Journal of the International Dragonfly Fund

1-12

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published 28.12.2016

No. 18

ISSN 2195-4534

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Internet: http://www.dragonflyfund.org/

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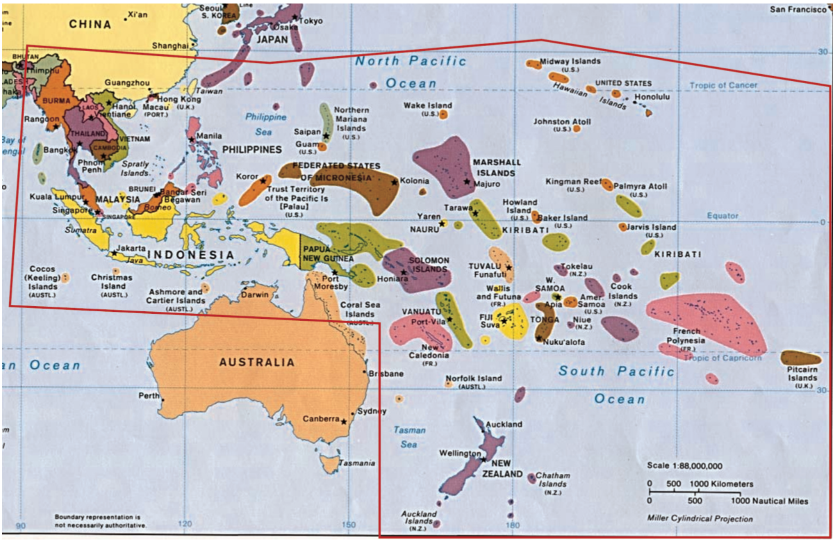

Editorial Work:	Martin Schorr, Milen Marinov and Rory Dow
Layout:	Martin Schorr
IDF-home page:	Holger Hunger
Printing:	Colour Connection GmbH, Frankfurt
Impressum:	Publisher: International Dragonfly Fund e.V., Schulstr. 7B, 54314 Zerf, Germany. E-mail: oestlap@online.de
Responsible editor:	Martin Schorr

Cover picture: *Pantala flavescens*

Photographer: Graham Reels

Published 28.12.2016

On a dragonfly collection from Nuku Hiva Island, Marquesas Islands and Paea, Tahiti (French Polynesia) with taxonomic discussion of some Polynesian genera (Insecta: Odonata)

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Abstract

A small collection of Odonata from Nuku Hiva Island, Marquesas Islands is presented. It adds *Anax guttatus* as a new species to this oceanic group. *Hemicordulia* sp. nov. is reported, but not described because the same species has been sampled before and is pending a formal description. A short taxonomic discussion on observed morphological similarity of male anal appendages in taxa presently assigned to *Amorphostigma*, *Hivaagrion* and *Ischnura* east of New Caledonia is provided. Important considerations for biogeography of the Pacific Odonata are discussed too.

Key words: Odonata, dragonflies, damselflies, Marquesas, Pacific Ocean, Coenagrionidae

Introduction

The Marquesas, an archipelago of French Polynesia comprising a dozen oceanic islands, is one of the most isolated in the world (Galzin et al. 2016). Adamson (1936) ranks it the third isolated island group after Hawaii and Easter Island. The remoteness of the islands have shaped a truly unique flora and fauna much of which is still under investigation and remains undescribed (Gillespie et al. 2008). Lorence et al. (2016) argue that despite their geographic isolation, relatively young geological age (between 1.1 and 5.5 My), small surface area (total of 1,050 km²) and height (highest summit at 1,276 m), the native (primary) vascular flora of the Marquesas is composed of approximately 332 taxa (313 species, 4 subspecies and 15 varieties), with 48% endemism. Marquesas shelter the most diverse assemblages of marine birds of the tropical South Pacific with 21 breeding species (Thibault et al. 2016). Terrestrial arthropods are characterised with both diversity and endemism with perhaps as many as 1,500 species in total (Roderick & Gillespie 2016). The young oligotrophic rivers harbour 17 freshwater fishes (nine endemic) and nine decapod crustaceans (one endemic) and are unique in having no introduced species (Keith & Sasal 2016). The herpetofauna is without endemism, but a finer scale analysis clearly shows genetic isolation of its populations and is also noteworthy by the higher density of several species which are rare at other places (Ineich 2016).

Aquatic macroinvertebrates on the Marquesas Islands are of particular interest for the absence of species from otherwise widely distributed orders such as Plecoptera, Ephemeroptera and Mecoptera (Adamson 1939). Aquatic Coleoptera are also not known while Trichoptera are represented with one still unidentified genus and species (Polhemus & Englund 2016). Remarkably the total aquatic communities of insects are represented mainly by members of two orders Odonata and Diptera with some Heteroptera living in the littoral zones of streams and rivers.

Generally Odonata species of the Marquesas Islands (as well as the whole of French Polynesia) have been understudied (Polhemus & Englund 2016). Until recently, information on arthropods (including Odonata) was largely confined to a series of articles published by the Bishop Museum (Honolulu), as a result of the Pacific Entomological Survey in the 1920s and 1930s (Gillespie et al. 2008). A more recent report on the freshwater entomological diversity on the Marquesas and Tahiti was published in Polhemus et al. (2000b). That report brings up very important discussion points on the taxonomy of *Hemicordulia* Needham, 1901 and the local endemic *Hivaagrion* Hämäläinen & Marinov, 2014. The latter is included in the report as *Bedfordia* Mumford, 1942, however Hämäläinen & Marinov (2014) demonstrated that this genus name has already been preoccupied by the name *Bedfordia* Fahrenholz, 1936 in Phthiraptera and suggested the replacement name *Hivaagrion*. Genus *Hivaagrion* is undergoing a taxonomic revision (Polhemus et al. 2000b) because it is supposed to be represented by endemic species especially at the higher altitudes with at least six new species strictly endemic to the islands of Eiao, Nuku Hiva, Hiva Oa and Ua Huka (Polhemus & Englund 2016). Therefore a detailed historic literature account of the Odonata fauna of the Marquesas, although of particular interest as it has never been done before, is beyond the scope of the current research. It will be postponed until after the completion of the revision of *Hivaagrion*.

Here we report on a small collection of Odonata from Nuku Hiva Island only. Faunistic data are analysed in conjunction with taxonomic information from other islands within French Polynesia and compared to endemic species on the neighbouring Samoan archipelago.

Material and Methods

According to Gazlin et al. (2016), the Marquesas Islands are located between 7°5' and 10°35' South latitude and 138° 30' and 140° 45' West longitude (Fig. 1). This Pacific group is the northernmost of the five archipelagos that make up French Polynesia and closest to the equator. Situated about 5,000 km from the continents, 4,000 km from the Hawaiian Islands and 1,400 km from Tahiti (Society Islands), the Marquesas

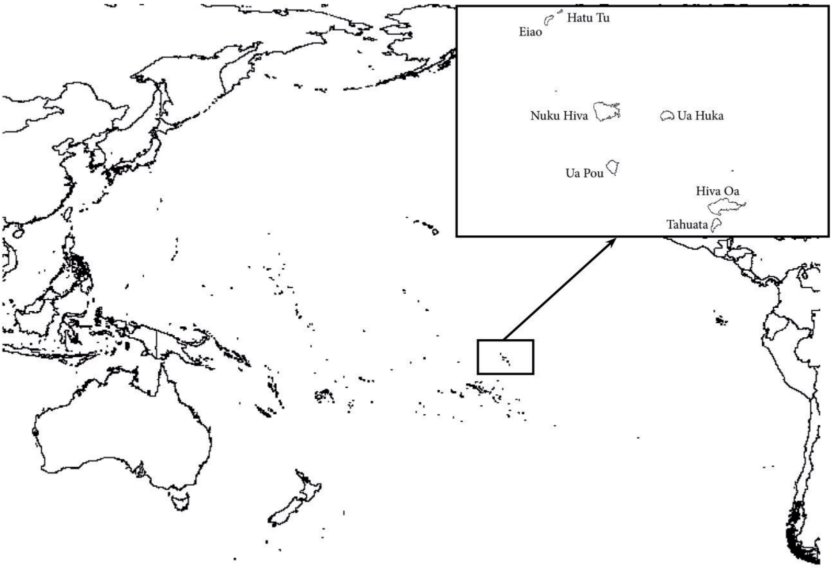

Figure 1. Geographic position of the island of Nuku Hiva and other Marquesas Islands. Inlet – Nuku Hiva and other major islands within the Marquesas.

archipelago is considered as one of the most distant from all continents and therefore the most isolated in the world.

Three geographic and geological groups can be distinguished: northern group (Eiao, Hatu Tu or Hatu Taa, the sandy islet of Motu One and the benches Jean Goguet and Clark which are shoals located respectively 30 and 10 m deep), one Central group (Nuku Hiva, Ua Pou, Ua Huka, Motu Iti or Haut Iti) situated about 90 km from the northern group, and a southern group (Fatu Uku, Hiva Oa, Moho Tani, Fatu Iva Islet of Motu Nao, the Thomasset rochet, the Dumont Durville highland) located about 110 km from the central group. The largest islands in the archipelago, which are Nuku Hiva with 340 km^2, and Hiva Oa with 315 km^2, each represent only one third of the surface of Tahiti (1045 km^2). The smaller ones include Motu One (0.5 km^2), Motu Iti (0.8 km^2), Fatu Uku (7.5 km^2), Hatu Tu (7.5 km^2) and Moho Tani (9 km^2).

Laurent (2016) identifies the climate on the Marquesas as low-moist tropical, an almost extra-tropical climate. Influenced by east trade winds and hot ocean waters, the average annual air temperature does not change much during the year and is usually between 25°C and 27°C. The rainfalls is mainly orographic. Annual precipitation varies from 927 mm in Hakahau located in the north of the archipelago to 2,227 mm in Vaitahu at the southern end. The atmospheric and oceanic conditions of the Marquesas Island do not generate are adverse at the processes of deep convection, hence the region exhibits scarce cyclonic activity. However, exceptionally, cyclogenesis conditions can be observed, for example in 1982-1983, generating an intense tropical cyclone. Finally, the Marquesan seasonal cycle looks to be influenced by the various phases of ENSO (El Niño Southern Oscillation) and IPO (Interdecadal Pacific Oscillation).

Keith & Sasal (2016) classify the rivers of the Marquesas into five zones according to the altitude and the speed of the current: - zone of the sources from 700 m, - superior course between 300 and 700 m, - average course between 100 and 300 m, - lower part of the rivers between 20 and 100 m, - lower course below 20 m. Their hydrology regime depends largely on rainfalls and varies between years (Fossati et al. 1994).

The material for this publication was sampled during the work on a programme to control the biting insect *Simulium buissoni* Roubaud, 1906 the results of which were reported in Fossati et al. (1998). Odonata specimens collected during that study were used only. A short faunistic list was prepared and comments given in relation to what is known so far for the Odonata species diversity of this Pacific archipelago. Specimens of the local endemic *Hivaagrion demorsum* (Needham, 1933) were compared with related species from the Pacific genera *Ischnura* Charpentier, 1840 and *Amorphostigma* Fraser, 1925. The taxonomic, faunistic and biogeographic implications were considered.

Below is a list of sampling localities for Odonata on Nuku Hiva Island reported here including a single locality on Tahiti Island:

Nuku Hiva Island

1. Pakiu ford, the main river close to the centre of Taiohae Village: 8.8965°S, 140.1036°W (02 March 1994).
2. Pakiu hose, upstream from the Taiohae Village: 8.8741°S, 140.1097°W (24 January 1991, 03-04 March 1994).
3. Walkway above Taiohae Village towards waterfall: coordinates not available (04 March 1994).
4. Vaipupui Village: 8.8893°S, 140.1418°W (07-08 March 1994).
5. Toovii, the main river course: 8.8899°S, 140.1643°W (08-09 March 1994).
6. Taipivai catchment area, upstream from Taipivai Village: 8.8649°S, 140.0780°W (04 March 1994).
7. Tcheko, road pass waterfall: 8.8716°S, 140.1100°W (04 March 1994).

Tahiti Island

8. Paea, Tahiti, 18.6 km south from Papeete: 17.6800°S, 149.5460°W (25 July 1994).

All specimens are deposited at the New Zealand Arthropod Collection (NZAC), Landcare Research, Auckland, New Zealand.

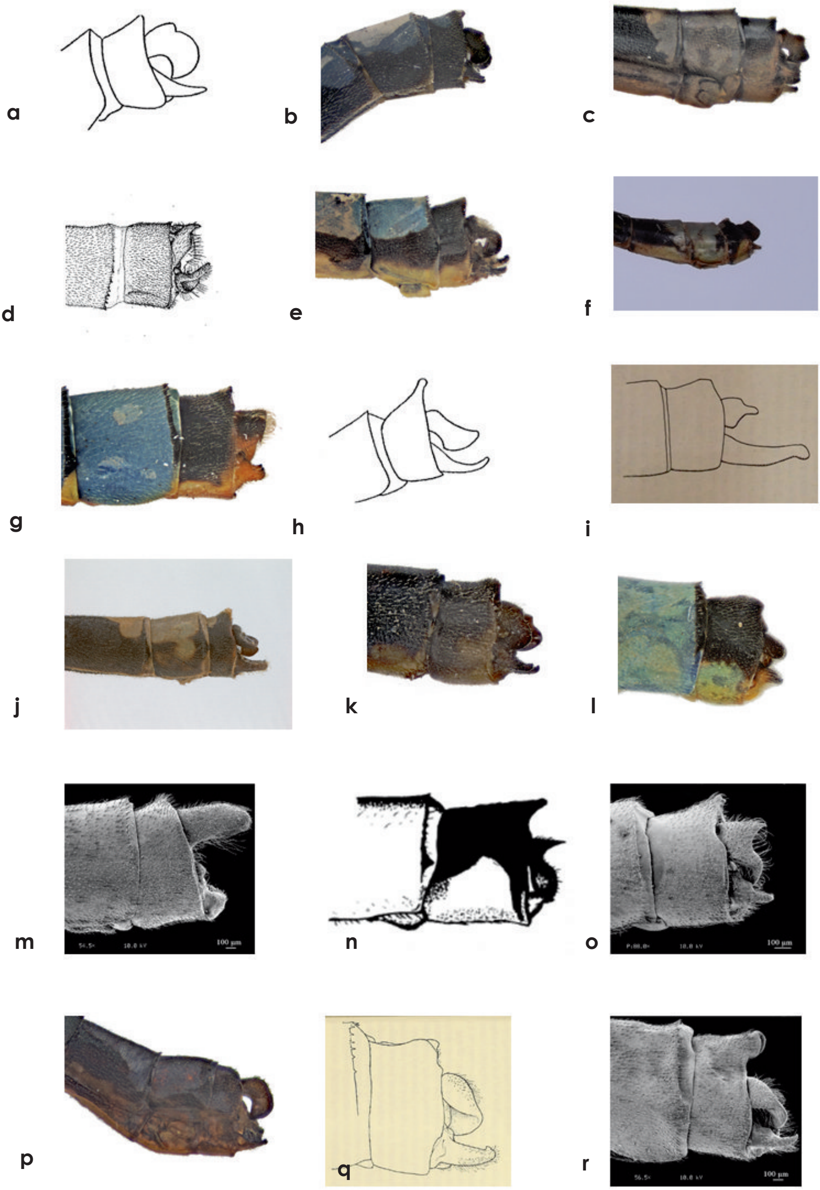

Figure 2. Lateral view of male appendages of species presently assigned to *Amorpho-stigma*, *Hivaagrion* and *Ischnura* east of New Caledonia. Original figures and photos of types from the Natural History Museum, London are used. Photos with not specified source were taken for this study: a) outlines of the general shape: example of *Isch-*

***nura haemastigma* (from Fraser 1927); b) *Amorphostigma armstrongi*; c) *A. auricolor*; d) *Hivaagrion halecarpenteri* (from Mumford 1942); e) *H. demorsum*; f) *Ischnura albistigma* (type); g) *I. aurora*; h) *I. buxtoni* (from Fraser 1927); i) *I. cardinalis* (from Kimmins 1929); j) *I. chromostigma* (type); k) *I. haemastigma*; l) *I. heterosticta*; m) *I. jeanyvesmeyeri* (from Englund & Polhemus 2010); n) *I. pamelae* (from Vick & Davies 1988); o) *I. rurutana* (from Englund & Polhemus 2010); p) *I. sanguinostigma*; q) *I. taitensis* (from Lieftinck 1966); r) *I. thelmae* (from Englund & Polhemus 2010).**

Results

Zygoptera

Coenagrionidae

Hivaagrion demorsum (Needham, 1933)

Localities: 1, 4

Figure 2 compares male appendages of selected Pacific Coenagrionidae so far assigned to three different genera: *Amorphostigma*, *Hivaagrion* and *Ischnura*. It includes all species described in those genera and reported for the Pacific region east of New Caledonia. Species not available for a direct comparison are represented with the original figures published with their descriptions. *Ischnura pamelae* Vick & Davies, 1988 is included too in spite of the poor quality of the original figure of the male appendages.

It is evident that several taxa follow a general scheme of the shape of the male appendages which is best illustrated in the original figure of *Ischnura haemastigma* Fraser, 1927 (Fig. 2a) published with the description of the species. Superior appendages in lateral view are broad, flat-shaped, twisted to concave with undulating outer dorsal edge and acutely pointed ventrally. Inferior appendages can be described as small horn-like with horizontally incurved tips and in most taxa are as long as the superior. Therefore, based on this character alone, species from three different genera (*Amorphostigma armstrongi* Fraser, 1925; *A. auricolor* Fraser, 1927; *Hivaagrion demorsum* (Needham, 1933); *Ischnura albistigma* Fraser, 1927; *I. buxtoni* Fraser, 1927; *I. chromostigma* Fraser, 1927; *I. haemastigma* Fraser, 1927; *I. rurutana* Englund & Polhemus, 2010; *I. sanguinostigma* Fraser, 1953; *I. taitensis* Selys, 1876; *I. thelmae* Lieftinck, 1966) appear to be closer to each other than to species presently assigned to the same genera, such as *Hivaagrion halecarpenteri* (Mumford, 1942), *Ischnura cardinalis* Kimmins, 1929 and *Ischnura jeanyvesmeyeri* Englund & Polhemus, 2010 (Fig. 2).

Hivaagrion demorsum is an endemic species to the Marquesas Islands previously reported by Needham (1933) and Polhemus & Englund (2016).

Ischnura aurora (Brauer, 1865)

Localities: 1, 4-5

Widespread species in the Pacific previously reported from Marquesas Islands by Cheesman (1927) and Mumford (1942).

Anisoptera

Aeshnidae

Anaciaeschna jaspidea (Burmeister, 1839)

Locality: 2

Widespread species in the Pacific previously reported from the Marquesas Islands by Polhemus et al. (2000b).

Anax guttatus (Burmeister, 1839)

Localities: not specified

First record for the Marquesas Islands.

Corduliidae

Hemicordulia sp. nov.

Localities: 3-5, 7

Four males were collected from each of the localities given above. These belong to an undescribed species already collected from the Marquesas (R. Garrison & D. Polhemus pers. comm.) which will be published separately by Dan Polhemus. Therefore the species is not illustrated here.

Libellulidae

Pantala flavescens (Fabricius, 1798)

Localities: 1, 5-8

Widespread species in the Pacific previously reported from the Marquesas Islands by Ris (1909-1919), Mumford (1942) and Polhemus et al. (2000b).

Discussion

The small collection of Odonata from Marquesas Islands presented here does not make a significant faunistic or taxonomic contribution. *Anax guttatus* is the only species reported as new to the archipelago, however this record is of no surprise knowing the wide species distribution and the fact that it was reported for the neighbouring island groups. Cheesman (1927) gives it as numerous on Tuamotu and Needham (1932) recorded it for the Society Islands.

The present paper calls for attention to be given to the taxonomy of particular Pacific genera: *Amorphostigma*, *Hivaagrion* and *Ischnura* species inhabiting the area east of New Caledonia. Various studies have employed cladistic analyses (morphological and molecular) to test the taxonomy of Coenagrionidae proposed by earlier researchers such as Fraser (1957) and Davies & Tobin (1984). O'Grady & May (2003) reassessed the subfamilies of Coenagrionidae based on 32 morphological characters. Their analysis included *A. armstrongi* within a clade with *Boninagrion ezoin* Asahina, 1952 and various *Ischnura* species occurring in Europe, Asia and North America.

Ischnura aurora was the only species in this analysis that is found in the Pacific. Karube et al. (2012) found great support by nuclear and mitochondrial genealogy for including *B. ezoin* within *Ischnura*, but could not resolve with strong support the relationships among *Ischnura*, *Amorphostigma* and *Pacificagrion* Fraser, 1926. The three genera appear to be closely related with *Amorphostigma* and *Pacificagrion* forming a separate clade based on the nuclear ITS1-5.8S-ITS2665 bp, while the mitochondrial 16rRNA and COI placed them in different parts of the phylogenetic tree. However, Dijkstra et al. (2014) made the suggestion to include *Amorphostigma* and probably *Pacificagrion* within *Ischnura* and this view has already been reflected in the World Odonata Checklist for convenience (Schorr & Paulson 2016). We think the decision of Dijkstra et al. (2014) is unfounded because of the obvious disparity between the results of the morphological and molecular studies. O'Grady & May's (2003) morphological study, although very detailed, worked on a coarser taxonomic resolution than the Karube et al. (2012) molecular analysis. The former investigated the relationships between *Ischnura* (from Europe, Asia and North America), *Boninagrion* and *Amorphostigma*, but did not include other closely related genera such as Pacificagrion, *Hivaagrion* or any of the *Ischnura* described from Samoa and French Polynesia. Karube et al. (2012) employed *Pacificagrion* in their study which resulted in different groupings of the taxa compared with O'Grady & May (2003). Obviously there is more work to be done on the taxonomy of the Pacific genera *Amorphostigma*, *Hivaagrion* and *Ischnura* species inhabiting the area east of New Caledonia.

Fifteen *Ischnura* species are known so far as validated from the Pacific (Schorr & Paulson 2016). The distribution of all but two was mapped in Marinov (2015). *Ischnura luta* Polhemus, Asquith & Miller, 2000 and *I. senegalensis* (Rambur, 1842) were excluded from this analysis which focused mainly on the endemic species at the eastern distribution range especially Samoa and French Polynesia. *Ischnura luta* is endemic to Rota Island, Northern Mariana Islands (Polhemus et al. 2000a) whereas *I. senegalensis* is a widely distributed species in SE Asia and also enters the Pacific where is so far known only from the Republic of Palau (Katatani & Muraki 1997). Marinov (2015) made a mistake including *I. spinicauda* (Brauer, 1865) as a separate species. This species name was proposed as a junior synonym of *I. aurora* by Papazian et al. (2007). All three taxa (*luta*, *senegalensis* and *spinicauda*) are not considered in the analysis below.

Marinov et al. (2015) commented on the morphological similarity of male appendages of *Amorphostigma* and Samoan plus French Polynesian species placed in *Ischnura*. They refrained from a thorough taxonomic discussion because of the lack of sufficient material and appealed for a wider analysis which will focus on morphological traits such as distance between occipital lobes of the head, projections on the mesostigmal plate, prenodal index in wings, spines on the hind femora and male anal appendages. Those were the ones suggested as some of the most important, however, a morphological analysis should include more structural feature from the entire body and must include the Marquesas Coenagrionidae taxa. As shown on Figure 2 male *H. demorsum* has appendages following the general shape of both *Amorphostigma* species and most of the *Ischnura* known from Samoa and French Polynesia. Considering this trait alone *H. halecarpenteri*, *I. cardinalis* and *I. jeanyves-*

meyeri are strikingly different from *A. armstrongi*, *A. auricolor*, *H. demorsum*, *I. albistigma*, *I. buxtoni*, *I. chromostigma*, *I. haemastigma*, *I. rurutana*, *I. sanguinostigma*, *I. taitensis* and *I. thelmae*. Donnelly (1986) and Marinov et al. (2015) suggested that species originally placed in Ischnura from Samoa might deserve a separate generic status. This hypothesis has never been tested because most of those species are known by type specimens only.

Such analyses will be important not only for establishing the faunal composition of the islands, but will be serving for testing biogeographic and evolutionary hypotheses. The remote islands within the Marquesas archipelagos have been used as models for various organism groups commented in Roderick & Gillespie (2016). They accepted that the fauna of the Marquesas Islands developed as a result of long-distance dispersal and has both western and eastern Pacific elements. Vicariance was ruled out and not discussed at all based on the presumably earlier evidences for the volcanic origin of the islands which have never been connected to other land masses (Gillespie et al. 2008). However, Heads (2012: 342-343) cites several studies in groups, such as fishes and passerine birds for example, for the possible vicariance origin of the Marquesas' fauna based on former biological connections within the region to the Hawaiian islands to north and southern islands of Society, Tuamotu, Austral, etc. The vicariance model was supported by both morphological and genetic evidences and therefore should be considered as possible in any further studies on the Marquesas Islands. The morphological similarity in the male appendages of species presently assigned to three different genera inhabiting remote islands like Samoa, Society, Austral and Marquesas is really remarkable and purports origin from a common widely distributed ancestor. However, this view is too premature at this stage when neither taxonomy nor phylogeny of the Pacific Coenagrionidae is close from completed.

Human mediated transport is another important point to consider in the Pacific island Odonata biogeography (Marinov 2015). The anthropogenic influence has been recognised as an important factor for the contemporary species distribution for oceanic islands in general (Gillespie 2007) and French Polynesian fauna in particular (Gillespie et al. 2008). Marinov (2015) demonstrated a possible anthropogenic impact on the faunal composition for New Zealand which is the only Pacific nation with very good historical records thanks to the studies of Dr John Armstrong. It is important to note that prior to the beginning of the XXth century possibly almost 100% of the New Zealand Odonata were endemic to a certain level – genus, species or some possible subspecies/forms that are still not well studied. Five wide spread species (four permanently established: *Ischnura aurora*, *Anax papuensis* (Burmeister, 1839), *Hemicordulia australiae* (Rambur, 1842), *Tramea loewii* Kaup in Brauer, 1866, and one: *Pantala flavescens* (Fabricius, 1798), found as occasional visitor) were reported as new to the country during the last 80-90 years. Therefore, researchers studying Odonata of New Zealand now and 100 years ago would have encountered different species assemblages and ended up with opposing biogeographic hypotheses if they did not consider the historical development of the local fauna. Without good historical records and with the lack of phylogenetic studies for the rest of the Pacific it is not possible to differentiate between natural distribution and human-mediated transport.

Acknowledgements

We are grateful for the scientific and technical advice, support and encouragement of: Rosser Garrison, Michael Heads, Haruki Karube, Oleg Kosterin, Jean-Yves Meyer, Dan Polhemus, Ben Price and Wolfgang Schneider.

Denis Gaschignard is thanked for collecting some of the Marquesan specimens.

Ian Endersby kindly provided help with the English proof reading.

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