Systematics expertise and taxonomic status of New Zealand's freshwater insects

Richard A.B. Leschen[1]*, Kevin J. Collier[2] , Russell Death[3] , Jon S. Harding[4], and Brian J. Smith[5]
[1]Landcare Research, New Zealand Arthropod Collection, Private Bag 92170, Auckland
[2]Environmental Research Institute, University of Waikato, Private Bag 3105, Hamilton 3240
[3]Institute of Agriculture and Environment, Massey University, Private Bag 11-222, Palmerston North 4442
[4]School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch, 8140
[5]National Institute of Water and Atmosphere Research, PO Box 11-115, Hamilton 3216

Introduction

Insects are important to ecosystem functioning in freshwater habitats. They have a rich diversity, fill every ecological niche, and as predators and scavengers and the prey of larger species, they play a vital role in nutrient cycling. There is no doubt that aquatic insects are under considerable threat in New Zealand (Grainger *et al*. 2014, Joy & Death 2014, Weeks *et al*. 2016, Collier *et al*. 2016). Some freshwater species are iconic to New Zealanders, like the ubiquitous sandflies with aquatic larvae (Craig *et al*. 2012), but also known to many systematists worldwide are New Zealand's endemic species, like the primitive dragonfly *Uropetala chiltoni* Tillyard (Petaluridae) or the ice worm *Zelandochlus latipalpis* Brundin (Chironomidae). To most biologists and almost any informed layperson, aquatic insects (along with a number of other invertebrates) are well-known biological indicators of water quality. The exact number of freshwater insects is unknown, but estimates range from 640–800 described species in New Zealand (McFarlane *et al*. 2010, Weeks *et al*. 2016). They exhibit intriguing adaptations to their stream environments that include symbiotic relationships (commensalism and phoresy) of chironomid midge larvae with mollusks, flies and mayflies (Forsythe & McCallum 1978, Winterbourn 2004, Cranston 2007), live birth (viviparity) in the caddisfly *Triplectides cephalotes* (Walker) (Pendergrast & Cowley 1966; Morse & Neboiss 1982) and adaptations to torrential water velocities (e.g. Blephariceridae) that make them interesting model organisms for ecological and evolutionary study (Buckley *et al*. 2015, McCulloch *et al*. 2016). New Zealand's long geographic isolation has led to high levels of regional and national endemism (Gibbs 2006), and biogeographic studies of aquatic insects have helped to reconstruct the geologic and climatic histories of New Zealand's ancient terrains and weathered landscapes.

Unwise land-use and water management (for example, inadequately responding to pressures from agriculture, mining and urbanisation) degrades water quality, alters flow regimes and disrupts connectivity within and among freshwater systems, all posing threats to New Zealand aquatic organisms. Concomitant with global climate change, a grim picture is emerging for the future of many aquatic organisms. Furthermore, introductions of alien species such as the mosquito fish *Gambusia affinis* (Baird and Girard) and the diatom *Didymosphenia* can markedly alter insect communities (e.g. Kilroy & Unwin 2011).

* Correspondence: LeschenR@landcareresearch.co.nz

Rich Leschen [top left] is a systematist at Landcare Research specialising in beetles (Coleoptera). His primary research is to describe New Zealand's beetle fauna and classify the species in global context to better understand their phylogenetic relationships, evolutionary history and ecology.

Kevin Collier [not pictured] is a freshwater ecologist with the Environmental Research Institute at the University of Waikato. He has spent over 25 years studying stream invertebrates and over this time has been involved in every assessment of aquatic invertebrate conservation status carried out in New Zealand.

Russell Death [top right] is a Professor in Freshwater Ecology in the Institute of Agriculture and Environment – Ecology at Massey University.

Jon Harding [bottom left] is a Professor of Freshwater Ecology at the University of Canterbury. He has been working on the effects of human activities on stream ecosystems for over 25 years and has conducted research in New Zealand, USA, Tonga, Singapore and Nigeria. He specialises on the ecology of stream invertebrates and is especially interested in regionally endemic freshwater species on Banks Peninsula.

Brian Smith [bottom right] is a freshwater entomologist at NIWA in Hamilton. He has over 22 years' experience in the taxonomy and ecology of aquatic insects particularly the winged adult stage. Brian's main research interest is the taxonomy of caddisflies but is also investigating the oviposition requirements of adult aquatic insects and how this knowledge can be applied to improving stream restoration success.

Aquatic ecosystems have a full range of microhabitats, such as this riffle in a high-energy stream that will be filled with insect predators, scavengers, scrapers, and filter feeders (photo by Crystal Maier).

Calls for mitigation to protect and conserve freshwater ecosystems and diversity via legislative action have been made (Peart & Brake 2013, Weeks *et al*. 2016) but knowledge from the natural sciences is often marginalised in such discussions (Dijkstra 2016) and, in New Zealand, the legislative process is complex and disjointed (Brown *et al*. 2015, Wallace 2016). Furthermore, the research focus and ecological understanding of many New Zealand aquatic insects is poor or absent, with nearly 90 taxa considered to be 'data deficient' (Grainger *et al*. 2014).

Taxonomy is one branch of the sciences that has been eroded by the lack of adequate funding. There is also general apathy towards the once-thriving discipline, partly perhaps due to molecular methodologies which some assume lessen the need for formal taxonomic description. Systematic studies now take a back seat to more lucrative and/or high-profile research; additionally invertebrates are less appealing than the larger fauna, which also hinders conservation and taxonomic work on invertebrates (Collier *et al*. 2016).

If we are to monitor the status of New Zealand freshwater species, identify factors that contribute to their decline or eventual extinction, or use them as proxies for water quality, investment in formal taxonomy for freshwater insects and other aquatic organisms is critical. Why? A valid, robust taxonomic name and description for a species underpins the language of biology. That Latin name gives an organism an identity that can be referred to across disciplines (and languages) and as a binomen it communicates its phylogenetic placement and location in classification, placing that species into a wider comparative framework for further study.

Since the dissolution of the Department of Scientific and Industrial Research (DSIR) and the formation of the Crown research institutes (CRIs), systematic studies of freshwater insects in New Zealand have been undertaken by a small community of freshwater ecologists and amateur researchers, keen to pursue these studies outside their core work or on personal time. But we are very concerned that the recent deaths and retirements of key workers will have a negative impact on the conservation, taxonomic and ecological studies of aquatic insects, one of many topics discussed during a recent meeting of New Zealand scientists concerned about the conservation of freshwater insects, held at Massey University. The systematics community has proposed a scheme to create a viable systematics future in New Zealand (Nelson *et al*. 2015), but here we focus on and briefly review the status of freshwater insect systematics research.

Taxonomic status and expertise

The insects of freshwater ecosystems represent most insect orders, including collembolans. The list of New Zealand's Insecta by McFarlane *et al*. (2010)* is more restricted to include 'aquatic' taxa, i.e. as those having one or all of their life stages living in the water. Arranged by numbers of species already known and estimates for the number of species remaining to be described or discovered are: Diptera (265 / unknown), Trichoptera (249 / 10–50), Plecoptera (120 / 20), Coleoptera (83 / 25**), Ephemeroptera (51 / 10), Odonata (15 / 0), and Neuroptera (5 / 0) with one species each in Megaloptera, Mecoptera, and Lepidoptera.

In New Zealand, there are currently no researchers at CRIs, public museums or universities who are employed *specifically* to monograph or revise freshwater insect groups, and many who have contributed are amateur workers (e.g. Winterbourn 2014). Tragically, the deaths of three diligent amateurs have left a large portion of the freshwater insect fauna without specialists: Ian McLellan (Plecoptera; unaffiliated [Patrick & Pawson 2009]), John Ward (Trichoptera; Canterbury Museum [Patrick 2016]), and Keith Wise (Neuroptera, Megaloptera, Trichoptera; Auckland Museum; [Early 2012]). Terry Hitching, an amateur ephemeropterist, continues his work, but the systematics research on freshwater insects has significantly slowed.

There are freshwater ecologists in New Zealand who have extensive taxonomic knowledge and have contributed occasionally to the systematics of freshwater insects (e.g. Ian Henderson, Trichoptera and other groups; Ian Boothroyd, Chironomidae) and to the New Zealand Threat List for freshwater insects (Grainger *et al*. 2014). Also, immature stages of most freshwater insects can be identified to genus-level using the keys in Winterbourn *et al*. (2006) and the online resources by the late Stephen Moore (2013) and NIWA staff (Anon. 2016). However, as for most insects, accurate species identification requires examination of the genitalia of mature adult males and comprehensive knowledge of faunas outside of New Zealand.

* McFarlane et al. (2010) also included Phthiraptera (47 spp.) in their tabulation of aquatic species, but these vertebrate parasites are excluded here (Ricardo Palma, New Zealand's specialist, recently retired from Te Papa, but continues his work).

** R. Leschen (unpubl. estimate of new species of Dytiscidae, Hydraenidae, Hydrophilidae, and Elmidae).

An adult caddisfly (Trichoptera), ***Oeconesus maori*** **McLachlan, one of few species with a larva that eats wood (photo by Brian J. Smith).**

Unfortunately, systematics research that is required to identify, and therefore help conservationists save vanishing species, is very limited.

Freshwater insect systematics at the 11th hour

The world is undergoing an unprecedented biological crisis (Wilson 1985; Dudgeon *et al*. 2006). Society is faced with ethical, practical, and economic decisions that balance the decline of natural environments with economic gain. The description and naming of New Zealand freshwater biota is particularly critical because much of the diversity has not been formally described, their geographic distributions have not been fully mapped, and their ecologies little understood or documented. Despite relatively strong programmes in freshwater ecology at five New Zealand universities, there is no formal training in taxonomy in any New Zealand institute, and emerging students lack understanding of the basic practice of the naming of species, classification, and comparative biology. While taxonomy underpins biological thought and communication how can freshwater insect taxonomy proceed without local expertise?

Dispensing with formal taxonomic names or providing informal names for species awaiting description has several drawbacks (Leschen *et al*. 2009); as does recognising species based solely on genetics. DNA-based studies, for example, may help reconstruct phylogenetic relationships, identify geographic limits of populations and corroborate species status, but morphological characters are needed to identify the organisms of interest. Without formal taxonomic treatment of species, the biological status of informally recognised entities is vague, and adds to uncertainty of their conservation status.

Insect-based indices of aquatic ecosystem health are based on measures that condense taxonomic information to individual metrics and require, at best, genus-level identifications. The Macroinvertebrate Community Index (MCI) (Stark 1985, Stark *et al*. 2001) is limited for insect conservation because it does not differentiate between threatened and common species that occur within a genus or higher levels of taxonomy for some groups. Furthermore, most of the national water quality monitoring with the MCI is focused on waterways that are already severely degraded by anthropogenic impacts and thus unlikely to provide refugia for rare or threatened species. The water quality monitoring also focuses on the in-stream larval stage that is often more difficult to differentiate into species level classification necessary to find rare species. In the environmental assessment for the proposed Mokihinui River dam no species of conservation interest were found with MCI sampling until a taxonomic expert collected and examined adult insects, whereupon nearly a dozen new species to science were discovered (Death 2012).

What is or can be done about the taxonomic impediment for freshwater insect studies? Despite the attraction of economically driven research, some ecologists have and continue to contribute to taxonomic studies either by undertaking targeted taxonomic research or via collaborations in their spare time (examples given above). Studies on aquatic hydreanid beetles by Juan Delgado, a beetle specialist in Spain, and Ricardo Palma, a New Zealand entomologist, and on elmid beetles by Paul Lambert, a technician at NIWA, Crystal Maier (Field Museum of Natural History, Chicago), and one of us (R. Leschen) are two examples of crossover research that could effectively close some of the taxonomic gaps in some freshwater groups. While taxonomy based solely on genetics is problematic (e.g. Collins & Cruickshank 2013), joint work between technologists and naturalists could address specific taxonomic issues, like some of the work we have been involved with (e.g. Hogg *et al*. 2009). However, such work is piecemeal and lacks cohesive national-level strategy.

The larva of the caddisfly (Trichoptera), ***Pycnocentrodes aureolus*** **McLachlan, builds a case of minute sand grains held together by silk spun from special glands in the head, and is further weighed down by a lateral line of larger sand grains (photo by Brian J. Smith).**

Future freshwater systematics

Freshwater research is vibrant in New Zealand, not only as an academic pursuit, but fuelled by the necessity for monitoring the health of the environment. If focus can expand to include taxonomic studies that contribute to the conservation of our unique and ancient insect faunas, the benefits would be far-reaching. As it stands, the ratio of species knowledge to environmental decay may be skewed towards extinction for some species, and we can only hope that protection of umbrella species, such as mudfish or blue duck, will have flow-on effects for freshwater invertebrates. Meanwhile, freshwater insect taxonomy may continue at a snail's pace and remain an after-hours activity for crossover researchers. Our hope is that the tide will turn for the environment and that the need for freshwater insect systematics capacity will be realised in New Zealand, especially for larger groups that presently lack expertise, despite the erosion of funding and perceived lack of relevance by some agencies. In the past, the New Zealand Freshwater Sciences Society used to run taxonomic fairs where people could bring species to experts for identification, but this may be no longer feasible without expertise existing for some groups. Empowerment of enthusiastic amateurs and scientists to share their zest for aquatic insects by engaging the public and participating in local surveys or Bioblitz will be central to raising general awareness of stream insect biodiversity.

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An adult beetle (Coleoptera), ***Hydora musci*** **Lambert, Maier & Leschen which is semi-aquatic as an adult and its larvae are associated with mosses at the edge of streams (photo by Crystal Maier).**

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