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THE FIJIAN *NESOBASIS*: A FURTHER EXAMINATION OF SPECIES DIVERSITY AND ABUNDANCE (ZYGOPTERA: COENAGRIONIDAE)

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Recently, an overview of the diversity, abundance, distribution and morphological characteristics of spp. of the genus *Nesobasis*, endemic to Fiji, was presented for spp. occurring on the 2 largest islands of the archipelago: Viti Levu and Vanua Levu. Here, this knowledge is extended by providing more extensive diversity and abundance data for the island of Vanua Levu, as well as for 4 smaller islands in Fiji: Taveuni, Koro, Ovalau and Kadavu. Previous research indicated that the *Nesobasis* spp. inhabiting Viti Levu and Vanua Levu are unique, with these islands having no species in common. The new data confirm this proposal and also show that smaller islands in proximity to these 2 larger islands usually contain a subset of the large island's *Nesobasis* fauna. The island of Koro, however, is unusual in that, while its *Nesobasis* spp. are predominantly those found on Vanua Levu, it also harbours *N. rufostigma*, a sp. occurring on Viti Levu. Further, *N. recava* is endemic to Kadavu and is not found on Viti Levu, the nearest large island. Species richness is higher on large than small islands while mean species abundances were consistently higher on large islands compared to small islands. The pattern of distribution and speciation in this genus is quite complex, and is the subject of ongoing research.

INTRODUCTION

The study of oceanic islands offers an excellent opportunity to explore the process and pattern of selection as well as the nature of speciation (DARWIN,

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1859; MacARTHUR & WILSON, 1967). Sadly, in many island groups, particularly those in the Southwest Pacific, our knowledge of basic biodiversity is limited. Moreover, there is a fundamental lack of information on the behaviour, life history and ecology of endemic island fauna (WHITTAKER, 1998). In this context BEATTY et al. (2007) reported information on the diversity, abundance and basic morphology of species of the genus *Nesobasis* (Odonata: Zygoptera). Not only is the genus *Nesobasis* endemic to Fiji, it is also species-rich, with species distributed over several islands within Fiji (DONNELLY, 1990). Moreover, for some of the species within the genus, males are seldom observed at oviposition sites (VAN GOSSUM et al., 2007). This male rarity has not caused sex role reversal as previously speculated (DONNELLY, 1990, 1994) but research is ongoing to explore what factors may explain male rarity in some species of *Nesobasis* but not in others (see also VAN GOSSUM et al., 2007).

In our previous report, based on research conducted in 2005 (BEATTY et al., 2007), we focussed on *Nesobasis* observed on Viti Levu and parts of Vanua Levu. During our research in 2006 we were able to explore other regions on Vanua Levu and also to include information on species diversity and abundance for four additional smaller islands: Kadavu, Koro, Ovalau and Taveuni. For these five islands we provide quantitative estimates of *Nesobasis* species diversity and abundance. Furthermore, as BEATTY et al. (2007) did for other species, we provide basic morphological characteristics for field identification for one described species (*N. recava*) and for a new species we encountered (*Uds 3*). We also make note of any reproductive behaviour (tandem, copulation wheel, and oviposition) observed for these species.

In this paper we characterise the inter-island distribution of species of *Nesobasis* based primarily on our own observational data, but also on earlier published work (DONNELLY, 1990; BEATTY et al., 2007). The islands of Taveuni and Koro are located closer to Vanua Levu (the second largest island in the archipelago) than Viti Levu (the largest island in the archipelago), while the islands of Ovalau and Kadavu are located nearer to Viti Levu (Fig. 1). If smaller islands share species with nearby larger islands, we expected the *Nesobasis* community on Taveuni and Koro to be a subset of species occurring on Vanua Levu, while Ovalau and Kadavu species were expected to occur also on Viti Levu.

Many ecological factors can influence whether a disperser from the mainland establishes on an island. However, abundant species are more likely to produce higher absolute numbers of dispersers than rare species (MacARTHUR & WILSON, 1967; GASTON et al., 2006). Therefore, if dispersal played an important role in determining establishment success, one might expect that those species found on smaller islands would comprise a subset of the more abundant species on the large island.

METHODS

The damselfly genus *Nesobasis* is abundant and widespread in the Fijian islands. They are the dominant Zygoptera in most stream habitats, particularly in mountain streams, but they are not found in large rivers or ponds (DONNELLY, 1990, 1994). We used topographic maps (1:50,000) in combination with our prior experience with the genus (BEATTY et al., 2007) to select regions on islands that were likely to contain appropriate *Nesobasis* habitat. In addition, T.W. Donnelly and D. Polhemus communicated their earlier experiences with *Nesobasis* on the different islands.

The Fiji Islands are located in the eastern Melanesian region of the South-western Pacific and have a warm, humid tropical maritime climate with mean monthly temperatures from 23°C in July to 27°C in January (RYAN, 2000). The islands are subequatorial and exposed to heavier rainfall between November and April, especially on the low islands and the leeward sides of the large islands (EVENHUIS & BICKEL, 2005). Our study was conducted during the dry season in Fiji from August 6 to October 4, 2006, a time of year similar to the timing of research summarised in BEATTY et al. (2007). Fiji consists of several hundred islands and occupies a total area of approximately 650,000 km^2 of which the land area is less than 3 percent. There are two large islands in the archipelago (Fig. 1): Viti Levu (10,388 km^2) and Vanua Levu (5,535 km^2) (see also EVENHUIS & BICKEL, 2005). Viti Levu and Vanua Levu are rugged, with landforms including volcanic plugs, eroded calderas, deep gorges, and ravines carved by mountain streams, flat-bottomed valleys with extensive food plains, and mangrove dominated deltas (EVENHUIS & BICKEL, 2005). Other islands in the archipelago are considerably smaller, many having less pronounced topography and lacking streams. However, several islands are sizable and predominantly volcanic in origin, having significant elevations and most importantly mountain streams that could hold species of *Nesobasis*. Of these smaller islands we sampled Kadavu (408 km^2), Koro (109 km^2), Ovalau (102 km^2) and Taveuni (434 km^2).

Study sites that complied to our selection criteria (see further) for VANUA LEVU (see Fig. 1) include: KR-01 (16°30.79' S, 179°32.70' E, alt. 265m), a large stream on the interior road above Korotesere, crossing approximately 1.2 km south of Seavaci Rd, we sampled upstream from the road; KR-02 (16°28.55' S, 179°33.32' E, alt. 170m), second stream above Korotesere, we sampled on the downstream side of the road crossing; Nagaci Creek (16°28.36' S, 179°35.32' E, alt. 130m), small stream crossing road near small

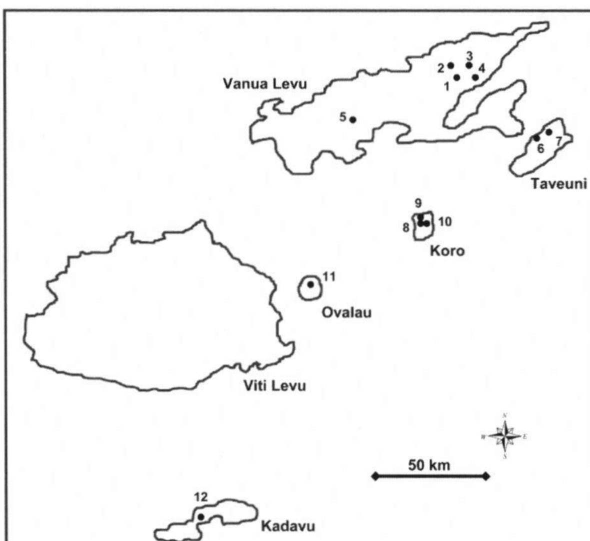

Fig. 1. Map of six islands of Fiji for which data are presented, showing sample locations. For VANUA LEVU: (1) KR-01; – (2) KR-02; – (3) Nagaci Creek; – (4) Vunigautulailai Creek; – (5) WR-01. For TAVEUNI: (6) Somosomo; – (7) TV-02. For KORO: (8) Buretini Creek; – (9) K-01; – (10) K-02. For OVALAU: (11) Lovoni. For KADAVU: (12) Vunisea East. Site descriptions and latitude/longitude coordinates are provided in the text.

settlement, we sampled downstream of the road; Vunigautulailai Creek (16°30.06' S, 179°37.20' E, alt. 110 m), stream at bridge on road above Vanuavou, we sampled downstream of the road; WR-01 (16°41.12' S, 178°55.29' E, alt. 335 m), river at high elevation in western Vanua Levu. For TAVEUNI (see Fig. 1) we sampled: Somosomo (16°46.40' S, 179°58.22' W, alt. 30 m), a large river at the southern edge of Somosomo village, we sampled upstream of the bridge; TV-02 (16°44.12' S, 179°54.57' W, alt. 395 m), small stream above Somosomo in agricultural area. We also sampled at Tavoro Falls, in Bouma National Heritage Park, a site that was indicated to be very good *Nesobasis* habitat (D. Polhemus, pers. com.). Despite searching an hour with two persons we were unable to locate any *Nesobasis*. For KORO (see Fig. 1) we sampled Buretini Creek (17°15.82' S, 179°22.08' E, alt. 150m), a stream with very low flow, and predominantly exposed bedrock with boulders and numerous small pools, we sampled immediately above a large waterfall, working upstream to the road crossing; K-01 (17°15.82' S, 179°22.08' E, alt. 40 m), a stream along the road crossing the interior of the island in the north; K-02 (17°19.82' S, 179°25.92' E, alt. 50 m), a large stream on the east side of Koro, which crosses the main road south of the intersection with the interior road across the north side of the island. For OVALAU (see Fig. 1) we sampled Lovoni (17°41.20' S, 178°47.38' E, alt. 85 m), a river near Lovoni village, high in the caldera of the island's volcano. For KADAVU (see Fig. 1) we sampled Vunisea East (19°01.93' S, 178°10.79' E, alt. 140 m), a large stream on the main road east of Vunisea, sampling upstream of the bridge in a region with much exposed bedrock, boulders and waterfalls.

Our sampling method consisted of netting all observed damselflies at a site, identifying every individual belonging to the genus *Nesobasis*. We decided only to include sites for which sampling lasted a minimum of one hour with a minimum of 2 people searching. While a one-hour sample period may not be long enough to detect all species present at a site (for example, those that are very rare or that may be present at the water at different times of the day than those sampled), this level of sampling effort allowed us to characterize the common species at a particular site effectively. We have also chosen to exclude sites for which we sampled for one hour or greater, but where our sample efforts were focussed on the capture of particular species for our research; in these cases sampling effort would not provide an unbiased sample of species abundances at a site. For each of the sites that met our criteria we recorded date, latitude and longitude, stream width and length of the stream sampled, and the approximate sampling duration (for 2 searchers). This information allowed us to calculate coarse abundance estimates: stream width and length were used to calculate area sampled (number of individuals per unit of area), while sampling time provided an alternative measure for calculating species abundances (number of individuals per unit of time) (see also BEATTY et al., 2007).

Analysis of species distributions among islands utilized a Mann-Whitney U Test (SPSS 13.0) to determine whether species occurring both on the large island and one or more of the smaller islands differed in mean abundances from those only occurring on the large island.

SPECIES DESCRIPTIONS

The following basic descriptions provide characteristics we used in the field for species identification. In some instances identification of species required magnifying lenses (20X magnification) or a field-microscope, as a close look at the exact structure of genitalia and/or mesostigmal laminae was required (see DONNELLY, 1990). More detailed descriptions can be found in TILLYARD (1924), DONNELLY (1990) and will appear in Donnelly unpubl. ms. With respect to the latter and as agreed upon with T.W. Donnelly, in what follows we use the first letter(s) of the species names Donnelly will be using in his forthcoming manuscript to allow convenient comparison (see also BEATTY et al., 2007). We found one species new to science during our sampling in 2006, which we refer to as undescribed species 3 (*Uds 3*). This allows for distinction between this species and two species (*Uds 1* and *Uds 2*) discussed in BEATTY et al. (2007).

N. recava (DONNELLY, 1990): Kadavu. This is a slender, medium-sized damselfly, endemic to the island. The thorax of males is bright blue laterally, dorsally black, while females are more pale blue or brown on the lateral thorax. Further, males are predominantly blue on the dorsum of abdominal segments nine and ten with blue colour extending laterally, while females have some pale blue/brown on the dorsum of abdominal segment ten and limited coloration on seg-

Table I

Species diversity and abundance for new locations visited on Vanua Levu in 2006. Total area sampled and duration of sampling are given in italics

Locality and date	Species	Number of individuals	Density (individuals/100m²)	Density (individuals/h)
KR-01 (27/09)			*2250m²*	*105min*
	N. al	29	1.3	16.6
	N. au	1	~0	0.6
	N. brachycerca	78	3.5	44.6
	N. f	2	0.1	1.1
	N. l	25	1.1	14.3
	N. r	5	0.2	2.9
	Uds 3	3	0.1	1.7
KR-02 (27/09)			*1400m²*	*60min*
	N. al	42	3	42
	N. brachycerca	42	3	42
	N. c	11	0.8	11
	N. l	75	5.4	75
Nagaci Creek (17/09)			*90m²*	*60min*
	N. al	2	2.2	2
	N. au	2	2.2	2
	N. brachycerca	10	11.1	10
	N. f	2	2.2	2
	N. l	4	4.4	4
	N. v	1	1.1	1
VanigautulailaiCrk(17/09)			*700m²*	*60min*
	N. l	3	0.4	3
WR-01 (26/09)			*1500m²*	*105min*
	N. al	25	1.7	14.3
	N. au	3	2	1.7
	N. brachycerca	105	7	60
	N. f	1	0.1	0.6
	N. l	59	3.9	33.7
	N. r	1	0.1	0.6

ment nine. The pterostigma of both sexes is dark brown. *N. recava* is somewhat similar to *N. selysi* on Viti Levu, though showing on average more extensive blue coloration on thorax and abdomen than in *N. selysi* (BEATTY et al., 2007). We did not observe any mating associations or ovipositions.

Uds 3: Vanua Levu. This is a very large damselfly, with extensive blue-green coloration on thorax and abdomen. The male is easily distinguished by the pterostigma on its forewings, which are enlarged and have a pearlescent pink coloration. Females are generally blue-green in colour, somewhat similar to females of *N. brachycerca*, but larger. Males were observed displaying to one another, but no tandems or egg-laying were observed.

RESULTS AND DISCUSSION

In total we sampled 27 sites on five islands, collecting 886 specimens of *Nesobasis*, with 12 sites meeting our criteria for inclusion (see Methods): 5 sites for Vanua Levu (Tab. I), 2 for Taveuni (Tab. II), 3 for Koro (Tab. III), 1 for Ovalau (Tab. IV) and 1 for Kadavu (Tab. V). Sites that did not meet our selection criteria contained no species that did not occur in nearby (within island) sites. Therefore, our interpretation of species distribution and abundance would not be changed if these sites were included.

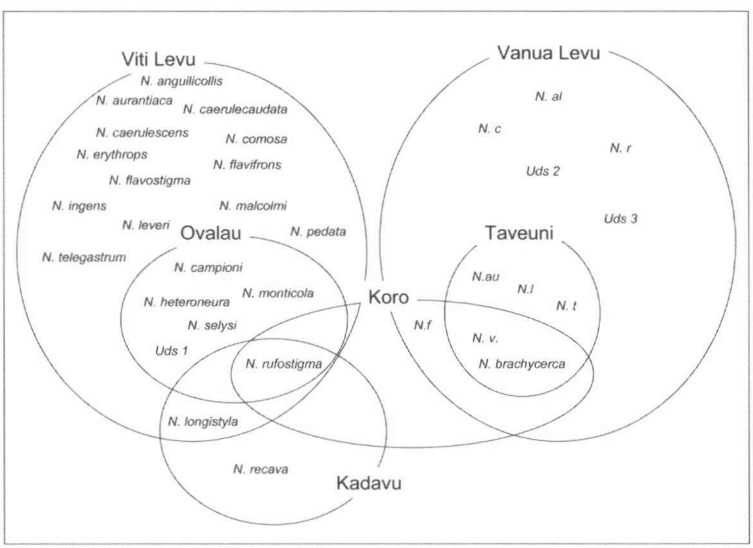

Fig. 2. Venn diagram of *Nesobasis* species distributions among the islands of Viti Levu, Vanua Levu, Ovalau, Kadavu, Koro and Taveuni. Species distributions are based on BEATTY et al., 2007 and present data, except for the following: *Nesobasis aurantiaca, N. caerulescens, N. flavostigma, N. ingens, N. leveri* and *N. pedata* on Viti Levu, *N. campioni* and *N. monticola* on Ovalau (DONNELLY, 1990), and *N. t* on Taveuni (J.H. Skevington, pers. com.).

We encountered a total of 9 species from the 'Vanua Levu' group, which were distributed over Vanua Levu, Taveuni and Koro (see Fig. 2 for a representation of known species distributions). All species found on Taveuni were also found on Vanua Levu. For Koro, this was not the case: whereas most species found on Koro are also found on Vanua Levu, we additionally encountered *N. rufostigma,* a species occurring on Viti Levu, but not Vanua Levu (Tab. III). We did not find *N. rufostigma* to be abundant on Koro (only two specimens were collected at a single location). The fact that Koro is located at a middle distance between Viti Levu and Vanua Levu may help to explain the presence of species from both Viti Levu and Vanua Levu there. As noted earlier, Viti Levu and Vanua Levu do not share species of *Nesobasis* (BEATTY et al., 2007 and results here included); at present Koro is the only island where *Nesobasis* species of the two large islands are known to co-exist.

We encountered 6 species from the 'Viti Levu' group, found on Ovalau and Kadavu, (as well as on Koro) (Fig. 2). All species encountered on Ovalau were also found on Viti Levu. Species we recorded on Kadavu were also found on Viti Levu, except for *N. recava.*, which is endemic to Kadavu (see also DONNELLY, 1990). Our findings for Kadavu are similar to DONNELLY (1990), where the same three species were found. For Ovalau three of the five species also found by DONNELLY (1990) were included in our sample, while we did not observe *N. campioni* or *N. monticola.* However, we did find *Uds 1* on Ovalau, which had not previously been described for this island (Tab. IV). For Taveuni and Koro, no previously published species accounts exist for comparison.

Species richness at sites within Taveuni varied between 2 and 3 species, for Koro it varied between 3 and 4 species, for Ovalau 4 species and for Kadavu 3 species. For both Viti Levu and Vanua Levu the most speciose locations harboured 8 species of *Nesobasis* (BEATTY et al., 2007). Maximal species richness per site thus appears higher on the large islands compared to the small islands.

Table II

Species diversity and abundance for locations visited on Taveuni in 2006. Total area sampled and duration of sampling are given in italics

Locality and date	Species	Number of individuals	Density (individuals/100m²)	Density (individuals/h)
Somosomo (3/10)			*5500m²*	*60min*
	N. au	1	~0	1
	N. l	17	0.3	17
TV-02 (3/10)			*600m²*	*60min*
	N. brachycerca	4	0.7	4
	N. l	1	0.2	1
	N. v	3	0.5	3

Table III

Species diversity and abundance for locations visited on Koro 2006. Total area sampled and duration of sampling are given in italics

Locality and date	Species	Number of individuals	Density (individuals/100m²)	Density (individuals/h)
Buretini Creek (7/09)			*1000m²*	*60min*
	N. brachycerca	4	0.4	4
	N. f	1	0.1	1
	N. rufostigma	2	0.2	2
	N. v	4	0.4	4
K-01 (7/09)			*200m²*	*60min*
	N. brachycerca	6	3	6
	N. f	6	3	6
	N. v	8	4	8
K-02 (8/09)			*4000m²*	*140min*
	N. brachycerca	1	~0	0.4
	N. f	13	0.3	5.6
	N. v	1	~0	0.4

Table IV

Species diversity and abundance for locations visited on Ovalau in 2006. Total area sampled and duration of sampling are given in italics

Locality and date	Species	Number of individuals	Density (individuals/100m²)	Density (individuals/h)
Lovoni (15/08)			*11000m²*	*135min*
	N. heteroneura	42	0.4	18.7
	Uds 1	2	~0	0.9
	N. rufostigma	23	0.2	10.2
	N. selysi	8	0.1	3.6

Table V

Species diversity and abundance for locations visited on Kadavu in 2006. Total area sampled and duration of sampling are given in italics

Locality and date	Species	Number of individuals	Density (individuals/100m²)	Density (individuals/h)
Vunisea East (22/09)			*3500m²*	*105min*
	N. longistyla	4	0.1	2.3
	N. recava	65	1.9	37.1
	N. rufostigma	6	0.2	3.4

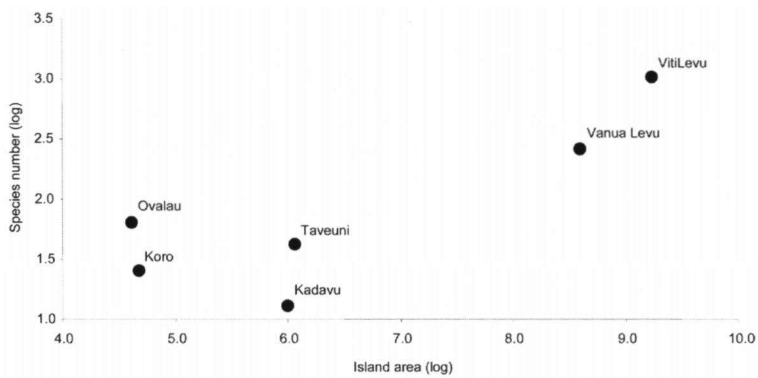

Fig. 3. Species/area relationship (log/log) for species of *Nesobasis* on the islands of Viti Levu, Vanua Levu, Ovalau, Kadavu, Taveuni and Koro. An overall positive correlation between island size and species richness is observed.

Comparing total known species diversity per island (Fig. 2), the two large islands, Viti Levu and Vanua Levu currently have 20 and 11 known species, respectively. The total species diversity of the four small islands is: 4 for Koro, 5 for Taveuni, 6 for Ovalau and 3 for Kadavu (DONNELLY, 1990; BEATTY et al., 2007; J.H. Skevington, pers. com. and data herein). Considering their smaller size and relative isolation from Viti Levu and Vanua Levu (see Fig. 1) the lower species diversity of these four islands is not surprising (e.g. MacARTHUR & WILSON, 1967). A species/area curve (Fig. 3) comparing island size versus species number (log/log transformations) shows an overall positive correlation between island size and species richness (R = 0.833, df = 4, P = 0.039). It should be noted that Kadavu, with its great distance from Viti Levu compared to Ovalau, is the only smaller island having an endemic, *N. recava*. Species relationships and the pattern of speciation within and between islands are the subjects of current phylogenetic research.

A positive relationship between species abundance and species range size/occupancy has been identified in a range of flora and fauna (GASTON et al., 1997; GASTON et al., 2000). This relationship has also been found to hold for species assemblages distributed on and among islands (GASTON et al., 2006). On the large islands in Fiji, Viti Levu and Vanua Levu, this general pattern also appears to hold for species of *Nesobasis*, with relatively abundant species also being encountered at a larger number of sites (BEATTY et al., 2007 and data herein). Between islands, this pattern is less clear. We compared the mean abundances of large island species found on adjoining small islands to large island species not found on small islands. When considering combined data from Viti Levu *versus* Ovalau and Kadavu, and Vanua Levu *versus* Taveuni and Koro (all abundance data in BEATTY et al. 2007 (tabs 1 & 2, pages 22-23, 25) and all abundance data from Vanua Levu (Tab. I) herein), there was little evidence that species found on one of the large islands and at least one small island had higher median abundance than those species found only on the large islands. (Mann-Whitney U = 62.0, $N = 25$, $P = 0.406$) (Fig. 4). While questions could be raised about the power of this test, it supports the general pattern seen in our species distribution data: while some "common" species on the large islands are likely to be found on smaller islands, species such as *N. monticola*, rare on Viti Levu but found on Ovalau, and *N. f.*, rare on Vanua Levu but locally abundant on Koro, suggest that this is not a hard and fast rule for *Nesobasis*.

The data presented here greatly expand our knowledge on *Nesobasis* species distribution and abundance, particularly for Taveuni, Koro, Ovalau and Kadavu, four islands for which distribution and abundance data were not previously published. As indicated in BEATTY et al. (2007) the damselfly fauna of Fiji remains relatively unexplored. Indeed, in total, three species previously unknown to science resulted from our sampling (BEATTY et al., 2007 and data herein). It

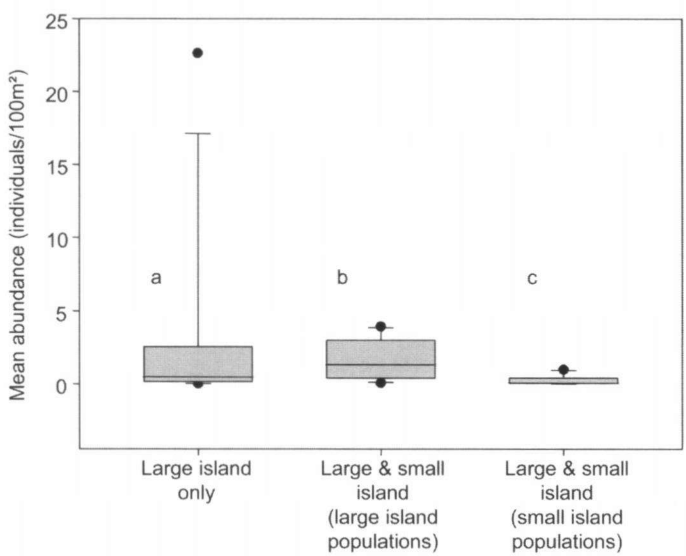

Fig. 4. Box and whisker plot of mean species abundances (individuals/100m²). Values are for (a) populations of species found only on one of the two large islands of Viti Levu or Vanua Levu (large island only), (b) large island populations of species found on the large islands and at least one small island, (c) small island populations. The dark line within the box represents the median, while the upper and lower boundaries of the box represent the 75th and 25th percentiles, respectively. The extent of the upper whisker represents the 90th percentile, while the extent of the lower whisker represents the 10th percentile. Dots represent any observations outside of these ranges. A non-significant trend is observed wherein species found on the large islands and at least one adjoining small island have higher abundances in large-island populations than those found only on the large island. Small island populations have consistently lower abundances than larger island populations.

would thus appear that the diversity and distribution of this group of endemic damselflies merits further study. We are hopeful that the unique fauna of the Fiji archipelago, as well as other island groups in the South Pacific, will continue to receive the attention of scientists, and that our understanding of species and ecosystems in this part of the world will continue to grow.

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