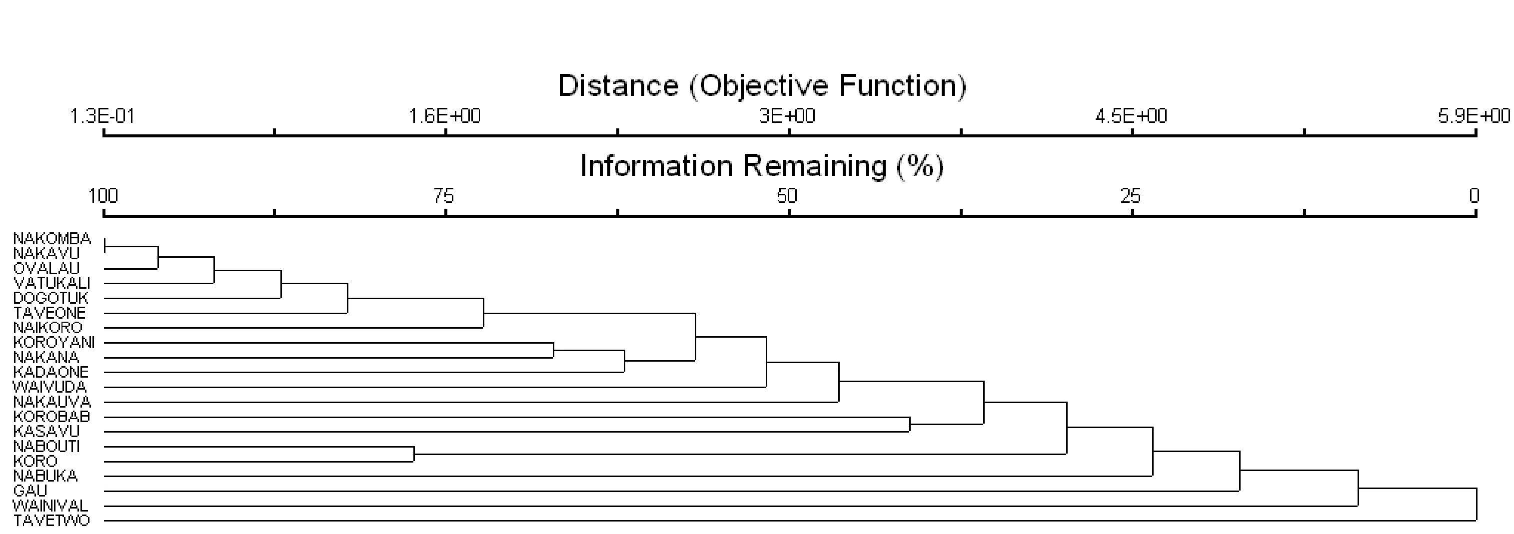

Figure 2.6.D Jaccards nearest neighbour analysis for Staphylinidae data.

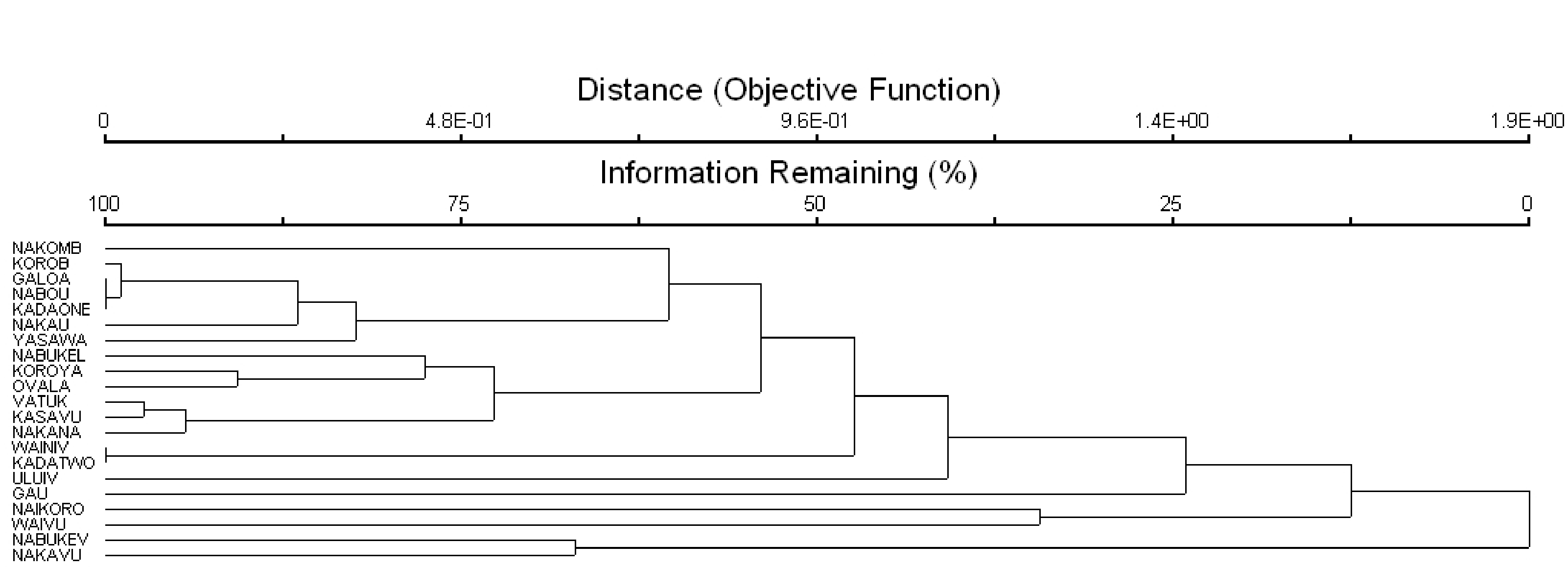

Figure 2.6.E Jaccards nearest neighbour analysis for Opilionae data.

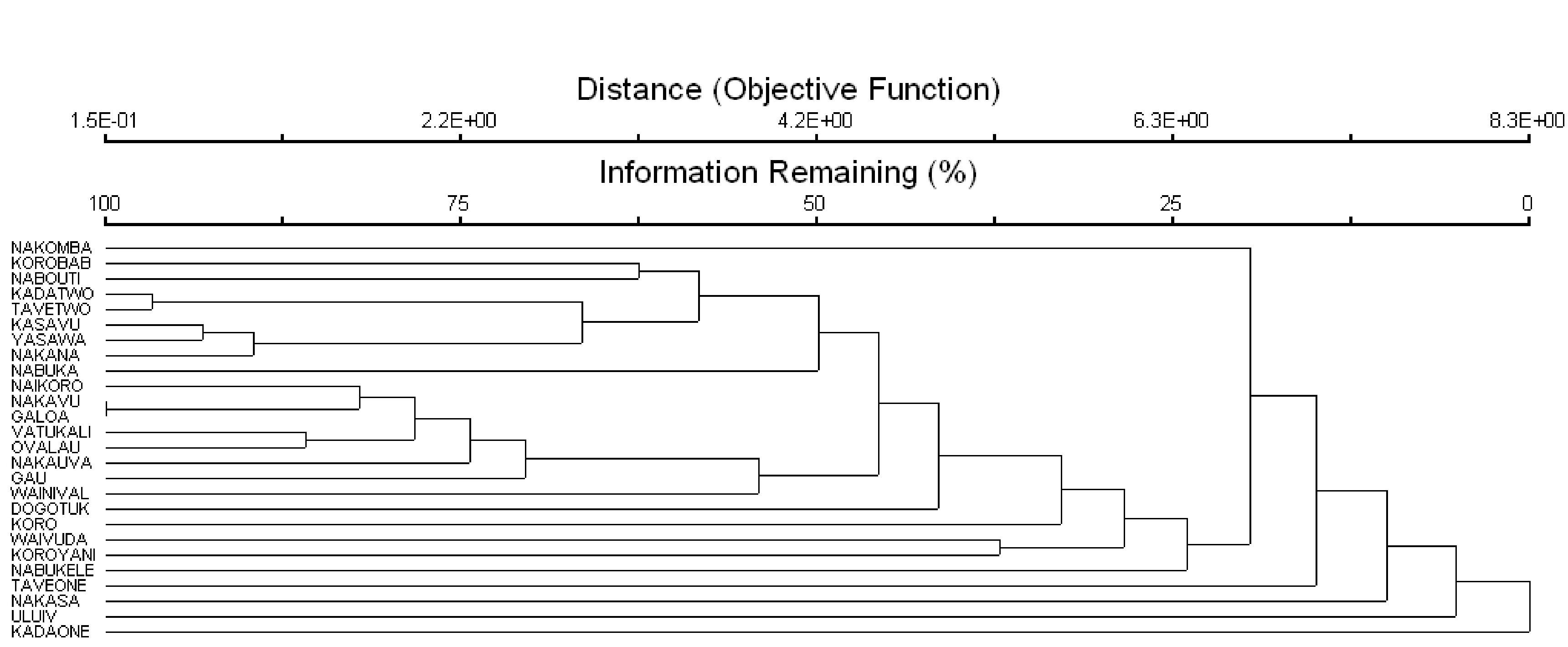

Figure 2.6.F Jaccards nearest neighbour analysis for Curculionidae data.

Table 2.2 Sites with high conservation value (biotic provinces) based on the complimentarity values of the site in the MDS plot.

Site (Code)	Island
Waivudawa (V10)	Viti Levu
Wainivalau (V34)	Viti Levu
Vatukalikali (V37)	Viti Levu
Naikorokoro (V38)	Viti Levu
Nabukelevu (V45)	Viti Levu
Nabukelevu (K46)	Kadavu
Namara (K51)	Kadavu
Gau (G40)	Gau
Koro (R27)	Koro
Momici (T52)	Taveuni
Lavena (T53)	Taveuni
Saqani (N49)	Vanua Levu
Dogotuki (N54)	Vanua Levu
Uluivuya (N56)	Vanua Levu

2.4 Discussion

Using conservation values is similar to the procedure used by the London Natural History Museum (http://www.nhm.ac.uk/research-curation/projects/worldmap/) to strategically choose areas for conservation. Areas with high conservation value are chosen first by choosing the areas that represent greater dissimilarity.A distinct separation of the samples between the main islands and the smaller islands is an indication that the data can be used for assessing the representativeness of leaf litter invertebrates in the designing of Fiji's forest reserves. Sites that have a high Simpson's index do not necessarily split on the edge of the MDS plot. In fact, the majority of the sites appear clumped in the centre, while the sites that split at the edge of the plot are sites with a low Simpsons index values. The sites with a low Simpsons index have a low species number, but have a lot of unique species, thus splitting at the edge because of distinct species richness.

Some sites have a higher conservation value than others. This is not because all the sites are clustered together. Sites that appear farther away from the centre of the MDS plot are dissimilar and thus have more conservation value. Dissimilar sties with different species richness should have at least one representative from similar sites. For the Viti Levu cluster it is seen that V45, V10 and V38 are away from the majority of the sites that appear at the centre of the MDS plot, these sites are dissimilar to the rest of the Viti Levu samples. This could be due to the isolation of these sites. Waivudawa, Naikorokoro and Nabukelevu have intact forest fragments surrounded by highly mosaic forest areas thus, these could be possible refuge areas for the invertebrates. Most of the Viti Levu samples are clustered close to each other which suggests they have a low conservation value.

2.4.1 Biogeographical influence on leaf litter invertebrates.

The Vanua Levu samples are not as strongly clustered as the Viti Levu. N47 and N48 are close to the cluster core and N48 overlaps with the sample from Gau Island G40. Conserving G40 would be preferable over N48 even though they have similar invertebrate diversity, because G40 is a small out-lying island. Taveuni samples display distinct separation, with one sample closer to the core cluster while the other is closer to the Kadavu sample, similar observation is made for the other Kadavu sample. Even though the Taveuni and Kadavu samples are close in biological species richness and abundance they are geographically quite distinct. The actual species composition need to be investigated to further explain this. The Ovalau sample is almost at the centre of the Viti Levu cluster core. This could be explained because Ovalau is geographically close to Viti Levu.

The development of biotic provinces makes prioritising sites and ecosystems for conservation extremely practical. Biotic provinces with high conservation value and unique invertebrate assemblages should be included in future reserves. The biotic provinces identified by my data will provide useful information for conservation planners and managers in any future reserve networks (Table 2.2).

Geographical features such as mountain ranges, major rivers and tributaries, ridges, cliffs that limit the dispersal of plants and restrict the range of these species can also limit invertebrate distribution. Ash and Vodonaivalu (1984) found that endemic species are mostly restricted to forest areas, although, some non-specialised unique species are found in areas affected by human disturbance, grazing and firing.

2.4.2 Environmental influence on leaf litter invertebrates.

Although the weather may play an important role in the distribution of weevils, this was not originally factored into the study. Nevertheless, Zimmerman's data suggest that Fijian weevils may divide themselves into wet and dry species (Zimmerman 1936, 1942). For example, *Orochlesis sp*, *Alsminthia longipes*, and *Calamus vitiensis* are only found on the southeastern side of Viti Levu and Vanua Levu. *Orochlesis* prefers the wet areas of Viti Levu and Vanua Levu as it tends to get higher precipitation. Similar patterns occur with the distribution of *O. tessellata* and *O. bryani* (Zimmerman 1939).

2.4.3 Habitat integrity

Habitat availability can also restrict the range of species (Buse and Good 1993). A greater diversity of species is observed in structurally complex localities than in structurally simple habitats (McColl 1974; Lawton and Schroder 1977; Moeed and Meads 1985; 1992). A locality with high species diversity of native plants will provide a greater range of habitats for the invertebrates by providing a higher number of host plants and higher diversity of litter. This is because different species have different leaf complexity and design and decomposition rates. This may help explain why some localities had higher diversity and unique species than other sites (Figure 2.3). Patchy distributions can also result from isolated habitats as few rare species rend to survive in these areas. Often, these sites will have a lower diversity but may harbour species that are rare, unique, and are of high conservation value.

Duffels and Ewart (1988) noted that the distribution of endemic cicada species were very localized, implying that cicadas prefer certain tree species. Another very specific host-plant association was shown in *Aceropyga pterophon* and *Gironniera certidifolia* where the adults of these species were found on the trunks and branches while the larvae were found in the roots of the same species of host trees (Duffels and Ewart 1988). If such associations exist between the litter invertebrates and specific tree species then this might lead to higher number of locally unique and rare invertebrate morphospecies. Lawton *et al.* (1996) suggests that the age of the taxa is also reflected by the distribution pattern. However, this was not examined in this study.

The complexity of the forest is decreased dramatically by invasive and other non-native species. Ash and Vodonaivalu (1984) have demonstrated that invasive species tend to decrease the vertical and horizontal forest heterogeneity leading to a structurally simple habitat rather than a complex habitat with a broad niche, this can also affect the distribution pattern.

2.4.5 Implications of invertebrate distribution on reserve design

The patchy distribution of the litter invertebrates collected (Figure 2.4) accounts for a lot of the rare and unique species in this analysis. This is because invertebrates generally occupy smaller areas than vertebrates. For slow dispersing species, colonizing a new patch within a few hundred meters, is highly unlikely, therefore, several distinct populations of invertebrates can exist within a single patch (Webb and Thomas 1993). Insect populations are often confined to sites because biogeographic features limit their dispersal. Therefore, at any single time an island of a favourable habitat may contain several, one or no invertebrate species. It is also possible that a habitat containing patches of one or two dominant species may not have other species (Webb and Thomas 1993). Therefore, the use of invertebrates and their habitat requirement becomes an important deciding factor when considering forest reserve designs.

2.5 Recommendations and conclusions

Leaf litter invertebrates form a crucial part of many ecological processes and because of this they are useful for biological monitoring, inventories and biodiversity assessment studies. In this study, comparisons between samples from the main island and between the main and smaller islands were distinct thus demonstrating to be an effective means of determining relatedness between small island states.

The method of identification of biotic provinces (through dissimilarity) for conservation purpose is proving to be efficient. However, Fiji still needs to campaign more to effectively include the use of invertebrates in its conservation programme. This can be achieved by:

- Completing an inventory of the native terrestrial invertebrates.

- When designing forest reserves the invertebrates should also be considered and the areas identified here as biotic provinces should be further investigated for their conservation value.
- The size of a reserve should not be made purely on the requirements of the charismatic fauna such as birds and mammals. Some small reserves which may represent localised hotspots of invertebrates should also be set aside
- Within larger reserves critical hotspots requiring extra protection could be established to conserve specialised invertebrates and their needs. This would assist those invertebrates that may not be able to disperse to another patch.
- Investigating the association of Fijian leaf litter invertebrates and plants.
- Investigating the effect invasive plant species such as the African tulip tree *Spathodea campanulata*, *Merrimia peltata* and others have on native invertebrate species.

Chapter 3 Mapping High Conservation Value Forested Areas in Fiji as Potential Inclusion Areas into Future Networks of Reserves

3.1 Introduction

The rapid loss of biodiversity is at the forefront of challenges facing conservationists worldwide. Numerous approaches will be necessary to address this. In order to maintain the world's remaining species *in situ* conservation is likely to play a crucial role in biodiversity conservation (Pressey *et al.* 1993; Putney 2003). The realization of this has put pressure on the establishment of forest reserves as one of the main methods to conserve terrestrial biodiversity.

Reserve boundaries are determined by two factors: design (shape, size, connectedness, etc.) and location (Pressey *et al.* 1993). Gilpin and Diamond (1980) state that reserves are "refuge islands in a sea of inhospitable habitat". Therefore, the Theory of Island Biogeography is applicable to reserves. According to this theory extirpation rates on islands are negatively correlated with island size. Further to this, metapopulation theory states that in order to have a constant population there needs to be a balance between the rate of extinction and colonization (Harrison 1994). In order for a successful reserve network to work it would need to have numerous habitat patches with connectivity (corridors) and a substantial buffer system. Diamond (1975) and Shafer (1997) proposed that the extinction rate in reserves would be reduced if the following criteria are pursued; (1) larger reserves are preferred than smaller fragmented ones, (2) reserves in a network protect complete ecosystems instead of partial ecosystems, (3) more reserves are better then fewer reserves, (4) reserves with corridors are better than isolated reserves, (4) reserves with diverse habitats are better than reserves with uniform habitats, (5) circular reserves are better than irregular shaped reserves, (6) reserves with a buffer zone are better than reserves with no buffer zone, and (7) a network of large and small reserves are better than a network of just small reserves.

FAO statistics (2000) states that 44.6% of Fiji's land is covered with forest (815, 000 ha). Unfortunately, between 1990 and 2000 Fiji lost 2, 000 ha of forest at an annual rate of 0.2% (FAO 2000). Having already lost more than 50% of forest cover, the rate of deforestation in Fiji will continue slowly eroding away at the remaining forest areas.

The continual reduction of Fiji's intact forest habitat and the operating pressure on the remaining fragments is diminishing the options for establishing reservations, therefore, if new reserves are to be established they have to be selected quickly and carefully so that whatever resources are deployed they will be cost effective. To date, Fiji's few reserves have not been established based on biodiversity representativeness, but instead have been based on whatever land has been available. Although little recent work has been completed to assess representation of a few taxa (Herpetofauna Morrison 2005, Plants Lear and Woods 1992, Birds Stattersfield *et al.* 1975; Birdlife International 2003 and Wildlife Conservation Society 2004), invertebrate representation is largely missing. Non-representative forest reserves are not effective in conserving the full range of biodiversity needed for the future. Areas with high biodiversity need to be identified now in order to prevent any further loss.

Similar problems have been observed elsewhere and have lead to the development of more reserve systems based on the representation of the different elements of biodiversity and landscape features (Pressey *et al.* 1993). A well designed reserve begins to fulfil its role when it is representative of all the elements of the biodiversity and this depends on how well and how effective biodiversity can be measured, and also how the available information is utilized (Pressey *et al.* 1993; Margules and Pressey 2000).

In this chapter the leaf litter hotspot data obtained from the previous chapter will be used along with the Fijian Giant Longhorned beetle *Xixuthrus spp* and cicada (Homoptera) data to suggest Important Invertebrate Areas (IIAs) for the Fiji Islands. The maps produced will then be compared with the important areas of other species to highlight areas where there is greatest conservation overlap. This will then permit the identification of forest areas to be proposed as part of the future network of reserves.

3.2 Method

3.2.1 Study Species

The comparative data used in this chapter was taken from other research (Duffels and Ewart 1988; Doyle and Fuller 1998; Olson 2003; Watling 2005; Wildlife Conservation Society 2004) and compared to the leaf litter invertebrate data obtained in Chapter two. The data gathered will be used to perform an intensive cross-taxa conservation analysis of areas in common across Fiji. This method will lead to the identification of reserve areas which harbours high biodiversity or local endemism.

3.2.2 Taxa considered

3.2.2.1 Palms

Fiji palm data (Doyle and Fuller 1998; Watling 2005) is one of the most complete plant distributional data sets available. The data shows the geographical distribution of all the different species of palms in Fiji.

3.2.2.2 Heritage trees

Heritage trees are those individual trees and groups of trees that have been designated as significant on the basis of their exceptional size, form, rarity and their importance in national or regional history. Heritage trees are often acknowledged in the development of landscape architecture, forestry, city planning, and culture (Olson and Farley 2003). Heritage trees often occur in areas where biodiversity is best protected. Individual maps of islands with known high heritage value and potential areas of heritage trees were provided by Olson and Farley (2003).

3.2.2.3 Other Invertebrates

The data on cicadas by Duffels and Ewart (1988) was used together with distributional data of the *Xixuthrus* beetles from the Department of Forestry's entomology collection. *Xixuthrus* beetles were chosen because of their important iconic and rarity status. Distribution data for the *Xixuthrus* beetles was used as they are known only from a few localities.

3.2.2.4 Plants

Floate *et al.* (1996) confirm that different types of plants increase the Beta diversity of the arthropod communities and this is an important consideration due to the strong plant-insect relationship. Bangert *et al.* (2005) established that patterns of arthropod diversity are reflected by the genetic diversity of plant species which are usually the host. Therefore, data on endemic and native plant areas were used to identify the important areas for the potential network of forest reserves (Wildlife Conservation Society 2004).

3.2.2.5 Leaf litter invertebrates indicators

The biological boundaries identified in Chapter 2 were used to overlay the data from palms, heritage trees, *Xixuthrus* and cicadas. This was also used to determine if the important areas (boundaries) identified from the other taxa matched the leaf litter indicator species boundaries as a surrogate measure for biodiversity. Detailed analyses and biological boundaries for the leaf litter indicator species are presented in Capter 2 while the method of matching the boundaries maps is presented below.

3.2.3 Developing Priority Areas

The maps for the geographical distribution of the target invertebrate specimens were drawn and overlaid with maps for other organisms. The maps were drawn in different colours so that the biological boundary for each organism could be easily identified. Two maps for two different organisms were overlaid on a third map and when the two different colours overlapped on the third map this represented the common area and was given a high conservation value and was incorporated into the IIAs. This was done subjectively as the base work for the assessment of important invertebrate areas.

The use of higher taxa is now supported for this method or collecting data (Williams *et al.* 1997). More emphasis was given to organisms which were rare or endemic (cicadas, *Xixuthrus*) as selecting these ensured that high complementary areas were well represented for reserve selecting (http://www.nhm.ac.uk/research-curation/projects/worldmap/index.html). Stoms *et al.* (2005) state that combination of surrogates increases the confidence of the overall protection.

The data obtained from Chapter two were used as surrogate data for describing the invertebrate biological provinces. This data was combined by evaluating sites with high conservation value to predict networks of forest reserves.

3.3 Results

There was a high level of overlap between my invertebrate data and the previous work (Duffels and Ewart 1988; Doyle and Fuller 1998; Morrison 2005; Watling 2005,) and this suggests that invertebrates can be used as surrogate for identification of important areas for conservation. My results provide a finer geographic level for the inclusion areas (see Figure 3.1 and Table 1.3). Figure 3.1 shows the forested areas with high conservation value based on Figure 3.2 and 3.3. The areas indicated are intact having greater than 75% canopy cover. This is to be expected given the lower mobility and highly localised distribution of the invertebrate fauna. Viti Levu is the main region for the IIAs but has many smaller sub-IIAs within this. This is caused by the localised distribution of the endemics. From my data Nakasa in Vanua Levu represents a vital IIA so does the Natewa Peninsula. Taveuni and Kadavu also represent distinct IIAs. Ovalau, Gau and Koro form a region of IIAs (see Figure 3.2).

The heritage trees show a strong biological affinity between the heritage trees boundaries and smaller IIAs (Figure 3.4). Same is true for the biological boundary for the palms (Figure 3.5) and Angiosperms (Figure 3.6). These overlap with the major boundaries of the IIAs are another indicative biological relationship with the invertebrates and the trees (heritage trees and palms).

These support the evidence that there is a strong relationship between the plants and the invertebrate communities in Fiji.

Table 3.1 List of areas with high conservation value after assessing the invertebrate representativeness.

IIA number	Region	Island
1	Kotoyanitu-Nausori highlands	Viti Levu
2	Tomaniivi-Nakauvadra-Wailevu	Viti Levu
3	Serua-Namosi-Wainimala-Sovi	Viti Levu
4	Mount Washington	Kadavu
5	Lovoni	Ovalau
6	Saqani	Koro
7	Gau	Gau
8	Momici-Lavena	Taveuni
9	Bua-Nocobola	Vanua Levu
10	Wailevu-Rokosalase	Vanua Levu
11	Labasa-Vaturova	Vanua Levu
12	Namuka	Vanua Levu
13	Natewa	Vanua Levu

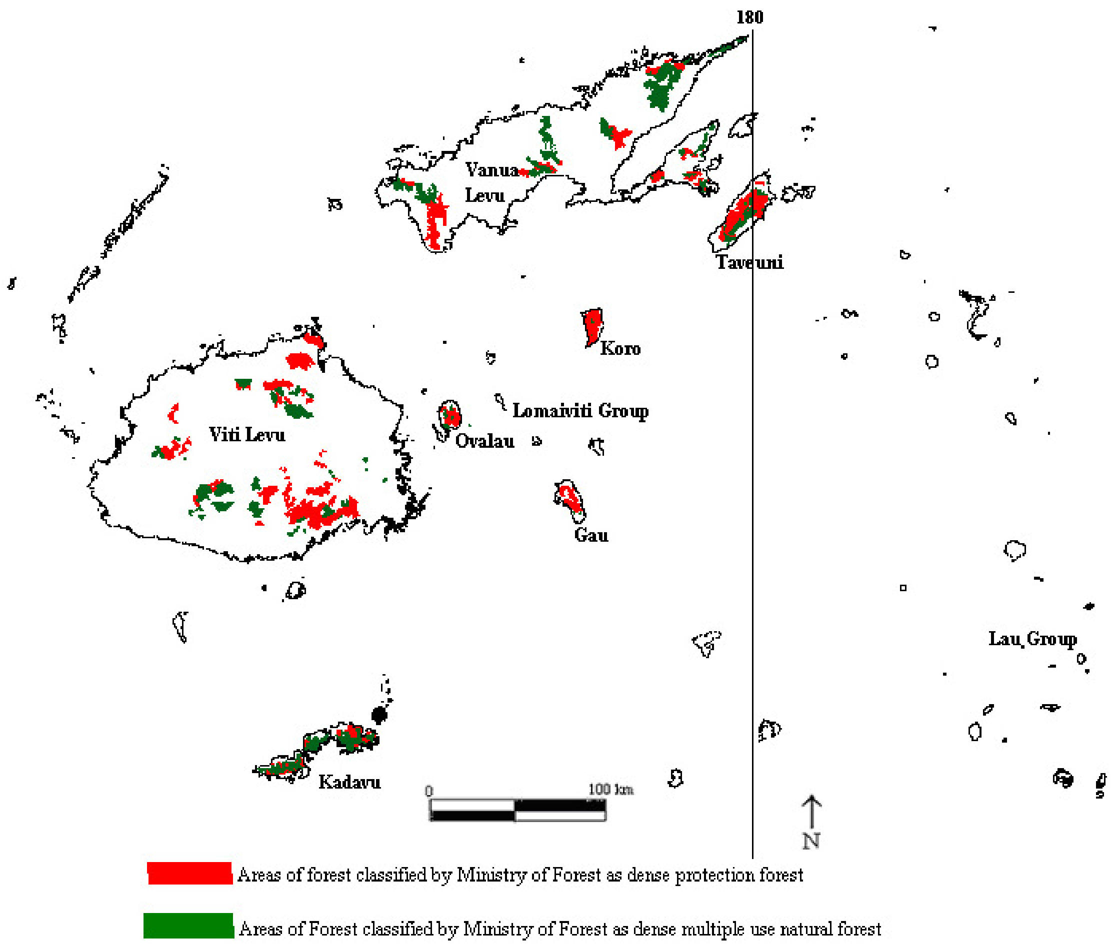

Figure 3.1 Forest areas in Fiji identified from this study as being potential areas for inclusion in the future network of forest reserves.

Dense has been classified as tree and/or fern crown density being 75-100%.

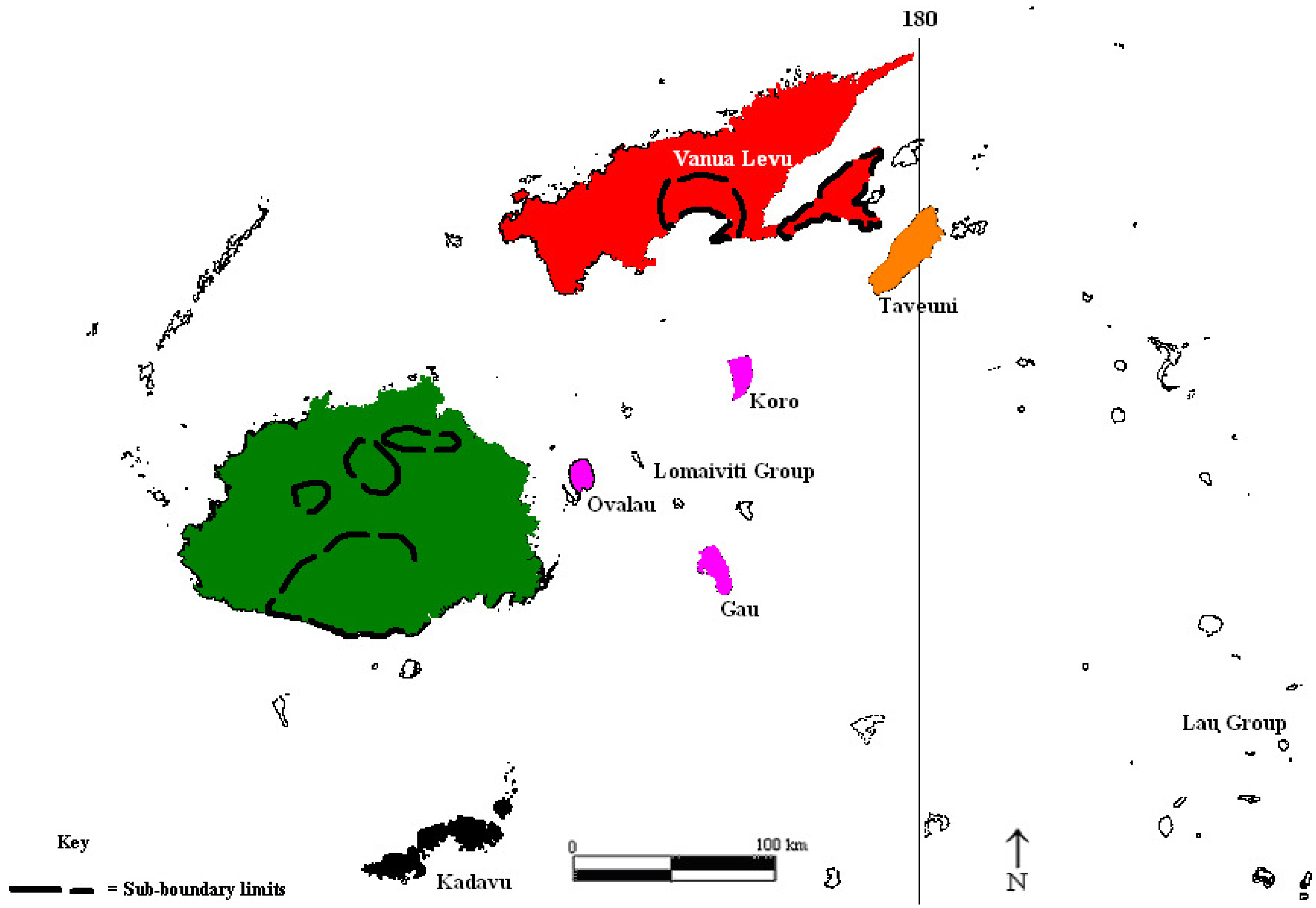

Figure 3.2 Important invertebrate areas (IIAs) based on *Xixuthrus* beetles*, Leaf Litter and Cicadas** data) (source: * = after Ministry of Forest and ** = after Duffels and Ewart 1988).

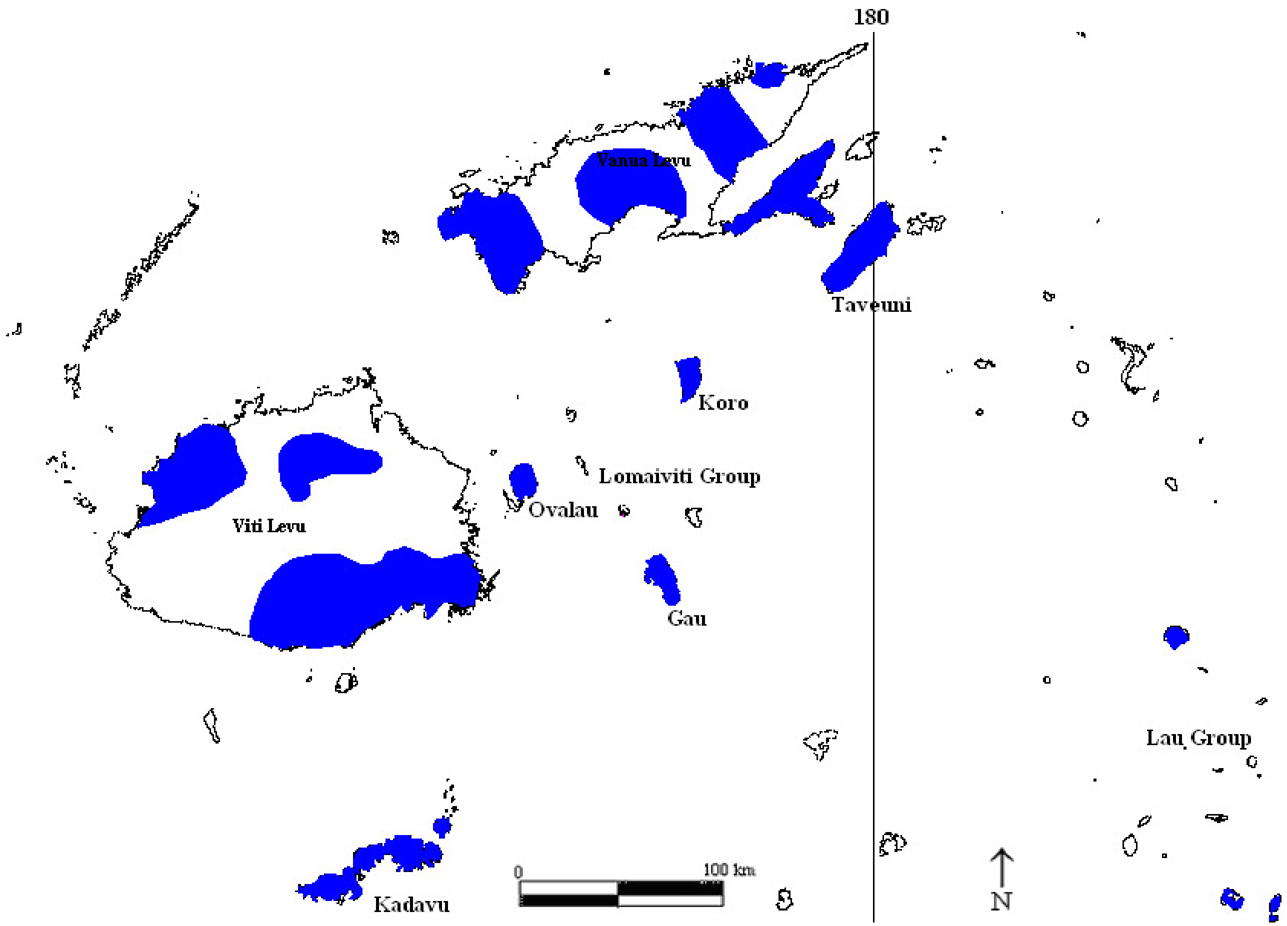

Figure 3.3 Areas in Fiji with high conservation value based on the overlapped areas of IIAs and the data from other taxa (after Duffels and Ewart 1988).

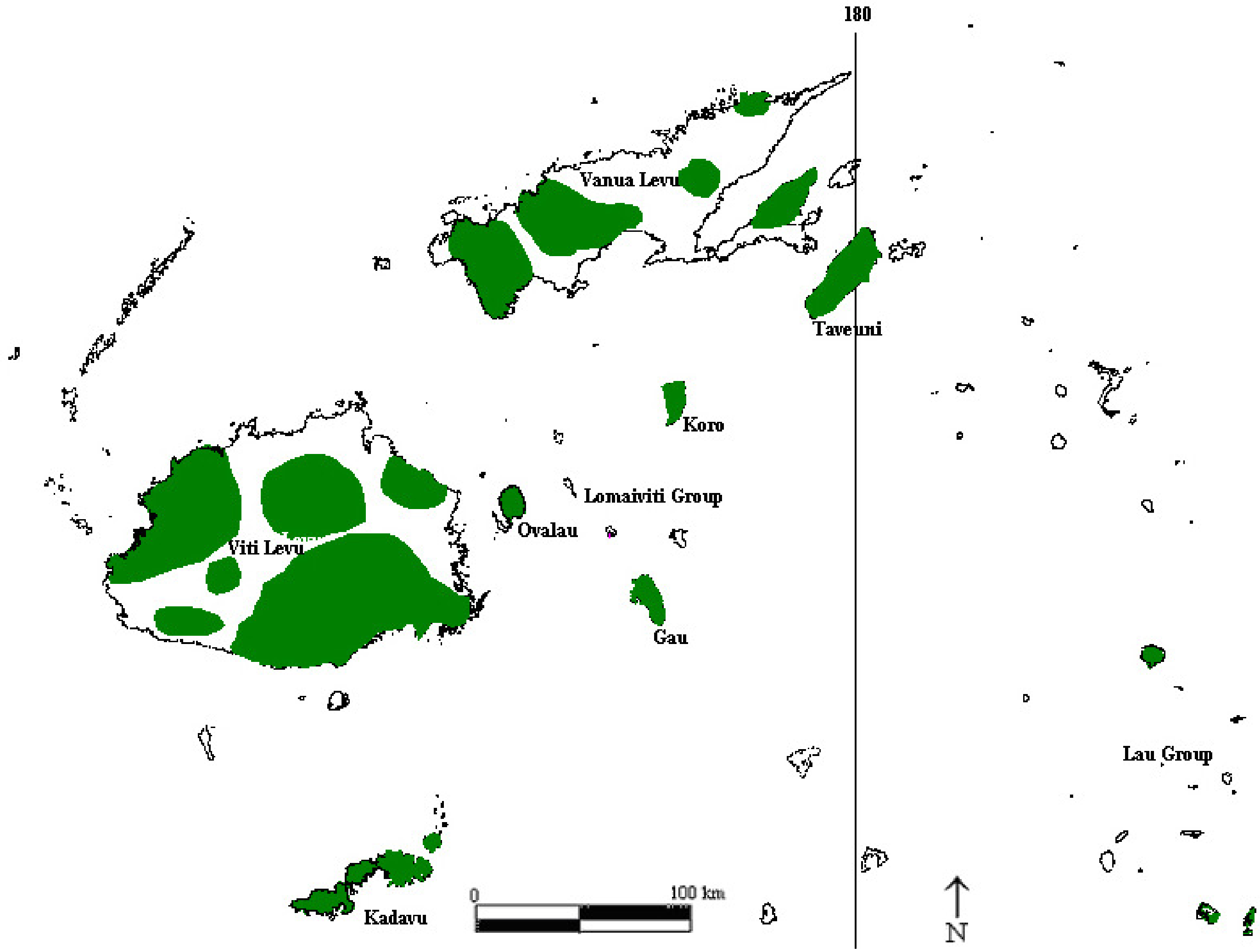

Figure 3.4 Confirmed and potential areas of heritage trees (after on Olson 2003).

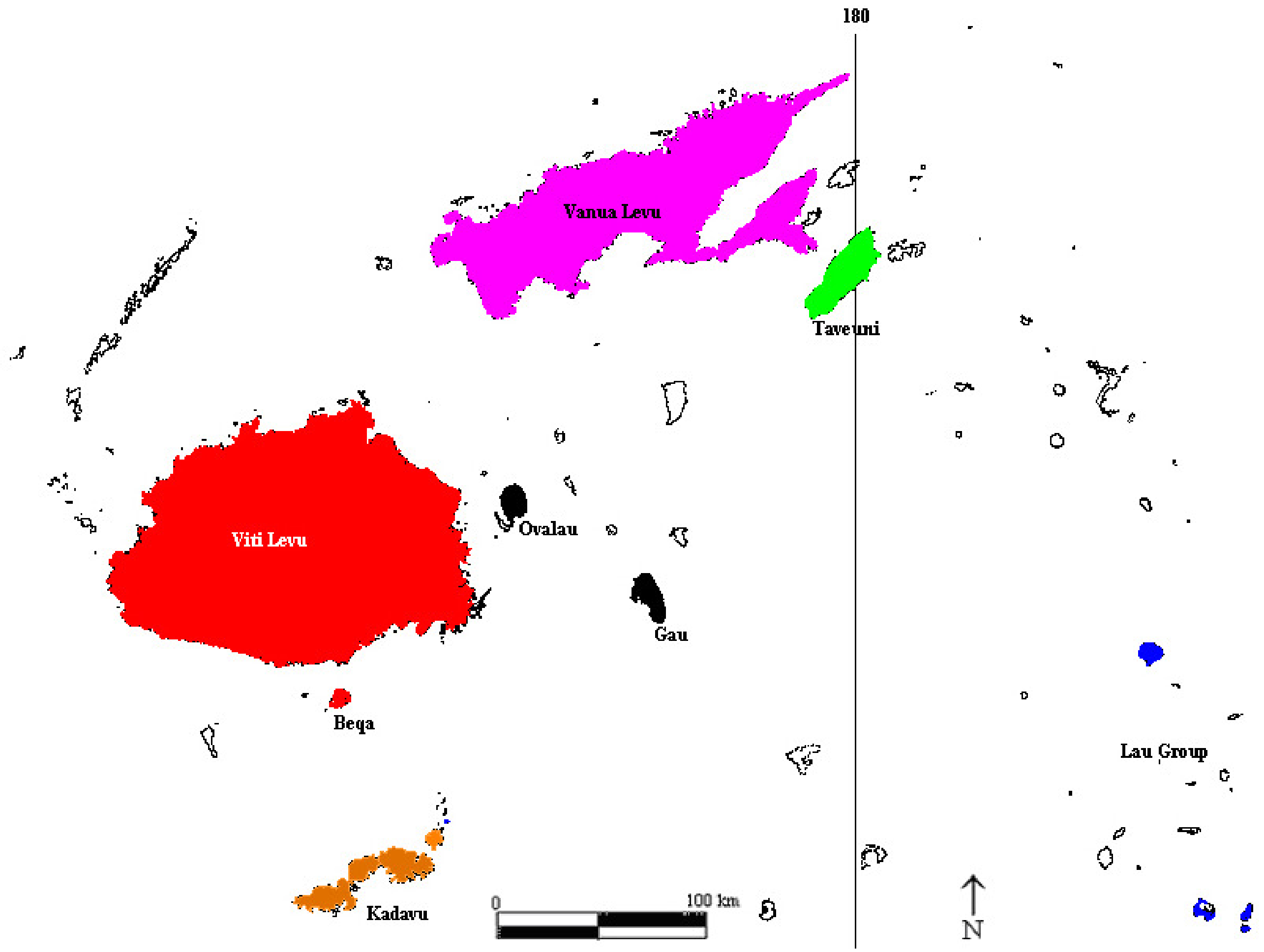

Figure 3.5 Biological boundaries of the indigenous palms of Fiji based on the number of indigenous species (species) and the species listed by IUCN, the different colours indicate the different boundaries (after Doyle and Fuller 1998 and Watling 2005).

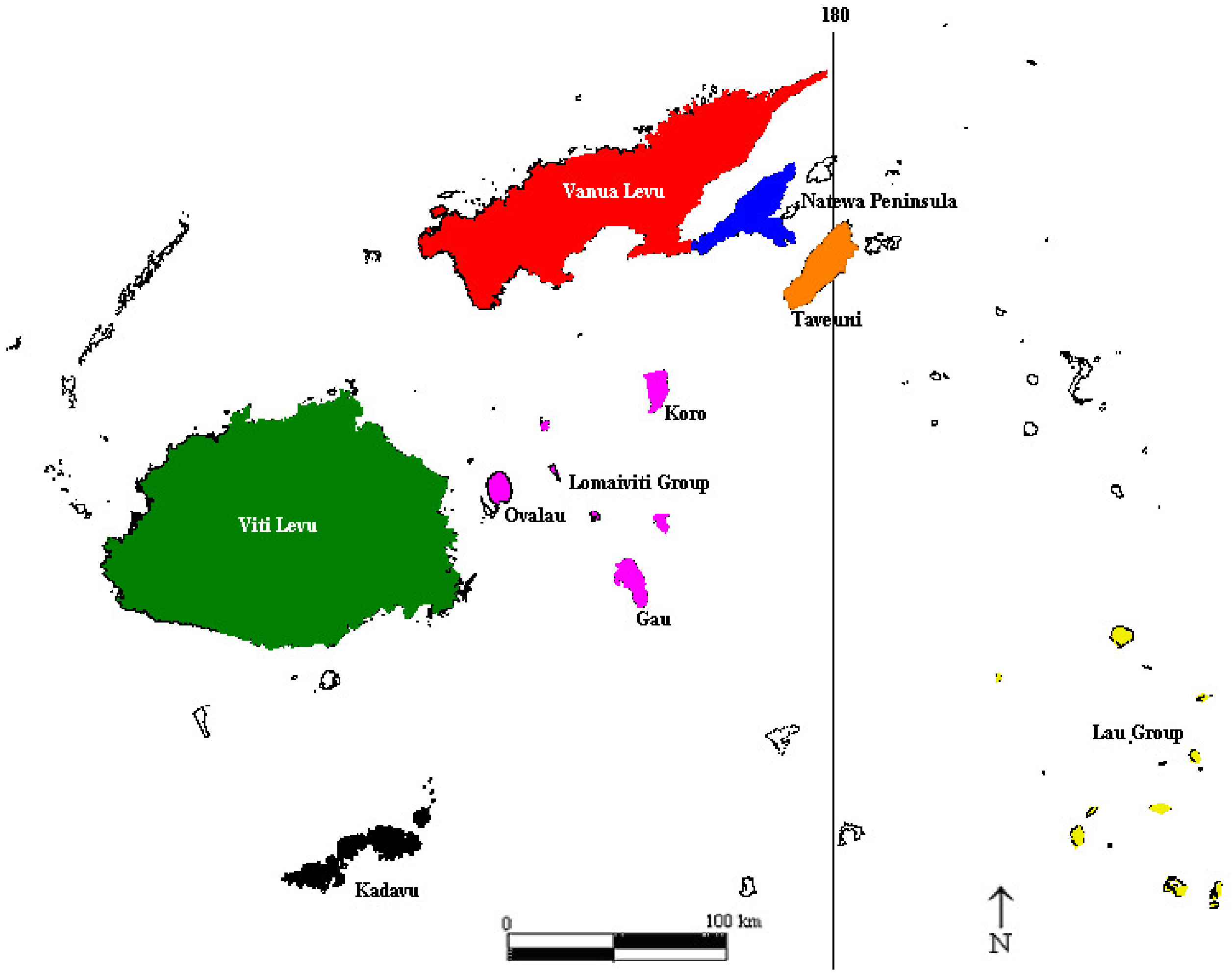

Figure 3.6 Biological boundaries of angiosperms, the different colours indicate the different boundaries (after Wildlife Conservation Society 2004).

3.4 Discussion

A close and strong correlaion between the plants and invertebrates was indicated however, this was not studied (Figure 3.2 and 3.6). Theoretically, both the invertebrate and plant data could be used to effectively design reserve areas for conservation which would protect a significant proportion of Fiji's endemic invertebrate fauna. The research on leaf litter insects revealed that many of Fiji's species utilize small ranges and some are confined to particular topographical areas so protecting entire ecosystem would be extremely beneficial to them (Webb and Thomas 1994). An ecosystem can have several focal hotspots of insect species while another adjacent ecosystem which is important to large vertebrates may not have any invertebrate hotspots. Therefore, it is necessary to identify invertebrate hotspots on a finer geographical scale in order to ensure full invertebrate representation when designing nature reserves. In other words, the data from the leaf litter study is useful in fine-tuning the information needed to define the important areas for conservation, especially that of the local endemic and rare invertebrate species. According to DeVries (2004) individual patches can have high conservation significance if the species involved have limited dispersal ability. Rare or endemic insects with the most limited dispersal ability require a separate assessment of their importance before reserve networks should be designed.

Protecting intact and unmodified habitats is the best approach to conserve native species as protected habitats often contain the rarest native fauna and flora (Olson *et al.* 2006). However, some species can still exist in modified habitats (Watt 1987). The diversity of the invertebrates in relation to the diversity of the native plants has not been fully studied for Fiji. Patterns of arthropod diversity are dependant and reflected in the diversity of the plants due to strong plant-insect interactions (Bangert *et al.* 2005).

The Ministry of Forestry Fiji has identified 7 nature reserves (57.4 km^2) and 17 forest reserves (262 km^2) totalling 319 km^2 (Table 3.2). Nevertheless, Fiji's existing system of nature reserves does not meet the requirements set aside under the Fiji Governments National Biodiversity Strategic Action Plan (NBSAP). In the NBSAP, at least 10% of total land area was to be set aside for biodiversity conservation but at present Fiji only has 1.7% set-aside as nature and forest reserves. Furthermore, the definition of what constitutes a nature reserve and a forest reserve is confusing and limited by legislation and management practices. Only nature reserves are considered for biodiversity conservation while forest reserves are designated for forest plantation (particularly the mahogany reserves). Therefore, if we put this into perspective, Fiji really only has 0.31% land area set aside for biodiversity conservation. From a conservation perspective only nature reserves should really be considered when designing forest reserve networks as plantation forest is planted with non-native exotic species (such as mahogany) for timber extraction. The results of this invertebrate study should be used as a guideline to help set aside forest areas for biodiversity conservation. By including important invertebrates it will not only strengthen the system of reserves in Fiji but it will assist us in meeting the goals set in the NBSAP.

This study identified several IIAs that need to be considered in the planning of any future reserve networks in for Fiji (Figure 3.1). It is unrealistic to protect all the forest areas, therefore, dense undisturbed primary forest areas within identified priority areas should be protected first. These areas include Kadavu, Waimanu, Gau, Koro, and Serua. and have already been proposed by the Wildlife Conservation Society (2004) to be included in a future network of forest reserves. This study supports the findings of the proposed forest network and since this study considers more taxa it should therefore, add extra weight to the WCS proposal. Prior to this study the use of invertebrates in reserve design in Fiji had not been considered. Therefore, the results of this study offer a more complete and complex picture of biodiversity that should be protected in a forest network for conservation and to some extent this fulfils the requirement of biological representation.

The forest areas identified in Figure 3.1 can be built into a well represented landscape conservation model if it is well buffered, linked using riparian vegetation, and has varying ecotypes. The importance of riparian vegetation has been identified as significant to any park system (Kirchner *et al.* 2003; Monkkonen and Mutanen 2003; and Hilty and Merenlender 2004) but the main advantage of using riparian vegetation is that watersheds are also included in the reserve network, thus providing freshwater conservation. The importance of buffering Fijian refuge forests against invasive species has been recommended by Olson *et al.* (2006).

Fiji has numerous freshwater species (such as freshwater fish, bivalves, gobies, snails, and freshwater organisms) (Wildlife Conservation Society 2004). Most of these organisms are endemic to Fiji, such as the Gobies (Jenkins 2003). Therefore, the survival of these species is directly related to the intactness of the freshwater systems of Fiji. To include the riparian vegetation as part of the reserve networks will provide a continuum for a range of other important species which track seasonal fruiting trees, such as Kakas (Masked Shining parrot *Prosopeia personata*) (Wildlife Conservation Society 2004).

It is critical that the reserves be legally designated and set aside before loggers harvest the remaining forests. The idea of establishing specifically designated plantation reserves was a good approach when first proposed, but, it is now apparent that loggers are logging in other nearby areas surrounding the plantation reserves. The main objective of the plantation reserves was to provide sustainable timber reserves which were to be harvested at a later date. The plantation reserves in Fiji are predominantly mahogany. Most mahogany plantations are surrounded by good native forest, and since logging from plantation reserves (or forest reserves) is prohibited unless the landowners have permission from the government, this has meant many loggers are now logging the surrounding native forests instead. The most prevalent areas currently being harvested are in Korolevu which has the most plantation reserves (see Figure 3.7). With all this logging activity in the native forest areas, the wildlife may be able to take refuge in the plantation reserves, however, the long-term survival of these species is in question when the plantation reserves will then be harvested themselves for their timber in the future. The lack of any intact native forest adjacent to plantation reserves will lead to an uninhabitable ‘mosaic’ environment for the wildlife once the mahogany timber has been harvested.

Failure to provide a good biodiversity refuge for Fiji’s unique flora and fauna in the plantation reserves will be devastating should the surrounding dense native forest be continually harvested and fragmented as is happening right now. Therefore, some protected reserve areas should be permanently set aside adjacent to the mahogany plantation reserves so that many species, such as Fiji’s threatened invertebrates, birds and plants can be protected in the future.

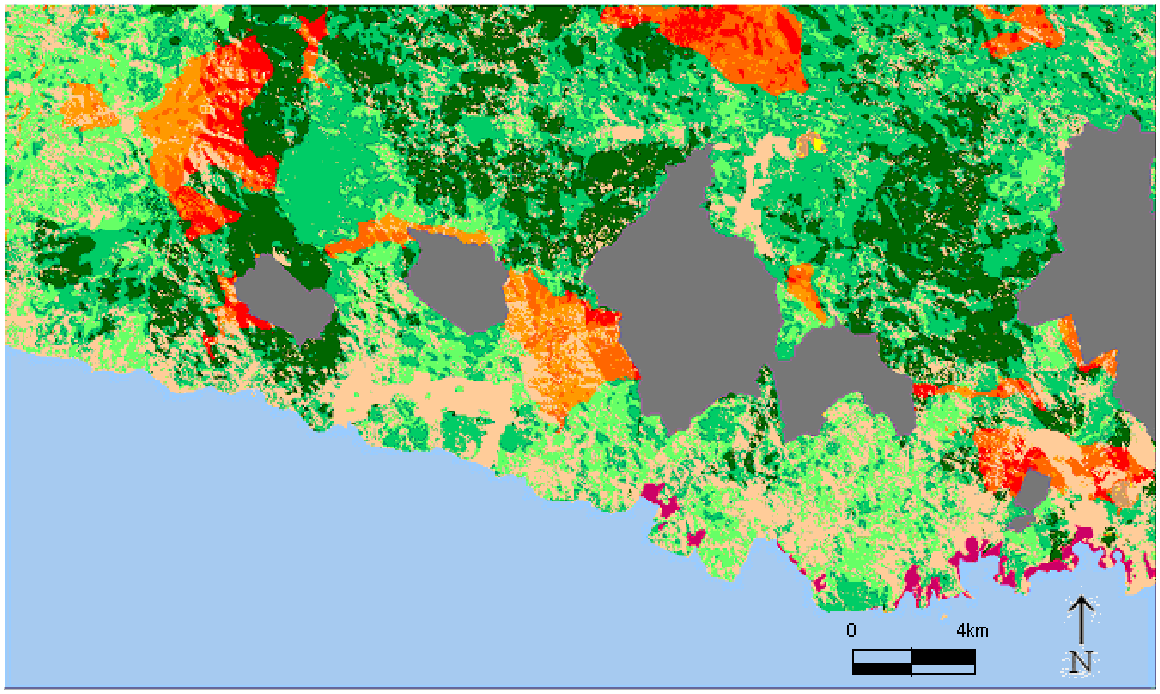

Figure 3.7 Map of the Korolevu (Viti Levu) area showing the highly mosaic nature of the dense forest (green and red) which are adjacent to the plantation reserves (purple areas), the beige areas indicates bare ground. The different shades of green and red indicates different density, the darker the colour the higher the density (Ministry of Forestry July 2001).

3.5 Conclusion

The leaf litter invertebrates data is powerful enough that it is able to capture the finer geographical details that are not found in studies using larger vertebrates (Birdlife International (Fiji) 2003). The invertebrate data help identify important forested areas with high conservation value for inclusion in a future network of forest reserves. These intact areas should be quickly protected before any significant fragmentation process leads to a further loss of intact native forest. Even though Fiji may not have a great deal of local taxonomic expertise, by using morphospecies characteristics it was possible to assign conservation values to areas that will ultimately help us design an important forest reserve network. In addition, by using invertebrates we are able to pin-point or define specific "hotspots" to meet our obligations according to the NBSAP.

3.6 Recommendations

My results suggest that the important biological areas found for invertebrates are smaller than those for other vertebrates such as birds and plants. This is intuitively logical because leaf litter and other invertebrates live in much smaller and localised patches. Therefore, these localised areas should be granted the same sort of protection given to many of the areas occupied by the larger more charismatic vertebrates. The best method to ascertain which areas should be accorded reserve status is by taking into account the habitat range, patch distribution, and connectedness of a whole range of species, including the invertebrates.

In future, the Ministry of Forestry and the Conservator of Forests should consider all the species (and not just select a few) when designing of any future reserve networks in Fiji. Another consideration is how well the remnant forest areas are connected to differing ecotypes and water-shed areas.

Some recommendations for future research work in the assessment of arthropods in Fiji: These include

i. Determining which groups of arthropods should be used as indicators for biodiversity conservation and in the design of forest reserves.

ii. Research into development of new models and techniques for identifying many of the unknown arthropods. We need a quick accurate method.

iii. To run training courses for local people to recognise various invertebrate species (morphospecies and taxonomic species) to assist in the rapid process of unidentified arthropods. Training could involve parataxonomy methods, microscopy work, field sampling methods, establishing voucher and reference collections and sending people to study under taxonomists at museums and universities.

iv. Encouraging the study of invertebrate ecology and the biology of arthropods at secondary and tertiary education institutions.

v. Ensure that the accumulated information complies with the objectives of the NBSAP.

vi. Promote iconic species through media such as the *Xixuthrus* species, swallow tail butterfly, brentid weevil, and *Placostylus* snails.

It is suggested that by investing in the above recommendations, Fiji’s invertebrate conservation knowledge and skills will greatly increase.

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Appendix 1

Sampling localities and locality codes used for this study.

Code	Locality	Longitude	Latitude
FJ 4	Naitasiri Province-Nakobalevu (logging road)	178°25'E	18°03'S
FJ 14	Rewa Province-Mount Korobaba	178°21'E	18°01'S
FJ 38	Rewa Province-Naikorokoro	178°17'E	18°05'S
FJ 36	Namosi Province-Nabukavesi	178°16'E	18°07'S
FJ 39	Namosi Province-Navua-Nakavu	178°06'E	18°15'S
FJ 44	Namosi Province-Galoa	178°57'E	18°15'S
FJ 45	Serua Province-Nabukelevu	177°50'E	18°06'S
FJ 43	Serua Province-Nabautini	177°50'E	18°16'S
FJ 30	Vuda Province-Koroyanitu	177°23'E	17°40'S
FJ 42	Ra Province-Vunisea village-Nakauvadra range	178°10'E	17°25'S
FJ 37	Tailevu Province-Vatukalikali	178°35'E	18°45'S
FJ 34	Naitasiri Province-Sovi basin-Wainivalau	178°14'E	17°45'S
FJ 10	Rewa Province-Waivudawa creek	178°21'E	18°02'S
FJ 33	Lomaiviti Province-Levuka-Lovoni track	178°49.5'E	17°42'S
FJ 46	Kadavu Province-Nabukelevu-Mt Washington	177°99'E	19°12'S
FJ 51	Kadavu Province-Kadavu Island-Namara road	178°19'E	19°02'S
FJ 40	Lomaiviti Province-Gau Islands	179°17'E	17°58'S
FJ 27	Lomaiviti Province-Koro island-Nasoqoloa	179°23'E	17°18'S
FJ 52	Cakaudrove Province-Taveuni-Naqilai, Momici	179°95'E	19°86'S
FJ 53	Cakaudrove Province-Taveuni-Lavena	179°89'W	16°85'S
FJ 56	Cakaudrove Province-Uluivuya	178°43'E	16°58'S
FJ 50	Macuata Province-Nakasa	179°15'E	16°40'S
FJ 48	Cakaudrove Province-Kasavu	179°40'E	16°45'S
FJ 49	Cakaudrove Province-Yasawa-Saqani	179°40'E	16°30'S
FJ 47	Cakaudrove Province-Nakanakana	179°50'E	16°40'S
FJ 54	Cakaudrove Province-Dogotuki	179°52'E	16°24'S

Appendix 2

Morphospecies number and endemic number of indicator species for this study (A = Total Number of morphospecies, B = Number of Endemic species, C = Percentage Endemics (Endemics/Total), D = Percentage Endemics (Endemics/total of area)).

A

	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
Curculionidae	22	10	19	19	17	10	50	31	10	24	45	28	44	27	23	23	14	13	26	5	24	28	23	12	31	3
Staphylinidae	3	1	2	5	3	4	12	10	4	6	4	7	16	8	3	12	5	2	1	2	0	0	3	0	9	0
Opilionidae	4	4	4	4	4	2	4	5	1	3	6	4	5	7	8	0	2	2	3	4	2	0	0	0	4	1
Total	29	15	25	18	24	16	66	46	15	33	54	39	65	43	34	35	21	17	30	11	26	28	26	12	44	4

B

	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
Curculionidae	9	2	1	1	3	1	14	6	3	7	12	4	12	2	7	8	5	4	7	0	2	7	8	4	8	0
Staphylinidae	0	0	0	0	0	0	3	2	1	0	1	1	3	0	0	3	1	0	0	0	0	0	0	0	1	0
Opilionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Total	9	2	1	1	3	1	15	6	3	7	12	4	13	3	7	9	5	5	7	0	2	7	8	4	4	0

C

	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
Curculionidae	4	0.9	0.4	0.4	1.33	0.4	6.22	2.7	1.3	3.1	5.3	1.8	5.3	0.9	3.1	3.6	2.2	1.8	3.1	0	0.9	3.1	3.6	1.8	3.6	0
Staphylinidae	0	0	0	0	0	0	6.25	4.2	2.1	0	2.1	2.1	6.3	0	0	6.3	2.1	0	0	0	0	0	0	0	2.1	0
Opilionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0
Total	2.8	0.6	0.3	0.3	0.95	0.3	4.73	1.9	0.9	2.2	3.8	1.3	4.1	0.9	2.2	2.8	1.6	1.6	2.2	0	0.6	2.2	2.5	1.3	1.3	0

D

	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
Curculionidae	41	20	5.3	5.3	17.6	10	28	19	30	29	27	14	27	7.4	30	35	36	31	27	0	8.3	25	35	33	26	0
Staphylinidae	0	0	0	0	0	0	25	20	25	0	25	14	19	0	0	25	20	0	0	0	0	0	0	0	11	0
Opilionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0
Total	31	13	4	5.6	12.5	6.3	22.7	13	20	21	22	10	20	7	21	26	24	29	23	0	7.7	25	31	33	9.1	0

Appendix 3

Presence/Absence and morphospecies data for the sampled sites (colour filled cell indicates presence while blank cells represents absence data, the colour of the cell matches the locality colour while the number in the cell corresponds to the morphospecies number).

A. Curculionidae data

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
1								1																		
2								2																		
3								3																		
4								4																		
5	5		5	5			5	5		5	5	5	5	5	5	5	5	5	5				5	5		5
6	6	6	6					6					6													
7							7	7			7	7	7			7										
8										8		8	8		8						8	8				
9											9															
10					10																					
11																11										
12			12	12			12					12	12			12										
13																13										
14	14															14	14									
15													15													
16													16													
17													17													
18												18	18		18											
19													19													
20											20		20													
21													21						21		21					21
22						.							22	22												
23													23													
24			24									24	24	24												
25			25						25							25										

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
26																26										
27												27				27										
28																28										
29																29										
30																	30									
31														31	31		31	31								
32											32															
33								33		33	33	33		33	33		33	33	33	33	33	33	33		33	
34	34	33			34		34			34	34			34					34		34	34		34	34	
35					36									35												
36														36												
37							37							37												
38			38	38			38	38					38	38												
39														39												
40							40							40						41						
41		41		41		41				41		44	41	41												
42									42			42		42												
43			43									43														
44					44			44																		
45								45		45		45														
46	46						46	46														46				
47			47	47		47					47														47	
48						48	48																			
49	49																									
50							50			50																

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
51							51				51															
52							52																			
53								53	53																	
54			54	54																				54		
55			55	55							55	55													55	
56			56	56																						
57			57	57																						
58			58																							
59					59								59													
60													60													
61													61													
62													62													
63					63																					
64					64																					
65	65																									
66	66																									
67	67																									
68															68											
69															69											
70															70											
71															71							71				
72															72											
73															73											
74															74											
75				75																						

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
76		78																								
77													77													
78													78													
79												79														
80		80																								
81																										
82	82																	82	82				82		82	
83	83																									
84	84																									
85	85																									
86	86																									
87	87																									
88												88														
89												89														
90											90	90														
91										91																
92										92																
93										93																
94										94																
95									95																	
96									96																	
97											97															
98											98															
99											99															
100							100				100								100					100		

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
101											101															
102											102															
103											103										103					
104											104						114									
105											105															
106										106																
107										107																
108										108								118					118			
109										109																
110																		110								
111																			111			111				
112																			112							
113																			113							
114																			114			114				
115																			115							
116																			116	116	116				116	
117																			117							
118																		118	118		118	118				
119																	119		119							
120																			120							
121																						121				
122																						122				
123											123											123				
124																						124				
125																						125				

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
126																									126	
127																									127	
128																									128	
129																							129			
130																							130			
131																							131			
132																			132							
133																					133					
134																									134	
135																		135								
136																		136								
137						137																				
138																										
139																	139									
140																	140									
141																	141									
142																	142									
143																									143	
144																									144	
145																									145	
146																									146	
147																									147	
148																										
149																		149					149			
150																							150			

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
151																	151						151			
152																							152			
153																							153			
154																							154			
155																							155			
156																		156						156		
157																		157								
158																			158							
159																								159		
160																								160		
161																			161		161					
162																					162					
163					163																163					
164							164														164					
165							165												165							
166							166																			
167							167																			
168							168																			
169							169																			
170							170																			
171							171																			
172							172																			
173							173				173															
174							174				174															
175							175				175															

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
176											176															
177											177															
178							178				178															
179											179															
180							180																			
181							181																			
182											182															
183											183				183									183		
184															184											
185		185		185	185						185		185	185	185						185	185				
186		186									186	186		186	186						186					
187															187				187		187		187	187		
188					188		188				188				188											
189				189	189	189	189	189					189	189	189						189	189	189			
190	190		190		190		190	190	190	190	190	190	190	190	190				190		190	190	190	190	190	190
191							191			191											191					
192		192		192				192		192				192				192	192							
193	193	193	193	193	193	195	193	195			193	193		193			193		193		193	193			193	
194	194		194					194			194		194	194					194		194		194		194	
195							195				195		195													
196	196		196				196	196				196					196								196	
197																								197		
198								198					198			198										
199											199		199			199									199	
200																200										

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
201								201		201	201					201				201		201			201	
202																202										
203	203				205		203							203	203	203									203	
204							204																			
205	205		205		205			205	205		205					205					205					
206		206		206	206	206	206	206	206	206	206	206	206	206					206			206			206	
207									207														207		207	
208											208				208	208										
209							209					209														
210																210									210	
211																211										
212																										
213				213		213	213			213		213	213	213		213										
214																										
215							215																			
216																										
217							217				217	217	217									217				
218					218		218															218			218	
219						219	219	219					219													
220									220																	
221													221													
222													222													
223							223						223													
224				224									224												224	
225							225	225			225		225													

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
226						226							226													
227																										
228											228	228	228													
229										229			229													
230				230				230		230			230	230							230	230				
231							231	231																		
232								232													232					
233							233																233			
234							234																			
235												235														
236			236									236														
237														237											237	
238															238										238	
239																						239				
240											240															
241				44						241			241													
242																										
243														243						243			243			
244							244	244			244											244	244		244	
245	245															245										
246											246											246				
247																						247				
248																					248	248	248		248	
249																						249				
250																								250		

Curculionidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
251								251																		
252								252																		
253							253				253															
254							254																			
255							255																			

B. Opilionae data

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
1															1											
2															2											
3		3		3	3						3		3	3	3					3						
4		4									4	4		4	4											
5															5											
6															6											
7				7	7	7	7					8	7	7	7		7			7						
8	8		8		8			8	8	8	8		8	8	8		8		8	8					8	8
9							9			9																
10		10		10				10		10		11		10					10							
11	11	11	11	11	11	11	11	11			11			11							11				11	
12	12		12					12			12		12	12					12	12					12	
13							13				13	14	13													
14	14		14					14													14				14	

C. Staphylinidae data

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
1								1					1			1										
2													2			2									2	
3																3										
4								4		4						4	4	4							4	
5																5										
6	6				6		6							6	6	6									6	
7							7																			
8	8		8					8	8							8				8						
9		9		9	9	9	9	9	9	9	9	9	9	9			9		9						9	
10									10														10		10	
11														11	11	11										
12							12					12														
13																13										
14														16		14										
15																										
16				16		16	16			16		16	16			16										
17																										
18							18																			
19																										
20							20				20	20	20				20									
21					21		21																			
22						22	22	22					22													
23									23																	
24													24													
25													25													

Staphylinidae data continued

Morphospecies	V43	V45	V44	V39	V36	V38	V10	V14	V34	V4	V30	V42	V37	O33	G40	R27	N56	N50	N49	N54	N48	N47	T52	T53	K46	K51
26													26													
27				27									27												27	
28								28					28													
29						29		29					29													
30																										
31											31	31	31													
32										32			32													
33				33				33		33			33	33			33			33						
34							34	34																		
35								35																		
36							36																36			
37							37																			
38												38														
39			39									39		39												
40														40											40	
41															41										41	
42																	42									
43											43															
44				44						44			44													
45								45																		
46														46				46					46			
47																									47	
48	48															48										

Appendix 4 Characters used for the identification of morphospecies.

Indicator species	Character
Curculionidae	• Size • Appendage length • Texture • Antennae shape • Number of antennal segments • Colour • Eye (is it obvious) • Antennal groove • Body proportions • Body hair/setae (presence/absence on different body parts) • Length of body hair/setae/bristles • Length of the mouth part • Body bumps • Scale (presence/absence) • Shape of the body • Barbs on appendages (presence/absence and length) • Wings (shape, presence/absence)
Staphylinidae	• Number of antennal segments • Shape of the antennal segments • Size • Wings (presence/absence) • Bristle/hair/setae on appendage • Bristle/hair/setae on body • Body texture
Opilionae	• barbs on palps (presence/absence and length) • Spines in body parts (presence/absence and length) • Position of eyes • Number of eyes • Appendage length • Pattern on abdomen • Colour • Shape of the palps • Size