CSIRO PUBLISHING

Pacific Conservation Biology
http://dx.doi.org/10.1071/PC14928

Freshwater ichthyofauna of the Pacific-Asia Biodiversity Transect (PABITRA) Gateway in Viti Levu, Fiji

Lekima K. F. Copeland[A,D], *David T. Boseto*[B] *and Aaron P. Jenkins*[C]

[A]South Pacific Regional Herbarium, Institute of Applied Sciences, University of the South Pacific, Private Mail Bag, Suva, Fiji.
[B]Ecological Solutions, PO Box 180, Gizo, Western Province, Solomon Islands.
[C]School of Natural Sciences, Edith Cowan University, Joondalup, WA 6027 Australia.
[D]Corresponding author. Email: copeland_l@usp.ac.fj

Abstract. The freshwater ichthyofauna of the Fiji islands remained poorly documented before the establishment of the Pacific-Asia Biodiversity Transect (PABITRA) network. The PABITRA approach assesses biodiversity along ocean-to-mountain transects and promotes sustainable land use on islands across the Pacific. Multiple surveys of freshwater fish species along the Viti Levu PABITRA transect have contributed six new occurrence records and one new species to the known freshwater fishes of Fiji since 2002. In total, 21 indigenous species of fish (9% endemic) from 10 families and no introduced fishes were found in the three PABITRA sites. Diversity was highest (16 species) at Savura forest reserve and decreased further inland into Sovi and Wabu. The assemblage found is dominated by highly migratory species (95%) that traverse the different aquatic habitats (marine, estuarine, lowland and upland streams) covered by the PABITRA transect. This high degree of connectivity highlights several growing issues affecting aquatic fauna on the high island of Viti Levu. The reduction in forest cover along the gateway transects, especially in the terminal reaches, and infrastructure development such as dams and weirs have deleterious effects on the migration routes of the Fijian ichthyofauna. Several species collected are important food sources and have cultural totemic importance to local inhabitants along the vertical transect. This paper documents the ichthyofauna of the Fiji gateway transect, ecological characteristics of this assemblage, IUCN Redlist conservation assessment status and highlights factors affecting the fragility and resilience of these communities, particularly focusing on the importance of life-history patterns and watershed conditions.

Additional keywords: diadromy, fish, landscape.

Received 13 October 2015, accepted 1 November 2015, published online 15 January 2016

Introduction

Fiji's archipelagic nature, biogeographical position and topography are the chief determinants of its freshwater fauna. A synopsis of pre-2000 ichthyological work carried out in Fiji's rivers by various researchers resulted in cataloging 75 species and one endemic species for the Fiji islands (Jenkins 2009). Current studies since the turn of the 21st century by several researchers (Jenkins and Boseto 2005; Boseto 2006; Jenkins *et al.* 2010; Larson 2010; Hoese and Allen 2011; Jenkins and Jupiter 2011; Copeland 2013) have all contributed new findings on Fiji's freshwater fish biodiversity and the factors affecting these faunal assemblages. Currently, 166 species (47 families) have been recorded from brackish water and freshwater with 156 (43 families) indigenous to Fiji. Ten species (4 families) have established invasive or non-indigenous populations in the wild although at least 15 non-indigenous species have been introduced. At least 13 species (4 families) (8.3%) are considered to be endemic to the Fijian archipelago (Jenkins 2009).

Fiji's insular freshwater ichthyofauna was erratically studied and documented before the Pacific-Asia Biodiversity Transect (PABITRA), along with aquatic field and expert support from Wetlands International–Oceania and the University of the South Pacific, was established in Fiji in 2002. A key objective of PABITRA was the development of comparisons of biodiversity both horizontally and vertically within and among the tropical islands of Oceania (Mueller-Dombois 2008). At the 9th Pacific Science Inter-Congress, Fiji was proposed as one of the original transects of the PABITRA network (Mueller-Dombois *et al.* 1999). Later in 1999 Fiji was chosen to be the gateway transect at the 19th Pacific Science Congress in Sydney, Australia (Mueller-Dombois *et al.* 1999). This wet zone transect was developed to capture a continuum of different habitats along a longitudinal ocean-to-mountain corridor on the high oceanic island of Viti Levu. This work was motivated by the lack of knowledge on landscape and seascape processes on the Fiji archipelago. Equally important was the need to train and develop taxonomic and ecological knowledge for local stakeholders and scientists, which has been a priority since the transect was established.

Journal compilation © CSIRO 2016

Along this wet-zone transect several rapid biodiversity surveys (fauna and flora) and detailed monitoring studies have been undertaken. Botanical studies within the transect, for instance, have focussed on the four basic categories of biodiversity data (species inventory, plant community description, ecological data on the species and community level, and long-term monitoring) (Keppel 2005). Although several papers have been published based on work along the PABITRA wet-zone transect in Fiji (Keppel 2005; Morrison and Naikatini 2008; Tuiwawa *et al.* 2008) no single paper has been published dedicated to the ichthyological studies undertaken in these sites. The freshwater fish fauna of Fiji is characteristic of oceanic islands in the Pacific in that they have developed unique assemblages that have important ecological linkages between marine and freshwater environments (McDowall 1998; Keith 2003). In this paper we review the available ichthyological knowledge compiled from the three PABITRA sites and present recent advances in understanding the primary ecological factors affecting these insular assemblages. We highlight several important factors affecting the fragility and resilience of these communities, particularly focusing on watershed conditions, the importance of life-history patterns and the impact of introduced species on indigenous ichthyofaunal resilience. We also suggest necessary and possible future directions of research.

Methods

Study area and sampling

The oceanic islands of Fiji lie between latitudes 16–20°S and longitudes 178°E–178°W and consist of 332 islands, of which about one-third are inhabited (Neall and Trewick 2008). The topography of Viti Levu and Vanua Levu is pronounced, with mountain heights between 900 and 1320 m above sea level. The gateway transect is on Viti Levu's wet zone from the highest peak (Mt Tomaniivi) to nearshore coastal habitats (Nasoata Island). This transect covers a total area of more than 2000 km^2 and has seven focal sites that represent the range of ecosystems covered by the transect (Keppel 2005).

Surveys for ichthyofauna were carried out on three PABITRA focal sites on the island of Viti Levu: (1) Savura forest reserve, (2) Sovi basin and (3) Wabu forest reserve (Fig. 1). The Savura focal site is located in south-eastern Viti Levu and is ~10 km north of Suva. It is mostly covered by lowland rainforest and this reserve is an important catchment that supplies drinking water to Suva. The Sovi basin is a 19 600-ha reserve area (250–1200 m above sea level) in the south-central region of Viti Levu. The primary vegetation type in the Sovi basin is lowland rainforest along with ridge-top vegetation (Keppel 2005). The Wabu forest reserve (500–1300 m above sea level) is an 1102-ha forest reserve in the north-central region of Viti Levu. The vegetation in the Wabu reserve is mainly upland rainforest and cloud forest (Keppel 2005).

A variety of methods were used at the three sites to assess for presence/absence of fish species. In Savura and lower-mid Wabu, an LR-24 Smith Root backpack (500 V, 10 A) electrofishing unit was used together with beach seine nets (0.4 cm^2 mesh). This machine was used extensively in wadeable waters of the creeks and rivers. A fine mesh net was attached to the wand and two other persons were positioned downstream from the electric current with the beach seine net (0.4 cm^2 mesh) and hand net (1 cm^2 mesh size) to collect the stunned fishes. A 100-m reach was sampled by 3–4 surveyors for ~1 h. Due to the remoteness of Sovi and upper Wabu, a mask, snorkel and spear-fishing method was employed.

At each of the sampling sites, a portable Global Positioning System (Garmin 8 hand-held) was used to take the position and altitude of the sampling sites. The physical parameters were measured and recorded before the fish survey began using a YSI meter 85 (model # 85/10FT) to measure the dissolved oxygen, conductivity, salinity and temperature. A YSI meter 83 (model #63/10FT) was used to measure the pH. During field collections all identified fish species were counted and returned to the water. Unidentified specimens and vouchers were brought back to the laboratory. The fish specimens were fixed in 10% formalin, stored in sampling bottles and labelled with site and date of collection. After the fixation process, the specimens were thoroughly rinsed in water and then transferred to 70% ethanol. Voucher specimens are catalogued and kept in the University of the South Pacific Marine Reference Collection.

Species list

To develop a comprehensive listing of fishes for sites within the Fiji PABITRA gateway transect we used a compilation of information from existing literature, unpublished data and the extensive knowledge of the authors. Boseto (2006) compiled a list of fish he caught from Savura River. For Sovi, records were obtained from the work done in the years 2003 and 2004 (Boseto 2003; Thaman and Boseto 2004), in which two rivers (Wainavobo River and Wainivalau River) that drain into the Sovi River were sampled. The upper Wabu Reserve was surveyed in 2003 and the mid-lower section was surveyed in 2006 (Morrison 2006).

Results

In total, 21 species of fish from 10 families were found in the three PABITRA sites (Table 1). Two of these species are considered endemic to the Fiji archipelago. Savura had the highest number of species (16) and this decreased further inland along the transect into Sovi (11 species) and Wabu (two species). Only two species were ubiquitous across the three sites: the eel (*Anguilla marmorata*) and the goby (*Sicyopterus lagocephalus*). No introduced species were recorded for these sites.

Nine of the species (43%) are considered to be of least concern on the IUCN Red List (www.iucnredlist.org). Another seven species (33%) have not been assessed by the Red List, while five species (24%) are data deficient (Table 1). More than one-third (38%) of the fish found along the vertical transect exhibit an amphidromous life-history (Table 1). Facultative catadromy and estuarine migrants comprise ~19% each while obligate catadromy accounts for 9.5% of the life-history patterns. Overall, 95% of the fishes found traverse different aquatic environments (marine, brackish and fresh water) during their lifecycle. Only one endemic goby, *Redigobius leveri*, is considered a freshwater resident and completes its lifecycle entirely in fresh water.

Over one-quarter (28.57%) of the species are piscivore generalists. This is followed by carnivores and invertivore

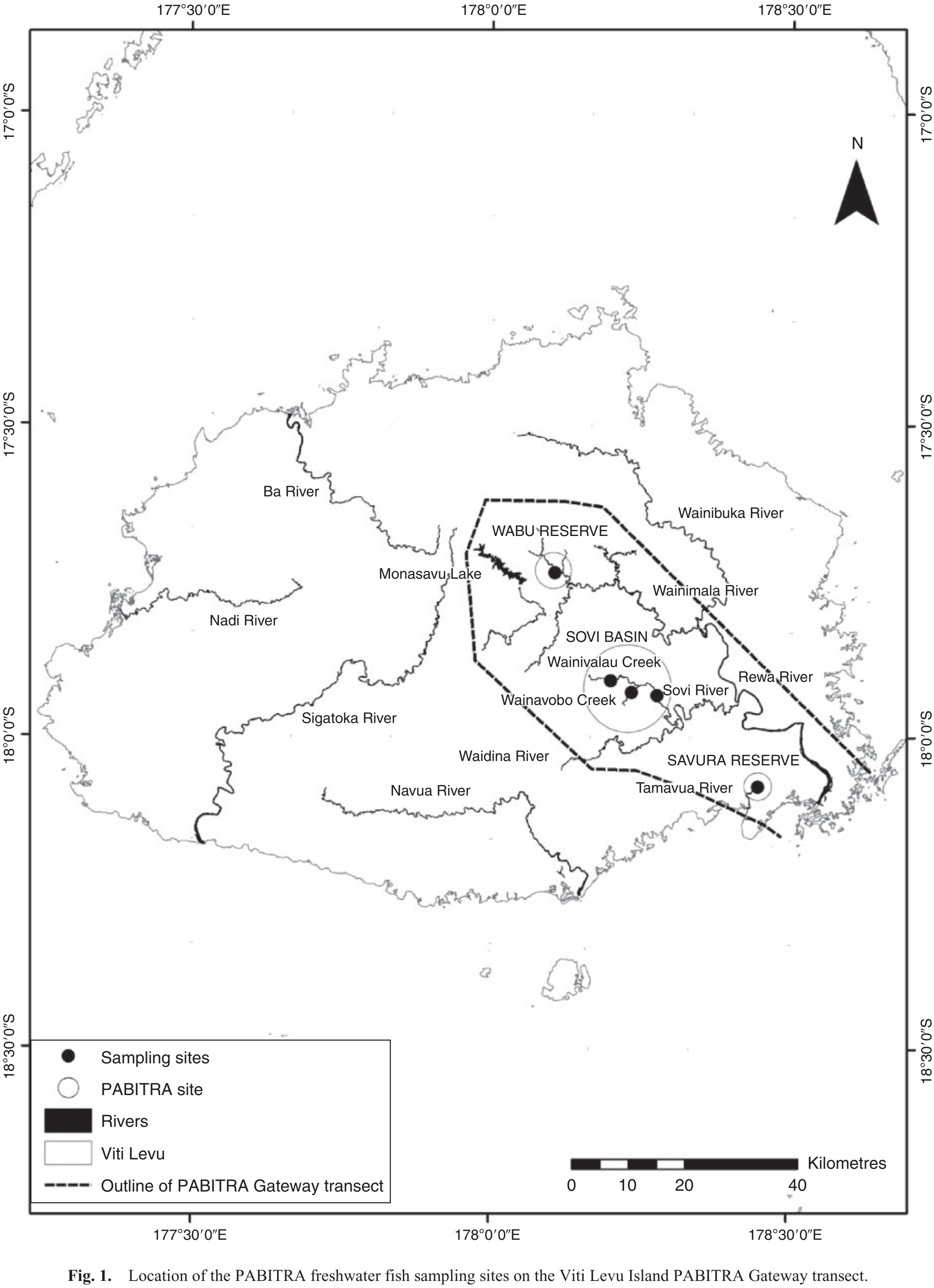

Fig. 1. Location of the PABITRA freshwater fish sampling sites on the Viti Levu Island PABITRA Gateway transect.

Table 1. Numbers of fish species encountered in the three PABITRA sites in Fiji, their IUCN Red List status, life history and feeding guilds
The life history categories of the ichthyofauna are adapted from Jenkins *et al.* (2010), which follows the descriptions of Elliott *et al.* (2007). Life history types are: freshwater resident (FR), freshwater straggler (FS), estuarine migrant (EM), marine migrant (MM), amphidromy (A) and obligate catadromy (COB). Feeding guilds are adapted from Jenkins *et al.* (2010). Feeding guilds are: herbivore specialist (HS), herbivore generalist (HG), invertivore specialist (IS), invertivore generalist (IG), insectivore generalist (InG), piscivore specialist (PS), piscivore generalist (PG), carnivore (C) and generalist (G). Inherent values are shown by superscripts, and include food (F) and totem (T)

Family	Species	Status	Status on IUCN Red list	Life history	Feeding guild	Savura	Sovi	Wabu
Anguillidae	*Anguilla marmorata* Quoy & Gaimard, 1824[FT]	Native	Least concern	C	C	1	1	1
	Anguilla megastoma Kaup, 1856[FT]	Native	Least concern	C	C	1	1	0
Apogonidae	*Apogon amboinensis* (Bleeker, 1853)	Native	Data deficient	EM	PG	1	0	0
Muraenidae	*Gymnothorax polyuranodon* (Bleeker, 1853)	Native	Least concern	COB	PG	0	1	0
Eleotridae	*Belobranchus belobranchus* (Valenciennces, 1837)[FT]	Native	Data deficient	A	PG	0	1	0
	Hypseleotris guentheri (Bleeker, 1875)	Native	Not assessed	FS	InG	1	0	0
Gobiidae	*Awaous guamensis* (Valenciennces, 1837)[FT]	Native	Least concern	A	G	0	1	0
	Sicyopus zosterophorum (Bleeker, 1856)	Native	Not assessed	A	IS	0	1	0
	*Schismatogobius vitie*nsis Jenkins & Boseto, 2005	Endemic	Least concern	A	PG	0	1	0
	Sicyopterus lagocephalus (Commerson, 1800)	Native	Least concern	A	HS	1	1	1
	Stiphodon mele Keith, Marquet & Pouilly, 2009	Native	Data deficient	A	HG	1	0	0
	Stiphodon pelewensis Herre, 1936	Native	Data deficient	A	HG	1	1	0
	Stenogobius sp.	Native	Not assessed	A	PG	1	0	0
	Redigobius leveri (Fowler, 1943)	Endemic	Data deficient	FR	G	1	0	0
Kuhliidae	*Kuhlia marginata* (Cuvier, 1829)[FT]	Native	Least concern	COB	IG	1	1	0
	Kuhlia rupestris (Lacepède, 1802)[FT]	Native	Least concern	COB	IS	1	1	0
Leiognathidae	*Leiognathus fasciatus* (Lacepède, 1803)[F]	Native	Least concern	EM	C	1	0	0
Lutjanidae	*Lutjanus argentimaculatus* (Forsskål, 1775)[F]	Native	Not assessed	FC	PG	1	0	0
Mullidae	*Upeneus sulfereus* (Cuvier, 1829)[F]	Native	Not assessed	MM	IS	1	0	0
Opichthidae	*Lamnostoma kampeni* (Weber & de Beaufort, 1916)	Native	Not assessed	EM	PG	1	0	0
	Yirrkala gjellerupi (Weber & de Beaufort, 1916)	Native	Not assessed	EM	PG	1	0	0
Species richness						16	11	2

specialists at 19% each. About 9.5% of the total assemblages are part of the generalist feeding guild. Generalist insectivores, herbivores and invertivores were the least common feeding guilds and contributed 4.8% each.

Discussion

The PABITRA study has contributed six new records to the total number of brackish and freshwater fishes recorded in Fiji, which is recognised as 166 species (Jenkins 2009). The new records are all from the family Gobiidae: *Stenogobius* sp., *Stiphodon pelewensis* and *Stiphodon mele*. The subfamily Sicydiinae, which includes the genus *Stiphodon*, contributes to the highest levels of endemism and diversity on tropical Indo-Pacific archipelagos (Keith 2003). One of the new species discovered, first found on the island of Taveuni and later in the Sovi basin, has been described by Jenkins and Boseto (2005) as *Schismatogobius vitiensis*. The other new records for Fiji are the snake eel, *Yirrkala gjellerupi*, and the gudgeon *Belobranchus belobranchus*. The findings of this study corroborate past studies where position in catchment has been shown to be a significant driver of fish assemblage, with lower reaches having significantly higher diversity and abundance when compared with mid and upper reaches of rivers and streams (Jenkins and Jupiter 2011; Copeland 2013). The Savura reserve had the highest diversity because it was at a lower elevation and was closer to the sea than Sovi and Wabu reserve.

The migration between freshwater and marine biomes by diadromous fish species raises several challenges and vulnerabilities. With a small land area compared with its vast marine exclusive economic zone and an increasing population, a substantial amount of pressure is being placed on land-based resources such as fresh water, agriculture and forestry in Fiji. The pressing issue for Viti Levu will be the protection of these migration corridors (maintaining landscape and seascape processes) along the PABITRA gateway transect. The findings from this study show a high degree of connectivity of the fauna across the three sites. In total, 95% of the species traverse different aquatic habitats along the gateway for various facets of their lifecycle. This is a similar finding to that of Jenkins *et al.* (2010), which documents 98% of the Fijian ichthyofauna traversing headwater to estuarine habitats. Like the fauna of most of insular Oceania, almost all Fijian fauna are of marine ancestry (McDowall 1997) and have evolved unique life-history patterns adapted to the temporal impermanence of island waterways. High-island tropical aquatic systems such as Fiji have an unusually high degree of faunal connectivity (Jenkins *et al.* 2010). The major consequence of this is that fish species must cross several habitats during their life history and are likely to be disproportionately affected by deleterious environmental conditions due to the greater probability of encountering an obstacle to free passage (Eikaas and McIntosh 2006; Walter *et al.* 2012). Larvae and post-larvae of diadromous fishes are particularly vulnerable during their downstream and upstream migrations (Jenkins *et al.* 2010; Gehrke *et al.* 2011). Obstacles preventing their safe passage along this migration pathway may be man-made (e.g. dams: Greathouse *et al.* 2006), consequences of non-native fish introductions (e.g. predation by invasives: Canonico *et al.* 2005), and/or consequences of degraded water quality (e.g. reduced ability to feed: Rowe and Dean 1998). Although physical obstacles would be less likely to impede species with unique climbing abilities, such as many gobies and eels, many appear sensitive to degraded water quality conditions. In Fiji, the primary threatening processes to this freshwater fauna are deforestation, mining, gravel extraction, building of obstacles to passage (e.g. dams, hanging culverts: Walter *et al.* 2012) and introduction of exotic species (Jenkins *et al.* 2010; Walter *et al.* 2012).

Despite these sites being protected at the headwaters, the mid to terminal reaches of these systems have been deforested or altered. For instance, the mangroves along the lower reaches of the Tamavua River for the Savura catchment have been converted to industrial zones for commercial purposes. Tuiwawa *et al.* (2012) documented a total cover of 8886 ha of mangrove forest and shrub based on the classification of Mueller-Dombois and Fosberg (1998) for the Rewa River delta. In view of the increasing coastal development in Fiji, unofficial estimates of mangrove area losses are as high as 30% (Agrawal *et al.* 2003). Further inland into Waibau, which is one of the seven focal sites on the wet-zone transect, most of the lowland rainforest has been transformed for agricultural purposes (Tuiwawa, pers. comm.).

The reduction in forest catchment cover and long-term effects of logging on our freshwater fauna in Fiji have been documented by Haynes (1999), Jenkins *et al.* (2010) and Jenkins and Jupiter (2011). Other deleterious instream activities such as gravel extraction and its effects on aquatic fauna in Fiji are yet to be studied. Native fishes such as gobies and gudgeons that are bottom dwelling are reliant on benthic food. Increased sediments and turbidity smothers these habitats and benthic food sources and affects visual predator–prey relationships (Bonner and Wilde 2002; Jenkins *et al.* 2010). Carnivores and generalist piscivores that feed on large macroinvertebrates will be affected through the reduction in their prey items and the reduced ability to see food in increased turbidity. As these species are feeding at higher trophic levels, likely mechanisms by which their feeding ability will be reduced are a reduction in the availability of prey items and a reduced ability to find prey in water that is heavily sediment laden. Increased sedimentation can inundate important habitats such as pools and riffles and benthic food sources for bottom-dwelling native gobioids (Eleotridae and Gobiidae). These fish also prefer clean rock or rubble substrate as habitat for resting and for laying eggs (Keith 2003). Most specialist insectivores and invertivores will also likely be affected by reduced overhanging riparian vegetation simply due to lack of insect supply.

The loss of critical habitats that support the various life stages of diadromous species, particularly amphidromous species, is another contributing threat process. For instance, juvenile recruits are attracted from the sea but are unable to complete their lifecycle in degraded catchments (e.g. catchments with reduced forest cover (Jenkins and Jupiter 2011) or catchments that have introduced species (Jenkins *et al.* 2010)). Particularly specialised habitats or restricted distribution may also contribute to vulnerability of species. Despite the widespread distribution of some amphidromous species (McDowall 1998; Keith 2003; Jenkins *et al.* 2010), some amphidromous fish may be confined to a single island or a few catchments. For instance, two sicydiine gobies that are new records to Fiji (*Akhito* sp. and *Smilosicyopus pentecost*) have been found only on the island of Taveuni (Boseto 2006). The rare snake eel *Yirrkala gjellerupi* has been documented only in the Savura catchment within Fiji (McCosker *et al.* 2007). This limited distribution throughout the Fiji archipelago results in these species being more vulnerable to changes in forest cover or infrastructure development (dams, weirs, culverts) that may directly or indirectly alter their migration routes and habitats across their entire range. This can lead to local extirpation or extinction.

Over half of the species (57%) are important food sources to several villages along the transect (Table 1). Several of the species carry inherent totemic value to land owners of the three PABITRA sites. For instance, the eels of the genus *Anguilla* are important totems to the villagers of Delailasekau and Nasevou (these two villages are important land owners in the Sovi basin). The formulation of watershed conservation plans will require the understanding of the relationship between biodiversity and their specific ecosystem requirements balanced with an understanding of local use and values. The current study has confirmed the presence of a mostly diadromous fish community along the PABITRA gateway transect that are not only important food sources, but are also an important cultural identity to the local villages.

Historically there have been an assortment of basic freshwater species surveys, but only recently have a few ecologically driven studies been carried out. In the short term, a major conservation priority is the protection and rehabilitation of the different aquatic biomes traversed by these highly migratory fauna. In the medium term, ecological studies focusing on migratory patterns, feeding ecology and the specific impact of different types of catchment degradation processes are needed. In the longer term, assessment of the conservation value of this migratory fauna will require ongoing biodiversity surveys for knowledge of distribution and a concerted effort to validate the taxonomy of all species found including the population genetics of these species.

Acknowledgements

We are grateful to our field assistants who aided us in sampling these remote parts of Viti Levu, especially Kinikoto Mailautoka, Baravi Thaman and the many field guides and assistants. We thank Ms Ferlisa Valentine for producing our map and Professor William Aalbersberg for providing useful advice on the manuscript. We thank the Institute of Applied Sciences, University of the South Pacific, Wetlands International-Oceania and Conservation International for funding the work.

References

Agrawal, S., Ota, T., Hagenstad, M., Smith, J., van Aalst, M., Koshy, K., and Prasad, B. (2003). Development and climate change in Fiji: focus on coastal mangroves. Working Party on Global and Structural Policies, Organisation for Economic Cooperation and Development.

Bonner, T. H., and Wilde, G. R. (2002). Effects of turbidity on prey consumption by prairie stream fishes. *Transactions of the American Fisheries Society* **131**, 1203–1208. doi:10.1577/1548-8659(2002)131<1203:EOTOPC>2.0.CO;2

Boseto, D. (2003). Fish surveys. In 'Baseline Flora and Fauna Survey of the Sovi Basin, Naitasiri 5–17th May, 2003'. (Ed. C. Morrison.) pp. 11–13. (Institute of Applied Sciences, University of the South Pacific: Suva.)

Boseto, D. (2006). Diversity, distribution and abundance of Fijian freshwater fishes. MSc Thesis. University of the South Pacific, Suva.

Canonico, G. C., Arthington, A. H., McCrary, J. K., and Thieme, M. L. (2005). The effects of introduced tilapias on native biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems* **15**, 463–483. doi:10.1002/AQC.699

Copeland, L. (2013). Seasonality, habitats and micro-habitats of fish in wadeable streams of Nakorotubu, Ra, Fiji Islands. M.Sc. Thesis, University of the South Pacific.

Eikaas, H. S., and McIntosh, A. R. (2006). Habitat loss through disruption of constrained dispersal networks. *Ecological Applications* **16**, 987–998. doi:10.1890/1051-0761(2006)016[0987:HLTDOC]2.0.CO;2

Elliott, M., Whitfield, A. K., Potter, I. C., Blaber, S. J. M., Cyrus, D. P., Nordlie, F. G., and Harrison, T. D. (2007). The guild approach to categorizing estuarine fish assemblages: a global review. *Fish and Fisheries* **8**, 241–268. doi:10.1111/J.1467-2679.2007.00253.X

Gehrke, P. C., Sheaves, M. J., Terry, J. P., Boseto, D. T., Ellison, J. C., Figa, B. S., and Wani, J. (2011). Vulnerability of freshwater and estuarine fish habitats in the tropical Pacific to climate change. In 'Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change' (Eds J. D. Bell, J. E. Johnson and A. J. Hobday.) pp. 369–431. (Secretariat of the Pacific Community: Noumea, New Caledonia.)

Greathouse, E. A., Pringle, C. M., McDowell, W. H., and Holmquist, J. G. (2006). Indirect upstream effects of dams: consequences of migratory consumer extirpation in Puerto Rico. *Ecological Applications* **16**, 339–352. doi:10.1890/05-0243

Haynes, A. (1999). The long term effect of forest logging on the macro-invertebrates in a Fijian stream. *Hydrobiologia* **405**, 79–87. doi:10.1023/A:1003757122717

Hoese, D. F., and Allen, G. R. (2011). A review of the amphidromous species of the *Glossogobius celebius* complex, with description of three new species. *Cybium* **35**, 269–284.

Jenkins, A. P. (2009). Freshwater and estuarine fishes of Fiji: current taxonomic knowledge and priorities for conservation. In 'Proceedings of the Inaugural Fiji Islands Conservation Science Forum'. (Eds A. P. Jenkins, S. R. Prasad, J. Bacchiochi, P. A. Skelton and N. Yakub.) pp. 50–51. (Ecosystem Based Management Project – Fiji: Suva.)

Jenkins, A. P., and Boseto, D. (2005). *Schismatogobius vitiensis*, a new freshwater goby (Teleostei: Gobiidae) from the Fiji Islands. *Ichthyological Exploration of Freshwaters* **16**, 75–82.

Jenkins, A. P., and Jupiter, S. D. (2011). Spatial and seasonal patterns in freshwater ichthyofaunal communities of a tropical high island in Fiji. *Environmental Biology of Fishes* **91**, 261–274. doi:10.1007/S10641-011-9776-4

Jenkins, A. P., Jupiter, S. D., Qauqau, I., and Atherton, J. (2010). The importance of ecosystem based management for conserving aquatic migratory pathways on tropical high islands: a case study from Fiji. *Aquatic Conservation: Marine and Freshwater Ecosystems* **20**, 224–238. doi:10.1002/AQC.1086

Keith, P. (2003). Biology and ecology of amphidromous Gobiidae of the Indo-Pacific and the Caribbean regions. *Journal of Fish Biology* **63**, 831–847. doi:10.1046/J.1095-8649.2003.00197.X

Keppel, G. (2005). Botanical studies within the PABITRA wet-zone transect, Viti Levu, Fiji. *Pacific Science* **59**, 165–174. doi:10.1353/PSC.2005.0020

Larson, H. K. (2010). A review of the gobiid fish genus *Redigobius* (Teleostei: Gobionellinae), with descriptions of two new species. *Ichthyological Exploration of Freshwaters* **21**, 123–191.

McCosker, J. E., Boseto, D., and Jenkins, A. P. (2007). Redescription of *Yirrkala gjellerupi*, a poorly known freshwater Indo-Pacific snake eel (Anguilliformes: Ophichthidae). *Pacific Science* **61**, 141–144. doi:10.1353/PSC.2007.0009

McDowall, R. M. (1997). The evolution of diadromy in fishes (revisited) and its place in phylogenetic analysis. *Reviews in Fish Biology and Fisheries* **7**, 443–462. doi:10.1023/A:1018404331601

McDowall, R. M. (1998). Fighting the flow: downstream–upstream linkages in the ecology of diadromous fish faunas in the west coast New Zealand rivers. *Freshwater Biology* **40**, 111–122. doi:10.1046/J.1365-2427.1998.00336.X

Morrison, C. (2006). Consolidated biodiversity report for the Wabu forest reserve. Institute of Applied Sciences.

Morrison, C., and Naikatini, A. (2008). Herpetofauna and bat monitoring at three Fiji sites in the Pacific-Asia Biodiversity Transect (PABITRA). *Micronesica* **40**, 131–137.

Mueller-Dombois, D. (2008). The evolution of the Pacific-Asia Biodiversity Transect Network (PABITRA) in the Pacific Science Association. *Micronesica* **40**, 1–7.

Mueller-Dombois, D., and Fosberg, F. R. (1998). 'Vegetation of the Tropical Pacific Islands.' (Springer: New York.)

Mueller-Dombois, D., Thaman, R. A., Juvik, J. O., and Kitayama, K. (1999). The Pacific-Asia Biodiversity Transect (PABITRA) a new conservation biology initiative. In 'Biodoversity and Allelopathy: From Organisms to Ecosystems in the Pacific'. (Eds C. H. Chou, G. R. Walter and C. Reinhardt.) pp. 13–20. (Academia Sinica: Taipei, Taiwan.)

Neall, V. E., and Trewick, S. A. (2008). The age and origin of the Pacific islands: a geological overview. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* **363**, 3293–3308. doi:10.1098/RSTB.2008.0119

Rowe, D. K., and Dean, T. L. (1998). Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. *New Zealand Journal of Marine and Freshwater Research* **32**, 21–29. doi:10.1080/00288330.1998.9516803

Thaman, B., and Boseto, D. (2004). Freshwater fish fauna. In 'Second Baseline Flora and Fauna Survey of the Sovi Basin, Naitasiri, 13–20th October, 2004'. (Ed. C. Morrison.) pp. 9–11. (Institute of Applied Sciences, University of the South Pacific: Suva.)

Tuiwawa, M., Osbourne, T., Biol, K., and Tuiwawa, F. (2008). Establishment of long-term vegetation monitoring plots in lowland and upland tropical rainforest, Fiji Islands. *Micronesica* **40**, 123–130.

Tuiwawa, S. H., Wendt, H., and Tuiwawa, M. V. (2012). Flora, vegetation and ecology. In 'A Rapid Biodiversity Assessment, Socioeconomic Study and Archaeological Survey of the Rewa River Mangroves, Viti Levu, Fiji'. (Eds M. V. Tuiwawa, S. Pene and S. H. Tuiwawa.) pp. 3–21. (Institute of Applied Sciences, University of the South Pacific: Suva.)

Walter, R. P., Hogan, J. D., Blum, M. J., Gagne, R. B., Hain, E. F., Gilliam, J. F., and McIntyre, P. B. (2012). Climate change and conservation of endemic amphidromous fishes in Hawaiian streams. *Endangered Species Research* **16**, 261–272. doi:10.3354/ESR00404