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Freshwater Invertebrate Assemblages and Ecological Status of the Ba River, Fiji by Bindiya Rashni¹

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 Surber sampling 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 (*Abacaria fijiana*, *Abacaria ruficeps*, *Anisocentropus fijianus*, *Goera fijiana* and *Oxyethira fijiensis*), the endemic damselfly, *Nesobasis* spp. (genus endemic to Fiji), a shrimp (*Caridina fijiana*), endemic genus of micro-water striders *Fijivelia* sp., the endemic water cricket (*Hydropedecticus vitiensis*) and spring snails *Fluviopupa* spp. Macroinvertebrate density recorded in riffle habitats ranged between 163 individuals/m² at upper Navisa (UNV) and 3,847 individuals/m² 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 macroinvertebrate 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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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 across 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 at 17 stations within six sub-catchments of Ba river catchment. Permanent creek systems were selected for this 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 on the 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., *Abacaria fijiensis* 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 m²) were calculated by multiplying mean Surber sample abundance data (per 0.1 m²) by a factor of ten to give abundance/m². 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 Table 2. 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 Platyhelminthes 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) (Figure 2). 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 (*Abacaria fijiana*), damselfly naiad (*Indolestes* sp.), purse-case micro-caddis (*Paroxyethira* sp. and *Oxyethira fijiensis*) 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 Figure 3. 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/m² at upper Navisa (UNV) and 3,847 individuals/m² 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 (*Abacaria fijiana*) and the weighted-case maker endemic caddis (*Goera fijiana*).

Average macroinvertebrate density across the 17 sites was 1473 individuals/m². 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/m²) and lower Waisali (LWS: 3,477 individuals/m²) 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/m²); 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 (*Abacaria fijiana*, *Abacaria ruficeps*, *Anisocentropus fijianus*, *Goerafijiana* and *Oxyethira fijiensis*), the endemic damselfly, *Nesobasis* spp. (genus endemic to Fiji), a shrimp (*Caridina fijiana*), endemic genus of micro-water striders *Fijivelia* sp., the endemic water cricket (*Hydropedecticus vitiensis*) and spring snails *Fluviopupa* spp. The five endemic caddisflies recorded are common throughout slightly modified to modified streams/creeks.

The most common group was the unconfirmed Fiji endemics represented by 33 taxa (Table 4) (i.e., 47%) (Figure 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 (Table 4) (i.e., 26%) (Figure 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 (Figure 4).

Figure 5 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 *Caridina fijiana* (shrimp). The introduced tropical snail *Melanoides tuberculata* was recorded across 10 sites. Of highest concern is the occurrence of highly invasive leech *Helobdella europaea* 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 (Figure 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 (Figure 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 (Figure 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 downstream 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 Levu³. 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

³EIA 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 (Džeroskiet *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 (Insect 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 by Mollusca (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/m². Macroinvertebrate density recorded in riffle habitats ranged between 163 individuals/m² at upper Navisa and 3,847 individuals/m² 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. Of highest concern was the occurrence of highly invasive leech *Helobdella europaea* which was recorded at upper (UWM) and mid (MWM) Wainamau sites; the species responsible for leech outbreak in Ba.

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

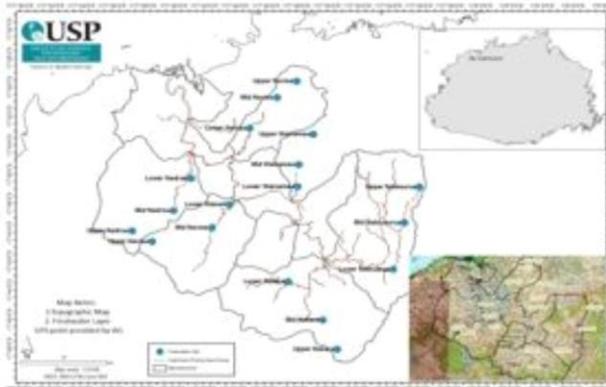


Figure 1: Location of sampling sites in the study area.

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

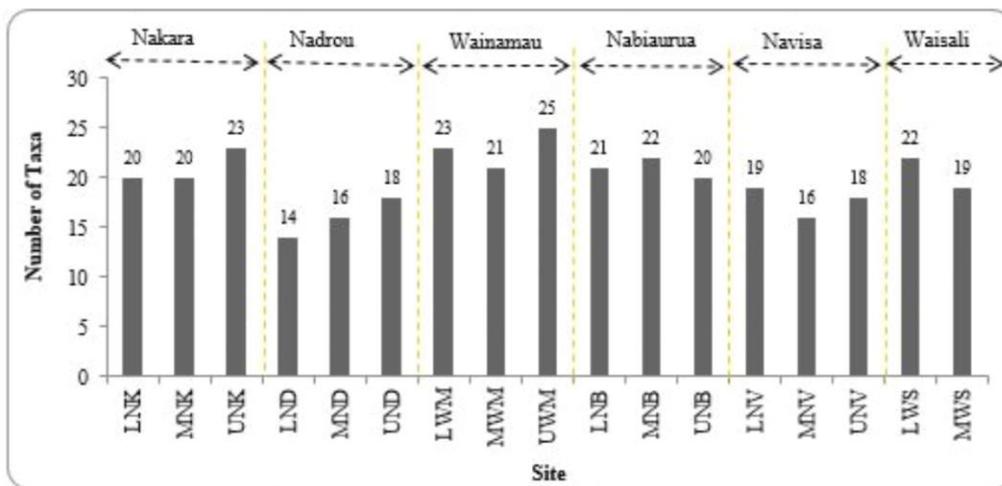


Figure 2 Number of unique taxa across all sampling sites

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

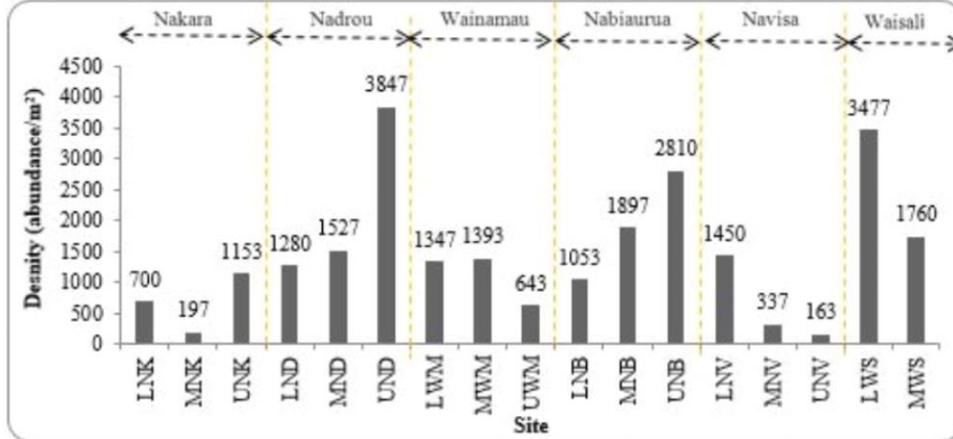


Figure 3 Macroinvertebrate density across all sampling sites

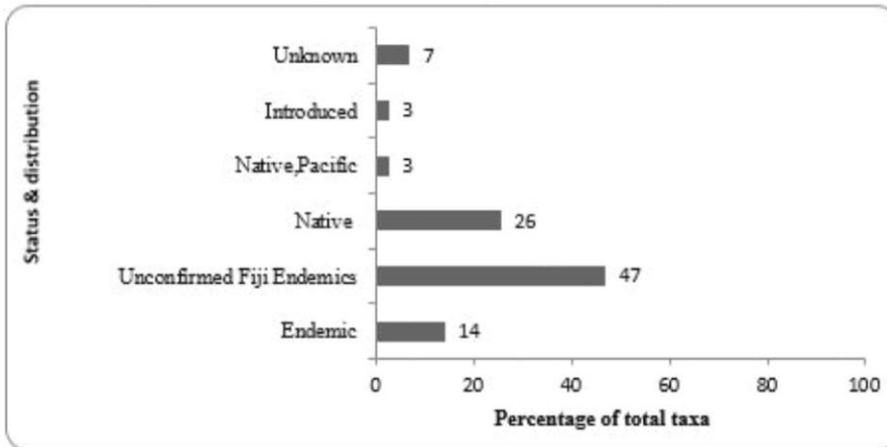


Figure 4: Status and distribution of macroinvertebrate taxa recorded across all sites

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	damsel fly	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	<i>Fluviopupa</i> spp.	Good	35	
	Mid Nabiaurua	<i>Chimarra</i> sp.,			
	Lower Nabiaurua	<i>Nesobasis</i> spp.,			
	Upper Nakara	<i>Hydrobiosis</i> sp.,			
	Mid Nakara	Polycetropodidae,			
	Upper Nadrou	<i>Apsilochorema</i> sp., <i>Baetis</i> spp. <i>Melanesobasis</i> sp., <i>Dineutus</i> sp. and <i>Tipula</i> sp.			
	Lower Nakara	Chironomidae,			24
	Mid Waisali	<i>Barbronia</i> sp.,			
	Mid Nadrou	<i>Nymphicula</i> sp., <i>Tipula</i>			
	Upper Waisali	sp. <i>Nesobasis</i> spp., <i>Chimarra</i> sp., <i>Baetis</i> spp., <i>Hydrobiosis</i> sp., <i>Polycentropodidae</i> , <i>Abacaria ruficeps</i> and <i>Fluviopupa</i> spp.			Moderate-good
	Lower Wainamau	<i>Nymphicula</i> sp., <i>Barbronia</i> sp.,			35
	Lower Waisali	Chironomidae, spp., <i>Caenis</i> sp. and <i>Tipula</i> sp.			Moderate- degraded
	Lower Nadrou	<i>Nesobasis</i> sp., <i>Abacaria</i>			
	Upper Navisa	<i>ruficeps</i> , <i>Apsilochorema</i>			
Mid Navisa	sp. <i>Polycentropodidae</i> ,				
Lower Navisa	and <i>Atyopsis spinipes</i>				
Upper Wainamau	<i>Helobdella europaea</i> ,	12			
Mid Wainamau	<i>Barbronia</i> sp., Chironomidae, <i>Harrisius</i> sp. and <i>Nymphicula</i> sp.,	Degraded			

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	<i>Chimarra</i> sp., <i>Hydrobiosis</i> sp., <i>Baetis</i> spp. Chironomidae, <i>Fluviopupa</i> 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	<i>Chimarra</i> sp., Polycetropodidae, <i>Nesobasis</i> spp., <i>Dineutus</i> sp., <i>Fluviopupa</i> 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	
LNB	Lower Nabiaurua	<i>Chimarra</i> sp., <i>Hydrobiosis</i> sp., <i>Apsilochorema</i> sp., Polycentropodidae, <i>Nesobasis</i> sp., Chironomidae, <i>Fluviopupa</i> 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	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
UNK	Upper Nakara	<i>Chimarra</i> sp., <i>Hydrobiosis</i> sp., <i>Apsilochorema</i> sp., <i>Tipula</i> sp., <i>Melanesobasis</i> sp., <i>Fluviopupa</i> spp. and Chironomidae	None at site surveyed.	Good	harvest is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture.	Mare Village, Tuvavatu Village, Nanoko Village, Bukuya village,
MNK	Mid Nakara	<i>Nesobasis</i> sp., Polycentropodidae, <i>Baetis</i> spp. <i>Abacaria ruficeps</i> 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.	Tabuquto Village, Tabulei Village Nadrugu Village

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation /Enhancement Measures	Mataqali landowning units
LNK	Lower Nakara	<i>Nymphicula</i> sp., <i>Abacaria ruficeps</i> , Chironomidae, <i>Chimarra</i> sp., <i>Baetis</i> spp., <i>Tipula</i> sp. and <i>Fluviopupa</i> 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	<i>Nymphicula</i> sp., <i>Abacaria ruficeps</i> , Chironomidae, <i>Nesobasis</i> spp., <i>Apsilochorema</i> sp., Polycentropodidae, <i>Helobdella europaea</i> and <i>Dineutus</i> sp.	1. Unstable stream bank. 2. Vegetation removal next to stream bank. 3. Sedimented streambed harboring invasive leech population. 4. Algal covered rocks indicating nutrient leachates.	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 treatment plan. 5. Proper rubbish disposal.	1. Proper waste management 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	Koroboya village

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation /Enhancement Measures	Mataqali landowning units
MWM	Mid Wainamau	Chironomidae, <i>Nymphicula</i> sp., <i>Abacaria ruficeps</i> , <i>Nesobasis</i> spp., <i>Apsilochorema</i> sp., <i>Harrisius</i> sp. and <i>Helobdella europaea</i>		Degraded	<ol style="list-style-type: none"> 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 treatment plan. 5. Proper rubbish 	<ol style="list-style-type: none"> 1. Proper waste management 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 	

ID	Site	Bioindicators (BMI)	Observed Impacts/Threats	Ecological status	Proposed Mitigation Measures	Additional Mitigation /Enhancement Measures	Mataqali landowning units
					disposal. 6. Proper fencing for livestock to avoid river access. 7. Be alert to avoid transporting invasive leech to other areas via boots or farming tools washed in the creek.	replacing weeds/grass covered bank with native/endemic plants (Tahitian chestnut, <i>Pandanus vitiensis</i> 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 invasives in collaboration with forestry, SPC and Ministry of Agriculture.	
LWM	Lower Wainamau	<i>Nesobasis</i> sp., Chironomidae, <i>Abacaria ruficeps</i> , Polycentropodidae, <i>Apsilochorema</i> sp. and <i>Baetis</i> 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, <i>Nesobasis</i> spp., <i>Chimarra</i> sp., <i>Baetis</i> spp., <i>Hydrobiosis</i> sp. and <i>Tipula</i> 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	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
LWS	Lower Waisali	<i>Nymphicula</i> sp., <i>Barbronia</i> sp., Chironomidae, <i>Apsilochorema</i> sp., <i>Baetis</i> spp., <i>Nesobasis</i> spp., <i>Caenis</i> sp. and <i>Tipula</i> sp.	Highly modified riparian vegetation.	Moderate-degraded	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	
UND	Upper Nadrou	<i>Nymphicula</i> sp., <i>Nesobasis</i> sp., <i>Chimarra</i> sp., <i>Abacaria ruficeps</i> , <i>Fluviopupa</i> spp. and Chironomidae	None at site surveyed.	Good	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	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
MND	Mid Nadrou	<i>Nesobasis</i> sp., Polycentropodidae, <i>Nymphicula</i> sp., <i>Abacaria ruficeps</i> , Chironomidae, <i>Barbronia</i> sp., <i>Hydrobiosis</i> sp. and <i>Baetis</i> 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	
LND	Lower Nadrou	<i>Nymphicula</i> sp., <i>Nesobasis</i> spp., Chironomidae, <i>Apsilochorema</i> sp. and <i>Nymphicula</i> 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	<i>Barbronia</i> sp., <i>Nesobasis</i> spp., <i>Caenis</i> sp., Chironomidae and <i>Hydrobiosis</i> 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 (derris plant) roots and chemicals for fish/prawn	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
					harvest is not recommended. 4. Livestock to be located far from riverbank 5. Gravel extraction is not recommended.		
MNV	Mid Navisa	<i>Nesobasis</i> spp., <i>Nymphicula</i> sp., <i>Abacaria ruficeps</i> 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 riverbank 5.Gravel extraction is not recommended.	Annual biomonitoring of invasives in collaboration with forestry, SPC and Ministry of Agriculture	
LNV	Lower Navisa	<i>Nymphicula</i> sp., <i>Barbronia</i> sp., <i>Apsilochorema</i> sp., Chironomidae, <i>Nesobasis</i> spp., <i>Abacaria ruficeps</i> , <i>Baetis</i> spp. and <i>Atyopsis spinipes</i>	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.	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
					4. Livestock to be located far from riverbank 5. Gravel extraction is not recommended.		

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		Nadroa		Wanama		Nuhama		Narisa		Waisali							
					LNK	MNK	LNK	LND	MND	LND	LVM	MVM	UVM	LNK	MNB	UNB	LVN	MNV	UNV	LMS	MWS	
Insecta	Trichoptera	<i>Abacaria fijiana</i>	E	Caddis fly	A	A	VA	A	A	VA	A	A	VA	VA	A	C	VA	VA				
		<i>Abacaria ruficeps</i>	E	Caddis fly	C	F	F		C	F	F	C	A			C	R					
		<i>Goera fijiana</i>	E	Caddis fly		F	A			C		F	A	A	VA				C			
		<i>Anticoentropus fijianus</i>	E	Caddis fly				R	R	R	F	F	F			F	R	C	F	C		
		<i>Chimarra</i> sp.	UFE	Caddis fly	F		VA			F			F	R	C				C			
		<i>Hydrobiostis</i> sp.	UFE	Caddis fly			C		F				R		C			R	F			
		<i>Apsilochorema</i> sp.	UFE	Caddis fly			C	F		F	C	C			C				C			
		<i>Oxyethira fijiensis</i>	E	Caddis fly			F			C	A		C	F								
		<i>Paroxyethira</i> sp. 1	UFE	Caddis fly				C		VA	C	A	A	F	A	A		R	C	R		
		<i>Paroxyethira</i> sp. 2	UFE	Caddis fly						C			F	C	F				C	F		
		<i>Paroxyethira</i> sp. 3	UFE	Caddis fly							C											
		Odontoceridae	UFE	Caddis fly			C	R			F	F		C	A	F		F	F	C		
		Polycentropodidae	UFE	Caddis fly			C	F		A	F		F	F	C							
		Ephemeroptera	<i>Pseudocloeon</i> spp.	UFE	Mayfly	VA	VA	VA	F	C	VA	VA										
			<i>Baetis</i> spp.	UFE	Mayfly	F	C		F	F		R		C	F	F			C	F		
	<i>Caenis</i> sp.		UFE	Mayfly														C	F			
	Odonata	<i>Nesobasis</i> sp.	E	Damselfly		C		C	A	C	C	C	C	C	C	C	C	C	C			
		<i>Indolestes vitiensis</i>	E	Damselfly	F	C		A		C		C	A	F	C	F	C	R	C			
		<i>Melanesobasis</i> sp.	N	Damselfly			F				R		R	F		R						
		<i>Anax</i> sp.	N	Dragonfly					F				F									
		<i>Ishnura</i> sp.	N	Damselfly									C									
		<i>Pantala</i> sp.	N	Dragonfly				F					C									
	Lepidoptera	Libellulidae	N	Dragonfly							C	C			R	F		F	F			
		<i>Nymphicula</i> sp.	UFE	Moth	C	C	C	VA	C	A	F	A	A	C	C	C	A	C	VA	C		
	Coleoptera	Crambidae	UFE	Moth														R				
		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				
		<i>Dineutus</i> 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
			Tanytopodinae	UFE	Midge												R					
	<i>Harrisius</i> sp.		UFE	Midge								F										
	<i>Simulium jolli</i>		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							
	<i>Psychoda</i> sp.		UFE	Drain fly										R					R			
	<i>Tipula</i> sp.		UFE	Cranefly	R		C												R	R		
	Hemiptera		<i>Limnogonus lactuosus</i>	N	Water bug					F												
		<i>Limnogonus fossarum</i>	N	Water bug					R													
		Saldidae	UFE	Water bug							R											
		<i>Fijivelia</i> sp.	E	Water bug		F							F									
<i>Anisops</i>		UFE	Back swimmer								C											
Heteroptera	<i>Tenagomonus</i> sp.	N	Water bug		R				R	R							R					
	<i>Limnometra</i> sp.	N	Water bug						R		F	C										
Orthoptera	<i>Hydropedecticus vitiensis</i>	E	Water cricket		F					R												
Malacostraca	Decapoda	<i>Atyopsis spinipes</i>	N	Shrimp											R							
		<i>Caridina serratiostris</i>	N	Shrimp	C					C								F				
		<i>Caridina gracilirostris</i>	N	Shrimp	R													R	C	R		
		<i>Caridina longirostris</i>	N	Shrimp	R			VA			R	C					A	C	C	C		
		<i>Caridina fijiana</i>	E	Shrimp											C							
		<i>Caridina typus</i>	N	Shrimp														F	R			
		<i>Caridina</i> sp. 1	U	Shrimp						C				A		F						
		<i>Caridina</i> sp. 2	U	Shrimp														F				
		<i>Antecaridina</i> sp.	U	Shrimp		C																
		<i>Macrobrachium latidacrylus</i>	N	Prawn	F	R								F					C			
	Ostracoda	UFE	Seed shrimp					F			F											
	Mollusca	Gastropoda	<i>Melanoides tuberculata</i>	I	Snail				A	F		A		F	A	C	C	A	C	C		
			<i>Melanoides lutosa</i>	N	Snail	A	F			A	C	C	R			C	C	R	F	C		
			<i>Physastra nasuta</i>	NP	Snail		R		R		F	C	C	F		C	A	A	F			
			<i>Gyraulus convexiusculus</i>	NP	Snail	R																
<i>Fluviopupa</i> spp.			E	Spring snail		R		F			F			C	A	F						
<i>Ferrisia</i> sp.			UFE	Limpet snail												R	R					
Annelida	Oligochaeta	<i>Oligochaeta</i> sp.	U	Worm	F	R	C	R						R	R	R		R				
	Hirudinea	<i>Barbronia</i> sp.	N	Leech				C	C	C	R	C	C		C	A	C	A	R			
Nematomorpha	Gordida	<i>H. europaea</i>	I	Leech							F	F										
		<i>Gordius</i> sp.	U	Horse hair worm			F															
Platyhelminthes	Tricladida	Dugesiidae	UFE	Flatworm					C	F	F		F		C	C						

Comments