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Freshwater Invertebrate Assemblages and Ecological Status of the Ba River, Fiji

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Abstract

This paper aims to document the first comprehensive study of freshwater macroinvertebrate community structure of Ba river catchment and the ecological status of the target lotic systems based on bioindicator taxa. Freshwater macroinvertebrate assemblages were explored during the dry season for permanent creek systems draining six distinct sub-catchments. Freshwater macroinvertebrate were sampled using kick-netting and Surbersampling techniques. A total of 73 unique taxa out of 10,120 individuals were recorded from 17 sampling stations. Insects represented 70% of the total taxa recorded while crustaceans represented only 15% and molluscs and worms represented the minority; 8% and 6% each respectively. A total of 33 macroinvertebrate taxa (47% of total recorded taxa) recorded were unconfirmed Fiji endemics and a total of 10 taxa (14% of total recorded taxa) were endemic to Fiji. These include the five caddisflies (Abacariafijiana, Abacariaruficeps, Anisocentropusfijianus, Goerafijiana and Oxyethirafijiensis), the endemic damselfly, Nesobasis spp. (genus endemic to Fiji), a shrimp (Caridinafijiana), endemic genus of micro-water striders Fijivelia sp., the endemic water cricket (Hydropedecticusvitiensis) and spring snails Fluviopupa spp. Macroinvertebrate density recorded in riffle habitats ranged between 163 individuals/m^2 at upper Navisa (UNV) and 3,847 individuals/m^2 at upper Nadrou (UND) stations. There was no general trend observed in density across upstream and downstream sites across the six sub-catchments. The results of bioindicator-based ecological assessment of the target lotic systems showed that 35% of the target sites were categorized as 'Good' status, 24% of them as 'Moderate-good' status, 35% of them as 'Moderate-degraded' status and 12% of them as 'Degraded' status. A bioindicator-based ecological assessment matrix was produced to aid with Ba riverine community resource management plan.

Key Words: Ba River, freshwater macroinvertebrates, bioindicator, ecological status

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Recommendations:

The R2R Technical Consultation is invited to discuss the paper and provide suggestions on the application of methodology employed for assessing macroinvetebrates assemblage and community structure in the Ba River.

The discussion could also focus on the implication of results for future R2R investments and planning, particularly with respect to use of bioindicator-based ecological assessment, and/or, “traffic light bioindicator guide” to inform the management and prompting community based water quality monitoring of the Ba River

Freshwater Invertebrate Assemblages and Ecological Status of the Ba River, Fiji

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Conference Paper for the R2R Regional Steering Technical Committee
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1. Introduction

Ba River catchment holds high economic, social and environmental significance as part of the largest province in Fiji (Brown *et al.* 2017).Ba river catchment lies in the North-West coast of Viti Levu Island of the Fiji archipelago and is located at roughly 17°S and 177° East. It comprises of well drained six sub-catchments with inland freshwater systems of ranging from upland forests (650m+ a.s.l) to coastal lowlands (Terry *et al.* 2001) Freshwater infauna of Ba riverine systems has been poorly studied. Previous study of freshwater infauna of Ba freshwater systems covered few sites with study limitations to the scope as specified in the Terms of Reference in three environmental impact study assessments of three different development initiatives and these were the Sigatoka-Ba hydropower project, the Ba hospital construction and a flood retention weir. The current study is the first comprehensive cross-catchment invertebrate assemblages of lotic systems draining the Ba river catchment. The current study aims to (i) investigate the structure of benthic macroinvertebrate (BMI) assemblages in the 17 sites across headwater, mid water and lowland systems of the Ba river catchment and (ii) identify bioindicator taxa to deduce the ecological status of target systems. In order to do so, freshwater macroinvertebrate assemblages were investigated 17 sites and established bioindicator taxa of ecological health of Fijian riverine systems were used to deduce the ecological conditions of the localized target freshwater systems.

2. Methods

2.1 Study site

The study was carried out in 17 stations within six sub-catchments of Ba river catchment. Permanent creek systems were selected in the six sub-catchments: Nakara, Nabiaurua, Waisali, Nadrou, Wainamau and Navisa (Fig 1).

2.2 Sampling

A total of 17 sites were sampled for BMI in the six sub-catchments catchments in the dry season. Sampling locations are shown in Figure 1. Samples of benthic macroinvertebrate communities were taken by Surber sampling (3 replicates, 300ml jars) and kick-netting (10m edge samples: 5m on each bank edge) technique (Stark *et al.* 2001). Collected benthic macroinvertebrate samples was preserved with absolute ethanol and stored in screw cap jars. In the laboratory, organisms were hand sorted and identified to the lowest possible taxonomic level. The identification and nomenclature is based onthe following guides; (Haynes & Rashni ; Nandlal ; Williams 1980; Jeng *et al.* 2003; Hasse *et al.* (2006); Winterbourn *et al.* 2006; Haynes 2009). Abundance of species that were present in large numbers in samples was estimated (e.g., *Abacariafijiensis* caddisflies and *Pseudocloeon* sp. mayflies). Sorted and

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Identified macroinvertebrates were placed in small vials containing 100% ethanol and kept for further examination if required.

2.3 Data analysis

BMI samples were collected using a Surber sampler and taxonomically identified to possible lowest level. The total number of taxa recorded at each site was calculated from the combined Surber and kick-net/opportunistic data set.Macroinvertebrates densities (per 1 m^2) were calculated by multiplying mean Surber sample abundance data (per 0.1 m^2) by a factor of ten to give abundance/m^2. Status and distribution of taxa presents a summary of whether taxa recorded were endemic to Fiji, unconfirmed endemics, native to other regions (e.g., Pacific, South Pacific, Indo-Pacific, Fiji-Australia, South East Asia), introduced tropical species or other (worldwide).

3. Results

4.

4.1 Taxonomic metrics

A total of 10,120 freshwater macroinvertebrates were collected across 17 sites and identified to lowest taxonomic level possible. A total of 73 distinct macroinvertebrate taxa were collected across all samples and sites during the survey (Table 4). Macroinvertebrates were distributed among the taxonomic groups shown in **Error! Reference source not found.**. The most diverse group was Insecta with 51 taxa and representing 70% of the total number of taxa recorded. Of the 51 insect taxa, 13 were caddisflies, 9 were dipterans (true-flies), 7 each were water beetles and water bug, 5 were mayflies, 4 were damselflies, 3 were dragonflies, 2 were aquatic caterpillar (moth) and 1 water cricket. The next most diverse taxonomic group was Crustacea (11 taxa) followed by Mollusca (6 taxa), Annelida (3 taxa) and Nematomorpha and Playhelminthes represented by 1 taxa each. Mollusca were relatively diverse with 11 distinct taxa recorded from edge habitat across sampling

The number of macroinvertebrate taxa recorded from sites ranged between 14 taxa from lower Nadrou (LND) and 25 taxa from the upper Wainamau (UWM). The upper Wainamau creek at Koroboya village supported a diverse insect fauna (i.e., 23 insect taxa) dominated by resilient/pollution tolerant species (net-spinner caddis (*Abacariafijiana*), damselfly naiad (*Indolestes*sp.), purse-case micro-caddis (*Paroxyethira* sp. and *Oxyethirafijiensis*) and the algal grazer aquatic moth (*Nymphicula* sp.). The modified upper Wainamau creek system supported additional micro-habitats such as silt covered macrophyte beds (green charophytic*Chara* sp.), invasive weed vegetation belt at bank and silted streambed which allowed population establishment of resilient species. Lower Nadrou (LND) supported low taxa richness (14 taxa) and reflected agriculturally modified aquatic habitat conditions and overhanging modified streambank vegetation. There was no general trend observed in total taxa richness across catchments most likely due to varying localized disturbance types. Average number of macroinvertebrate taxa across the 17 sites was 20 (27% of the total distinct taxa recorded).

4.2 Macroinvertebrate Density

Macroinvertebrate density across survey sites is presented in **Error! Reference source not found.**. Macroinvertebrate density was calculated for Surber samples while kick-net samples represent total abundance of individuals collected across multiple habitats. Invertebrate density recorded in riffle habitats ranged between 163 individuals/m^2 at upper Navisa (UNV) and 3,847 individuals/m^2 at upper Nadrou (UND). There was no general trend observed in density across upstream and downstream sites across sub-catchments. Exception was at sites of Nabiaurua catchment whereby invertebrate density decreased downstream. This was due to downstream decline in the abundance of the three dominant taxa; clinging mayfly (*Pseudocloeon*spp), net-spinner caddis (*Abacariafijiana*) and the weighted-case maker endemic caddis (*Goerafijiana*).

Average macroinvertebrate density across the 17 sites was 1473 individuals/m^2. The relatively low density at upper Navisa (UNV) was due to lack of representatives from certain groups in the riffle habitat; Trichoptera (2 taxa only) and two representatives of odonata (damselfly), zero representatives of odonata (dragonfly), single representative of hemiptera (water bug), coleopteran (aquatic beetle) and zero representative of gastropod and crustacean (prawn, shrimp and crab). The highest densities at upper Nadrou (UND: 3,847 individuals/m^2) and lower Waisali (LWS: 3,477 individuals/m^2) creek sites was due to the large number of Baetid mayfly nymphs (*Pseudocloeon* spp. recorded in riffle habitat representing the largest proportion of invertebrate densities; 42% and 72% of the total macroinvertebrate density respectively. The purse-case micro-caddis (*Paroxyethira* sp.1) contributed to the second largest proportion of invertebrate density at upper Nadrou (UND: 3,847 individuals/m^2); 34% of the total macroinvertebrate density.

4.3 Status and distribution of taxa

A total of ten of the macroinvertebrate taxa recorded over the survey were endemic to the Fijian Islands (Table 4) and represented 14% of the total number of taxa recorded. Many of the endemic taxa recorded are common throughout Fiji Island streams. These include the five caddisflies (*Abacariafijiana, Abacariaruficeps, Anisocentropusfijianus*, *Goerafijiana and Oxyethirafijiensis*), the endemic damselfly,*Nesobasis* spp. (genus endemic to Fiji), a shrimp (*Caridinafijiana*), endemic genus of micro-water striders *Fijivelia* sp., the endemic water cricket (*Hydropedecticusvitiensis*) and spring snails *Fluviopupa* spp. The five endemic caddislfies recorded are common throughout slightly modified to modified streams/creeks.

The most common group was the unconfirmed Fiji endemics represented by 33 taxa (i.e., 47%) (Table 4). Many freshwater macroinvertebrates that has only been identified to genus level and yet to be matched with their respective adults to confirm their species name in order to confirm their status. Hence many macroinvertebrates identified to family/genus level only (eg. Cordullidae or Odontoceridae, *Tipula* sp., Polycentropodidae and *Hydrobiosis* sp.) are unofficially known to be endemic to Fiji but has been placed in the UFE status as of present; which in this survey represented the highest (47%) of the total taxa recorded (Table 4). The next most common group were those native to Fiji represented by 18 taxa (i.e., 26%) (Table 4); crustaceans being the dominant taxa. Two taxa were native to the South Pacific region (3%) and two introduced the Pacific region (3%). The remaining 7% of taxa had unknown status (**Error! Reference source not found.**).

Error! Reference source not found. shows the total number of taxa recorded at each site and status/distribution shown as a proportion of total taxa richness within each community. The number of endemic taxa recorded across the 17 sites ranged between 2 endemic taxa in the upper Navisa (UNV) and eight endemic taxa in the upper Nakara Creek (UNK). The majority of endemic taxa recorded were insects (eight out of 10 taxa in total). The only other endemic taxa recorded were the small (<4 mm) micro spring snail *Fluviopupa*spp. and *Caridinafijiana* (shrimp). The introduced tropical snail *Melanoidestuberculata* was recorded across 10 sites. Of highest concern is the occurrence of highly invasive leech *Helobdellaeuropaea*which was recorded at upper (UWM) and mid (MWM) Wainamau sites. It is likely that *H. europaea* also occurs in the connecting waterways but was just not recorded during the surveys due to selected sampling site limitation.

5. Ecological status of Ba catchment riverine systems

Bioindicator-based ecological status of Ba river catchment (Fig 6 and Table 3) was developed to aid in community specific freshwater resource management plan with a focus on the status of riverine systems

and recommendations on maintenance of ecological integrity of these systems for continued harnessing of ecosystem services. Ecological status of the Ba catchment riverine systems was deduced based on established bioindicators of riverine ecological health for Fijian systems (Rashni 2014a, b)with guidance from Australian SIGNAL scores system (Chessman 2001; Chessman 2003). The eco-status map (Fig 6) shows the ecological status of the freshwater sites surveyed with respective colored keys as indicators of ecological status type and corresponding water quality adopted from the local water quality monitoring tool- 'Traffic Light Bioindicator Guide' (Rashni 2014b, Rippon *et al*. 2015); a section of the Fiji RiverCare toolkit (Rippon *et al*. 2015). Taxa in the 'Good' status category comprise 'sensitive' organisms while moderate-good category comprises a mixture of 'sensitive' and 'fairly resilient' organisms. Taxa in the 'Degraded' category comprise highly 'resilient' organisms while taxa in 'moderate-degraded' category comprise a mixture of 'highly resilient' to 'fairly resilient' organisms.

Inland catchments with forest cover associated sites appear to have moderately good to good (green circles) waterways while systems in close distance to coastal areas (less vegetated areas, concentrated agriculture) appear to have moderately degraded to degraded waterways (Fig 6). Despite being impacted by continued agricultural activity over the years moderately degraded sites appear to be receiving good water quality from upstream sites which allow freshwater biodiversity to thrive and thus the shown amber circle per site on the map. A matrix (Table 3) was developed in association with the eco-status map to reflect the bioindicator community recorded per site, observed threats, mitigation and enhancement measures and site associated villages. It is highly recommended that upstream and down communities work in collaboration to observe the recommendation as per matrix.

6. Discussion

Freshwater macroinvertebrates are pivotal in functioning of freshwater ecosystems. They contribute towards crucial ecosystem functions such as nutrient cycling, assisting in litter decomposition and plant community regulation as well as being food for higher-level organisms (MacDonald *et al*., 1991). Higher level organisms such as large prawns and fish (except Gobidae which are algal grazers) are important food supply for the local riverine communities They feed on these macroinvertebrates such as freshwater snails, juvenile shrimps and prawns and insect larvae (IAS, 2004). Therefore in order to maintain desired number of fish and prawn population in a river/stream, the presence of aquatic macroinvertebrate population is necessary. Higher number of macroinvertebrate diversity increases the number and complexity of aquatic food chains and leads to more stable and resilient freshwater communities.

Macroinvertebrate communities recorded from sampling sites were fairly typical of those expected in western inland streams draining the dry side of Viti Levu[3]. Freshwater survey recorded a total of 73 macroinvertebrate taxa out of 10,120 specimens. An interesting observation was that the small riffle shrimps that were caught during the survey were all kept by our local guides in Ba for consumption. This clearly illustrates the importance of crustaceans to the diets of villagers in the upper reaches of the Ba catchment. The minute spring snails *Fluviopupa* have undergone considerable speciation and each geographic region has its own species. These 3-5mm snails were recorded from the waterways of interest for the first time for a total of six sites (35% of the total sites surveyed). These species were the only gastropod recorded that is endemic to Fiji during the survey, more specifically they are area endemics and therefore of very high conservation significance. Currently Fiji records a total of 28

[3]EIA Reports (Confidential)

Fluviopupa species, all of which are endemic and area endemics (Zielke and Haase 2014). A rich density of the *Fluviopupa* spp. collected from mid Nabiaurua suggested that larger populations are thriving well in connected areas of assessment. However their absence in other sites may reflect the intactness of the system as spring snails are highly sensitive to any type of environmental disturbance that affects natural water quality and substrate biofilm smothering. Spring snails are bioindicators of excellent water quality and intact forest systems. The *Fluviopupa* spp. collected from Nakara, Nabiaurua and Nadrou catchments are potentially new species as the spring snails are known to evolve in the headwaters of catchments and usually catchment endemic. Hence, a very high possibility of a total of six new records to science and an increase in the diversity of the area endemic risoodean gastropods for Fijian highlands. The site specific bioindicator based ecological assessment matrix is designed to assist localized villages benefiting from riverine ecosystem services harnessed for livelihood support.

The quality of inland surface waters are dependent on their physical, chemical and biological properties. These attributes are reflected by the types of living organisms present in the water and their density (this includes the community composition and its diversity). Based on the above properties, surface waters are classified into (one of) several quality classes (Džeroski*et al*. 2000, MacDonald *et al*. 1991) with country/ region specific water quality biological indices for water quality monitoring (Lydy*et al*., 2000). The Oceania region currently lacks a biotic index for water quality monitoring and the globally favored EPT (Orders Ephemeroptera, Plecoptera and Trichoptera) index is not applicable in Oceania as the countries containing freshwater systems lack the Order Plecoptera (stoneflies).

Therefore until a biotic water quality index is developed for Fiji the most economical and user-friendly method suggested for community based water quality monitoring would be the application of 'Traffic Light Bioindicator Guide', a color coded simple Fiji River invertebrate spotting tool (Rashni 2014b, Rippon *et al*. 2015).This matrix (Table 3) was developed using the Fijian river health and water quality bioindicators and is therefore recommended for use in Community Based River Monitoring (CBRM) river rehabilitation related projects as well as decision making in relation to proposed developments in the immediate areas and or connected lotic systems.

7. Conclusions

Freshwater macroinvertebrate survey of 17 sites across the six sub-catchments of Ba revealed total of 73 unique taxa out of 10,120 individuals. The most diverse group was Insecta with 51 taxa and representing 70% of the total number of taxa recorded. The next most diverse taxonomic group was Crustacea(11 taxa) followed byMollusca (6 taxa), Annelida (3 taxa) and Nematomorpha and Platyhelminthes represented by 1 taxa each. There was no general trend observed in density across upstream and downstream sites across sub-catchments. Average macroinvertebrate density across the 17 sites was 1473 individuals/m^2. Macroinvertebrate density recorded in riffle habitats ranged between 163 individuals/m^2 at upper Navisa and 3,847 individuals/m^2 at upper Nadrou. With regards to status and distribution of taxa, the most common group were the unconfirmed Fiji endemics represented by 33 taxa (i.e., 47%) while Fijian endemics represented 14% of the total number of taxa recorded.

A total of 16 taxa were recorded as bioindicators of ecological health of waterways. Bioindicator-based ecological status assessment of sites sampled revealed that 35% of the sampled sites were categorized as 'Good' status, 24% of them as 'Moderate-good' status, 35% of them as 'Moderate-degraded' status and 12% of them as 'Degraded' status. A bioindicator-based ecological assessment matrix was developed specific to land owning sites to aid with Ba riverine community resource management plan.

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Figures and Tables

Figure 1: Location of sampling sites in the study area.

Note: In the lower left of the map, sites mid Navisa and upper Navisa are supposed to be mid Waisali and upper Waisali

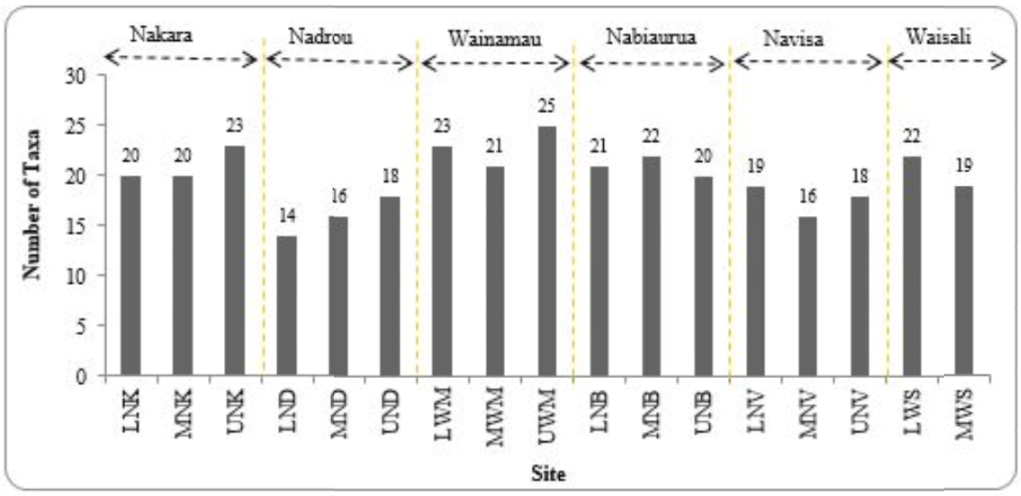

Figure 2 Number of unique taxa across all sampling sites

Note: site code abbreviation= (catchment location (lower=L) + 2 letters of catchment name (Nakara=NK); e.g. LNK

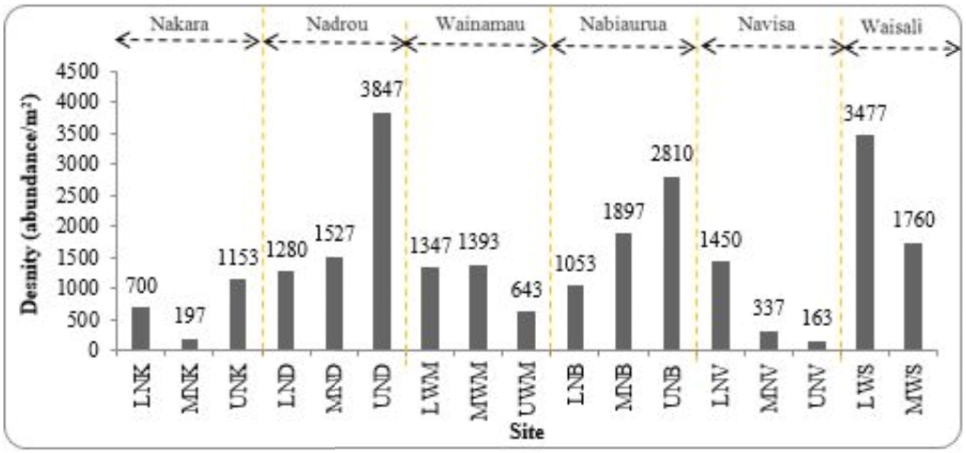

Figure 3 Macroinvertebrate density across all sampling sites

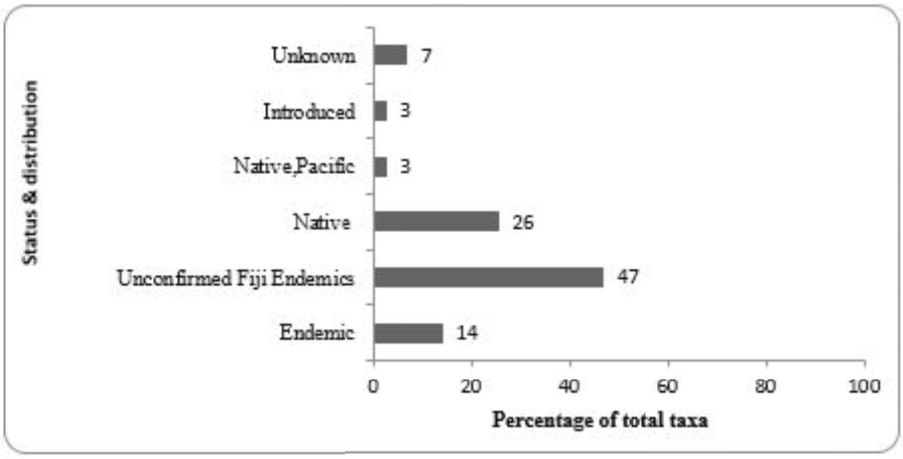

Figure 4: Status and distribution of macroinvertebrate taxa recorded across all sites

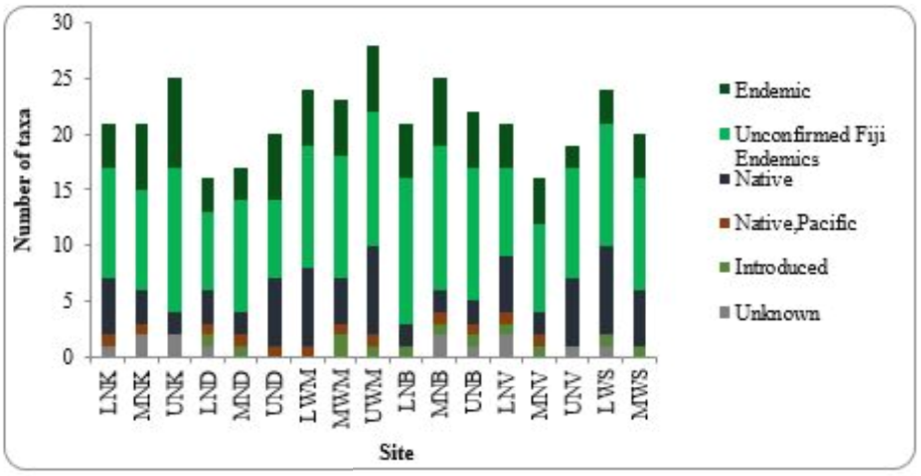

Figure 5: Status and distribution of macroinvertebrate taxa recorded across individual sites

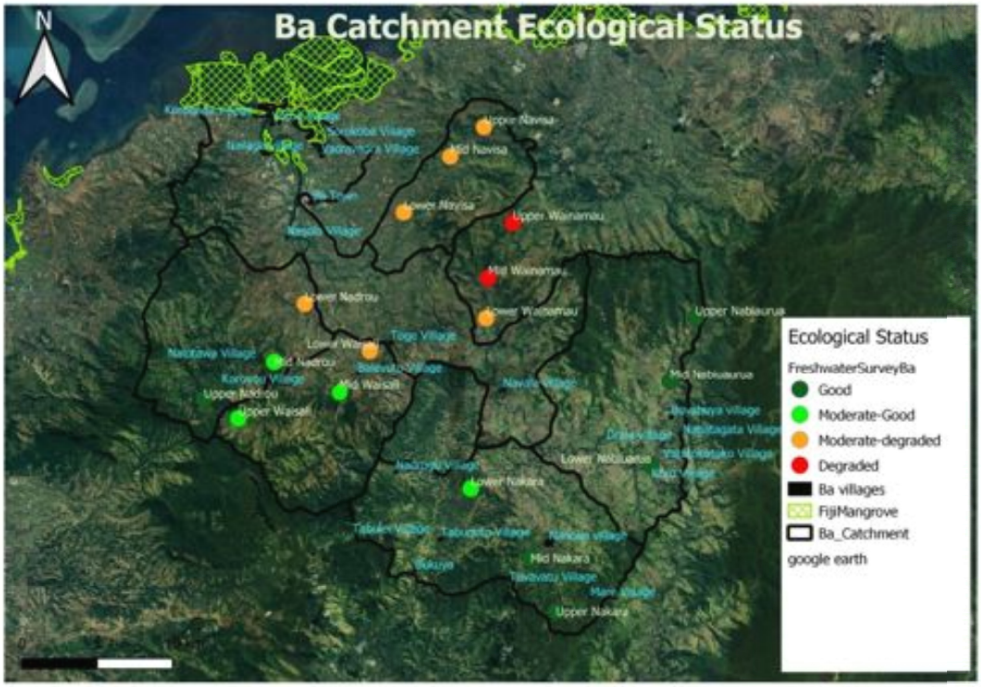

Figure 6: Bioindicator based ecological status of freshwater systems surveyed

Table 1: Number of macroinvertebrate taxa recorded in each of the taxonomic groups across all sites

Higher taxonomic group	Order / class	Common name	Number of taxa
Insecta	Trichoptera	caddisfly	13
	Ephemeroptera	mayfly	5*
	Lepidoptera	moth	2
	Diptera	true-fly	9
	Zygoptera	damselfly	4
	Anisoptera	dragonfly	3
	Coleoptera	beetle	7
	Hemiptera	water bug	5
	Heteroptera	water bug	2
	Orthoptera	water cricket	1
Crustacea	Caridea	shrimp	9
	Dendrobranchiata	prawn	1
	Ostracoda	seed shrimp	1
Mollusca	Gastropoda	snails	6
Annelida	Oligochaeta	worms	3
Nematomorpha	Gordiida	Horse hair worm	1
Platyhelminthes	Tricladida	Flatworm	1
			73

Note: * = likely to include more species than the number indicated.

Table 2: Summary of ecological status of sites surveyed

Island/ province	Sites	Associated bioindicator taxa	Ecological status	Percentage (%) of sites
Viti Levu, Ba	Upper Nabiaurua Mid Nabiaurua Lower Nabiaurua Upper Nakara Mid Nakara Upper Nadrou	*Fluviopupa* spp. *Chimarra* sp., *Nesobasis* spp., *Hydrobiosis* sp., Polycetropodidae, *Apsilochorema* sp., *Baetis* spp. *Melanesobasis* sp., *Dineutus* sp. and *Tipula* sp.	Good	35
	Lower Nakara Mid Waisali Mid Nadrou Upper Waisali	Chironomidae, *Barbronia* sp., *Nymphicula* sp., *Tipula* sp. *Nesobasis* spp., *Chimarra* sp., Baetis spp., *Hydrobiosis* sp., *Polycentropodidae*, *Abacaria ruficeps* and *Fluviopupa* spp.	Moderate-good	24
	Lower Wainamau Lower Waisali Lower Nadrou Upper Navisa Mid Navisa Lower Navisa	*Nymphicula* sp, *Barbronia* sp., Chironomidae, spp., *Caenis* sp. and *Tipula* sp. *Nesobasis* sp., *Abacaria ruficeps*, *Apsilochorema* sp. Polycentropodidae, and *Atyopsis spinipes*	Moderate-degraded	35
	Upper Wainamau Mid Wainamau	*Helobdella europaea,* *Barbronia* sp., Chironomidae, *Harrisius* sp. and *Nymphicula* sp.,	Degraded	12

Table 1: Ba river ecological status matrix for riverine resource management

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
UNB	Upper Nabiaurua	*Chimarra* sp.,*Hydrobiosis* sp., *Baetis* spp. Chironomidae, *Fluviopupa* spp.	None at site surveyed.	Good	1. To maintain the riparian vegetation on both sides of the bank. 2. Gravel extraction is not recommended. 3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture.	Drala village, Vatutokotoko Village, Buyabuya village, Koro Village &Nagatagata Village
MNB	Mid Nabiaurua	*Chimarra* sp., Polycetropodidae, *Nesobasis* spp., *Dineutus* sp., *Fluviopupa* spp.	None at site surveyed.	Good	1. To maintain the riparian vegetation on both sides of the bank. 2. Gravel extraction is not recommended. 3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
					and chemicals for fish/prawn harvest is not recommended.		
LNB	Lower Nabiaurua	*Chimarra* sp., *Hydrobiosis* sp., *Apsilochorema* sp., Polycentropodidae, Nesobasis sp., Chironomidae, *Fluviopupa* spp.	None at site surveyed.	Good	1. To maintain the riparian vegetation on both sides of the bank. 2. Gravel extraction is not recommended. 3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture.	
UNK	Upper Nakara	*Chimarra* sp., *Hydrobiosis* sp., *Apsilochorema* sp., *Tipula* sp., *Melanesobasis* sp., *Fluviopupa* spp. and Chironomidae	None at site surveyed.	Good	1. To maintain the riparian vegetation on both sides of the bank. 2. Gravel extraction is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture.	Mare Village, Tuvavatu Village, Nanoko Village, Bukuya village, Tabuquto

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
					3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.		Village, Tabulei Village Nadrugu Village
MNK	Mid Nakara	*Nesobasis* sp., Polycentropodidae, *Baetis* spp. *Abacariaruficeps* and Chironomidae	None at site surveyed.	Good	1. To maintain the riparian vegetation on both sides of the bank. 2. Gravel extraction is not recommended. 3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture.	

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
LNK	Lower Nakara	*Nymphicula* sp., *Abacariaruficeps*, Chironomidae,*Chimarra*sp., *Baetis* spp., *Tipula* sp. and *Fluviopupa* spp.	Algal covered rocks indicative of excess nutrient leachate.	Moderate-Good	1. Identify point and non-point pollution sources to stream draining the village and farmed areas. 2.To maintain the riparian vegetation on both sides of the bank. 3. Gravel extraction is not recommended. 4. Bank/slope farming is not recommended. 5. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture.	
UWM	Upper Wainamau	*Nymphicula* sp., *Abacariaruficeps*, Chironomidae, *Nesobasis* spp., *Apsilochorema* sp., Polycentropodidae, *Helobdellaeuropaea* and *Dineutus* sp.	Unstable stream bank. Vegetation removal next to stream bank. Sedimented streambed harboring	Degraded	1. Identify point and non-point pollution sources to stream draining the village and farmed areas. 2. Implement Nature-based	1. Proper waste managemeng plan in place (including hazardous wastes). Appoint an Environmental Officer Environmental Management Plan.	Koroboya village

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
			inasive leech population. Algal covered rocks indicating nutrient leachates.		solutions (long-term) for Sedimentation Control Plan. 3. Use of engineering control measures (e.g. gabions, straw bale or sandbags) to avoid discharge of contaminated/grey water into the river. 4. Grey water treatement plan. 5. Proper rubbish disposal. 6. Proper fencing for livestock to avoid river access. 7. Be alert to avoid trasporting invasive leech to other areas via boots or farming tools washed in the creek.	2. Define boundaries of the river rehabilitation project for impact (undercutting, bare bank areas) areas to limit socio-ecological disturbance. 3. Consider transplanting (when possible) or replacing weeds/grass covered bank with native/endemic plants (Tahitian chestnut, *Pandanus vitiensis* and Sago palm) seedlings in suitable areas (bare bank/eroded areas). 4. Develop and implement leech eradication plan. 5. Annual biomonitoring of water quality and invasivesin collaboration with forestry, SPC and Ministry of Agriculture.	

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
MWM	Mid Wainamau	Chironomidae, *Nymphicula* sp., *Abacariaruficeps*, *Nesobasis* spp., *Apsilochorema* sp., *Harrisius* sp. and *Helobdellaeuropaea*		Degraded	1. Identify point and non-point pollution sources to stream draining the village and farmed areas. 2. Implement Nature-based solutions (long-term) for Sedimentation Control Plan. 3. Use of engineering control measures (e.g. gabions, straw bale or sandbags) to avoid discharge of contaminated/grey water into the river. 4. Grey water treatement plan. 5. Proper rubbish disposal. 6. Proper fencing for livestock to avoid river access. 7. Be alert to avoid trasporting	1. Proper waste managemeng plan in place (including hazardous wastes). Appoint an Environmental Officer Environmental Management Plan. 2. Define boundaries of the river rehabilitation project for impact (undercutting, bare bank areas) areas to limit socio-ecological disturbance. 3. Consider transplanting (when possible) or replacing weeds/grass covered bank with native/endemic plants (Tahitian chestnut, *Pandanus vitiensis* and Sago palm) seedlings in suitable areas (bare bank/eroded areas). 4. Develop and implement leech eradication plan.	

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
					invasive leech to other areas via boots or farming tools washed in the creek.	5.Annualbiomonitoring of water quality and invasivesin collaboration with forestry, SPC and Ministry of Agriculture.	
LWM	Lower Wainamau	*Nesobasis* sp., Chironomidae, *Abacariaruficeps*, Polycentropodidae, *Apsilochorema* sp. and *Baetis* spp.		Moderate-degraded	1. Piggeries to be located far from riverbank Rubbish to be disposed properly in landfill.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture.	
MWS	Mid Waisali	Chironomidae, *Nesobasis* spp., *Chimarra* sp., *Baetis* spp., *Hydrobiosis* sp. and*Tipula* sp.	1. Eroded bank areas. 2. Modified riparian vegetation.	Moderate-good	1. To rehabilitate and maintain the riparian vegetation on both sides of the bank. 2. Bank/slope farming is not recommended. 3. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended. 4.Livestock to be located far from riverbank	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	Balevuto village and Toge village

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
					5. Gravel extraction is not recommended.		
LWS	Lower Waisali	*Nymphicula*sp, *Barbronia* sp., Chironomidae, *Apsilochorema* sp., *Baetis* spp., *Nesobasis* spp., *Caenis*sp. and *Tipula*sp.	Highly modified riparian vegetation.	Moderate-degraded	1. To rehabilitate and maintain the riparian vegetation on both sides of the bank. 2. Gravel extraction is not recommended. 3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	
UND	Upper Nadrou	*Nymphicula* sp., *Nesobasis* sp., *Chimarra* sp., *Abacariaruficeps*, *Fluviopupa* spp. and Chironomidae	None at site surveyed.	Good	1. To maintain the riparian vegetation on both sides of the bank. 2. Gravel	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	Korovou village, Nalotawa village and Nasolo village

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
					extraction is not recommended. 3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.		
MND	Mid Nadrou	*Nesobasis* sp., Polycentropodidae, *Nymphicula* sp., *Abacariaruficeps*, Chironomidae,*Barbronia* sp., *Hydrobiosis* sp. and *Baetis* sp.	None at site surveyed.	Moderate-good	1. To maintain the riparian vegetation on both sides of the bank. 2. Gravel extraction is not recommended. 3. Bank/slope farming is not recommended. 4. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
LND	Lower Nadrou	*Nymphicula* sp.,*Nesobasis* spp., Chironomidae, *Apsilochorema* sp. and *Nymphicula* sp.	1. Highly modified riparian 2. Eroded bank areas	Moderate-degraded	1. To rehabilitate and maintain the riparian vegetation on both sides of the bank. 2. Bank/slope farming is not recommended. 3. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended. 4.Livestock to be located far from riverbank 5. Gravel extraction is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	
UNV	Upper Navisa	*Barbronia* sp.,*Nesobasis* spp., *Caenis* sp., Chironomidae and *Hydrobiosis* sp.	1. Highly modified riparian 2. Eroded bank areas 3. Bank farming	Moderate-degraded	1. To rehabilitate and maintain the riparian vegetation on both sides of the bank. 2. Bank/slope farming is not recommended. 3. Use of Duva	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	Sorokoba village and Vadravadra village

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
					(derris plant) roots and chemicals for fish/prawn harvest is not recommended. 4.Livestock to be located far from riverbank 5. Gravel extraction is not recommended.		
MNV	Mid Navisa	*Nesobasis* spp., *Nymphicula* sp., *Abacariaruficeps* and Chironomidae	Modified riparian on the True right bank	Moderate-degraded	1. Plant native trees to enhance bank stability on the true right bank and maintain the riparian vegetation on both sides of the bank. 2. Bank/slope farming is not recommended. 3. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended. 4.Livestock to be located far from	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation / Enhancement Measures	Mataqali landowning units
					riverbank 5.Gravel extraction is not recommended.		
LNV	Lower Navisa	*Nymphicula* sp., *Barbronia* sp., *Apsilochorema* sp., Chironomidae, *Nesobasis*spp., *Abacariaruficeps*, *Baetis* spp. and *Atyopsisspinipes*	1. Modified riparian 2. Eroded bank areas 3. Bank farming	Moderate-degraded	1. To rehabilitate and maintain the riparian vegetation on both sides of the bank. 2. Bank/slope farming is not recommended. 3. Use of Duva (derris plant) roots and chemicals for fish/prawn harvest is not recommended. 4.Livestock to be located far from riverbank 5. Gravel extraction is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	

Table 4: List of freshwater macroinvertebrates, status, common name and categorized abundance recorded across the survey sites

Note: Abundance: VA = very abundant (>100); A = abundant (20-99); C = common (5-19); F = few (2-4); R = rare (1).

Higher taxonomic group	Order /class / family	Taxa	Status	Common name	Nakara			Nadrou			Wainamau			Nabiarua			Naviusa			Waisali	
					LNK	MNK	UNK	LND	MND	UND	LWM	MWM	UWM	LNB	MNB	UNB	LNV	MNV	UNV	LWS	MWS
Insecta	Trichoptera	*Abacaria fijiana*	E	Caddisfly	A	A	VA	A	A	VA	A	VA	A	A	VA	VA	A	C		VA	VA
		Abacaria ruficeps	E	Caddisfly	C	F	F		C	F	F	C	A				C	R			
		Goera fijiana	E	Caddisfly		F	A			C			F	A	A	VA					C
		Anisocentropus fijianus	E	Caddisfly	F			R		R	F	F	F	R			F	R	C	F	C
		Chimarra sp.	UFE	Caddisfly	F		VA			F				F	R	C					C
		Hydrobiosis sp.	UFE	Caddisfly			C		F					R		C			R		F
		Apsilochorema sp.	UFE	Caddisfly			C	F			F	C	C	C			C			C	
		Oxyethira fijiensis	E	Caddisfly			F					C	A		C	F					
		Paroxyethira sp. 1	UFE	Caddisfly				C		VA	C	A	A	F	A	A	A		R	C	R
		Paroxyethira sp. 2	UFE	Caddisfly							C			F	C	F					F
		Paroxyethira sp. 3	UFE	Caddisfly								C									
		Odontoceridae	UFE	Caddisfly	C	R			F		F		F	C	A	F			F	F	C
		Polycentropodidae	UFE	Caddisfly		C	F		A		F		F	F	C						
	Ephemeroptera	*Pseudocloeon* spp.	UFE	Mayfly	VA	VA	VA	VA	VA	VA	VA	VA	C	VA	VA	VA	VA	F	C	VA	VA
		Baetis spp.	UFE	Mayfly	F	C		F	F		R				C	F	F			C	F
		Caenis sp.	UFE	Mayfly															C	F	
	Odonata	*Nesobasis* sp.	E	Damselfly		C		C	A	C	C	C	C	C	C		C	C	C	C	C
		Indolestes vitiensis	E	Damselfly	F	C		A		C		C	A	F	C	F	C		R	C	
		Melanesobasis sp.	N	Damselfly			F				R		R	F		R			R		
		Anax sp.	N	Dragonfly						F			F								
		Ishnura sp.	N	Damselfly									C								
		Pantala sp.	N	Dragonfly				F					C								
		Libelluliidae	N	Dragonfly								C	C			R	F			F	F
	Lepidoptera	*Nymphicula* sp.	UFE	Moth	C	C	C	VA	C	A	F	A	A	C	C	C	A	C	C	VA	C
		Crambidae	UFE	Moth														R			
	Coleoptera	*Hydrophilidae*	UFE	Water bug		R															
		Dytiscidae	UFE	Diving beetle	R								F								
		Elmidae	UFE	Riffle beetle														F			
		Hydraenidae	UFE	Minute moss beetle														R			
		Chrysomelidae	UFE	Leaf beetle														R			
		Dineutus sp.	UFE	Whirligig beetle									R		R						
		Scirtidae	UFE	Marsh beetles															R		
	Diptera	Chironomidae	UFE	Midge	C	F	C	C	C	F	C	A	C	C	F	C	C	R	F	A	A
		Tanypodinae	UFE	Midge											R						
		Harrisius sp.	UFE	Midge								F									
		Simulium jolli	N	Black fly			VA					C									
		Empididae	UFE	Dance fly			F		C					C						F	
		Dolichopodidae	UFE	Long-legged flies	R																
		Stratiomyidae	UFE	Soldier fly		F					R					R					
		Psychoda sp.	UFE	Drain fly										R					R		
		Tipula sp.	UFE	Cranefly	R		C													R	R
	Hemiptera	*Limnogonus lactuosus*	N	Water bug						F											
		Limnogonus fossarum	N	Water bug						R											
		Saldidae	UFE	Water bug								R									
		Fijivelia sp.	E	Water bug		F									F						
		Anisops	UFE	Back swimmer									C								
	Heteroptera	*Tenagogonus* sp.	N	Water bug		R					R	R							R		
		Limnometra sp.	N	Water bug							R		F	C							
	Orthoptera	*Hydropedecticus vitiensis*	E	Water cricket		F					R										
Malacostraca	Decapoda	*Atyopsis spinipes*	N	Shrimp													R				
		Caridina serratirostris	N	Shrimp	C					C										F	
		Caridina gracilirostris	N	Shrimp	R														R	C	R
		Caridina longirostris	N	Shrimp	R			VA			R	C					A	C		C	C
		Caridina fijiana	E	Shrimp												C					
		Caridina typus	N	Shrimp															F	R	
		Caridina sp. 1	U	Shrimp							C				A		F				
		Caridina sp. 2	U	Shrimp															F		
		Antecaridina sp.	U	Shrimp		C															
		Macrobrachium latidactylus	N	Prawn	F	R					C				F					C	
	Ostracoda	Ostracoda	UFE	Seed shrimp					F			F									
Mollusca	Gastropoda	*Melanoides tuberculata*	I	Snail				A	F			A		F	A	C	C	A		C	C
		Melanoides lutosa	N	Snail	A	F			A	C	C		R				C	C	R	F	C
		Physastra nasuta	NP	Snail		R		R		F	C	C	F		C	A	A	F			
		Gyraulus convexiusculus	NP	Snail	R																
		Fluviopupa spp.	E	Spring snail	R		F			F				C	A	F					
		Ferrissia sp.	UFE	Limpet snail													R	R			
Annelida	Oligochaeta	Oligochaeta sp.	U	Worm	F	R	C	R							R	R	R			R	
	Hirudinea	*Barbronia* sp.	N	Leech				C	C	C	R	C	C		C		A		C	A	R
		H. europaea	I	Leech								F	F								
Nematomorpha	Gordiida	*Gordius* sp.	U	Horse hair worm			F														
Platyhelminthes	Tricladida	Dugisiidae	UFE	Flatworm					C	F	F		F		C	C					

Comments