Belize

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1.1. Abstract

Belize is a small, highly forested Caribbean country located in Central America. It is subtropical and has numerous terrestrial ecosystems and protected areas distributed across four distinct geographical regions that include the northern lowlands, the coastal plain, the offshore cays and atolls, and the Maya Mountains. Along with their transboundary portions, the country's 16 major watersheds cover more than twice Belize's land territory; these watersheds ultimately drain into the Caribbean Sea. Knowledge about the macroinvertebrates of Belize is relatively poor with little information about most groups, although some of the important Dipteran human disease vectors are better known. A checklist that summarizes published and grey literature for many of the macroinvertebrate groups has been compiled, but an in-country centrally curated taxonomic collection remains a pressing need. Few ecological studies have focused on the composition, structure and factors controlling freshwater macroinvertebrate assemblages but the limited studies undertaken indicate lotic communities are dominated by an insect taxon comprised of a rich Ephemeropteran, Dipteran, Trichopteran and Coleopteran fauna. There is also some evidence of wet/dry seasonality in macroinvertebrate assemblages in Belize and geological influence has been identified as an important determinant of community composition in southern streams. The most important threats to freshwater systems in Belize include deforestation for agriculture, other impacts of agriculture, and climate change. Although there are no specific conservation efforts for macroinvertebrates, Belize's national protected areas system serves a major role in the conservation of freshwaters. Knowledge about the response of macroinvertebrates to environmental change associated with natural and human disturbance is very lim-

* Este capítulo está escrito en inglés por ser el idioma oficial en Belice

ited, but recent research indicated the potential utility of family-level macroinvertebrate metrics for monitoring large-scale effects. Through enactment of the National Integrated Water Resources Act, Belize has recently consolidated legislation for the use and protection of freshwater resources and begun the process of coordinating associated regulatory processes. This legislation as well as the National Biodiversity Monitoring Program being developed as part of the implementation of the National Protected Areas System Plan provides the framework for the use of macroinvertebrates as bioindicators. Significant research and work is still needed in Belize in the areas of macroinvertebrate taxonomy, natural history, ecology and their utility for bio-assessment. However, with a now established Environmental Research Institute at the national University of Belize, improved frameworks for coordinated, collaborative research efforts and capacity building, and the continued commitment and interest of natural resources managers across Belize, there has never been a more opportune time to advance macroinvertebrate knowledge and use for the sound management of Belize's freshwater resources.

1.1. Resumen

Belice es un pequeño país caribeño, con grandes recursos forestales, ubicado en América Central. Presenta un tipo de clima subtropical, con numerosos ecosistemas terrestres y áreas protegidas, distribuidas en cuatro distintas regiones geográficas, que incluyen las tierras bajas del norte, la llanura costera, los cayos y atolones, y las Montañas Mayas. A lo largo de su territorio transfronterizo, se encuentran las 16 principales cuencas del país, de un tamaño dos veces mayor al territorio de Belice y que desembocan en el mar Caribe. El conocimiento sobre los macroinvertebrados dulceacuícolas de Belice es relativamente pobre, con poca información sobre la mayoría de los grupos, aunque se ha puesto atención a algunos de los dípteros vectores de enfermedades humanas importantes. Se cuenta con un listado que resume la literatura publicada y gris para muchos de los grupos de macroinvertebrados, pero a la fecha se carece de una colección taxonómica representativa del país lo cual sigue siendo un tema apremiante. Pocos estudios ecológicos se han centrado en la composición, estructura y factores que controlan los ensambles de macroinvertebrados de agua dulce, pero los limitados estudios realizados indican que las comunidades de ambientes lóticos están dominados por una rica fauna de Epheme-

roptera, Diptera, Trichoptera y Coleptera. También hay alguna evidencia del efecto de la estacionalidad húmedo / seco en el ensamblaje de los macroinvertebrados y la influencia geológica ha sido identificada como un factor determinante de la composición de la comunidad en los arroyos del Sur. Las amenazas más importantes para los sistemas de agua dulce en Belice incluyen la deforestación con fines de cambio de uso de suelo, impactos por la agricultura y el cambio climático. Aunque no existen esfuerzos de conservación específicos para los macroinvertebrados, el Sistema de Áreas Protegidas Nacionales de Belice juega un papel importante en la conservación de las aguas dulces. El conocimiento sobre la respuesta de los macroinvertebrados a los cambios ambientales asociados a las perturbaciones naturales y humanos es muy limitado aún, pero la investigación reciente indica la posible utilidad de las métricas de macroinvertebrados a nivel familia para el seguimiento de los efectos a gran escala. A través de la promulgación de la Ley Nacional Integrada de Recursos Hídricos, Belice ha consolidado recientemente una legislación para el uso y la protección de los recursos de agua dulce y comenzado el proceso de coordinación de los procesos regulatorios asociados. Esta legislación, así como el Programa Nacional de Monitoreo de Biodiversidad se están desarrollando como parte de la implementación del Plan de Nacional de Áreas Protegidas el cual proporciona el marco para el uso de macroinvertebrados como bioindicadores. Es un hecho que en Belice aún hace falta mucha investigación y trabajo en las áreas de la taxonomía de macroinvertebrados, historia natural, ecología y su utilidad para la bioevaluación. Sin embargo, con el establecimiento del Instituto de Investigación Ambiental de la Universidad Nacional de Belice, se cuenta con una estructura de esfuerzos coordinados de investigación en colaboración así como de desarrollo de capacidades, que permitirán mantener un compromiso e interés continuo en la conservación y manejo de los recursos naturales de Belice, y con ello la oportunidad de avanzar en el conocimiento de macroinvertebrados y su potencial uso para la gestión racional de los recursos de hídricos de Belice.

1.2. Introduction

Belize is the second smallest country in the Central American mainland and Mesoamerica, its land territory covering 22,966 km^2. It is located below the Yucatán Peninsula, shares its northern border with Mexico and its western and southern borders with Guatemala, while the Caribbean Sea sweeps its approximately 386 km of coastline along the east. Based on this latter feature as well as the cultural, political and economic history it shares with other former British colonies in the region, Belize is also recognized as part of the Caribbean (Kay and Avella 2010). Like the rest of the region, Belize has an overall subtropical climate. The months of November to January usually represent the coolest period of the year, while May to September represent the warmest period (Wright *et al.* 1959). There is wide variation in temperatures throughout the year and by district. However, mean annual temperatures range from 21-27 °C, with the lower mean annual temperatures experienced at higher elevation areas of the Maya Mountains, and the higher mean annual temperatures experienced on the coast. Although it is generally hot throughout the year, temperatures can cool off considerably due to "northers" or "nortes", which are weather systems that only last a few days (Bridgewater 2012).

Annual precipitation also varies widely across the country, with up to a fourfold difference in rainfall from the drier north to the wetter south (Bridgewater 2012). WorldClim data for Belize that represents interpolations of observed data from 1950-2000 shows a historical mean annual rainfall of 1,750 mm and an annual precipitation range of 1,051-4,126 mm (Cherrington *et al.* 2014). The country experiences a fairly marked dry season that lasts 3-4 months, usually February to May, in the northern part of the country, but usually less in the south; the onset of the dry season varies from year to year (Wright *et al.* 1959). Weather patterns in Belize can also be strongly influenced by Atlantic tropical storms and hurricanes to which the country is subject every few years. Based on records from the National Hurricane Center of the National Oceanic and Atmospheric Administration (NOAA), at least 16 hurricanes and just as many tropical storms have affected Belize since 1930. Hurricanes and storms not only influence weather patterns in Belize but are major forces influencing the structure and composition of Belize's ecosystems.

Belize has an estimated 85 terrestrial ecosystems that span several forest, savanna and swamp vegetation types and are distributed across four distinct geographical regions: the northern lowlands, the coastal plain, the offshore cays and atolls, and the Maya Mountains and their foothills. The northern lowlands are characterized by broadleaf forest over limestone and pine savanna on sandy soils; wetland swamps, and low gradient, slow flowing freshwater rivers and lagoons are also common to this region (Bridgewater 2012). The Crooked Tree Wildlife Sanctuary, one of two wetlands of international importance forms part of this geographical region. The coastal plains are formed from erosional rock deposits from the Maya Mountains and are usually covered by pine savanna; mangrove forests characterize the coastal edge of this region (Bridgewater 2012). Belize's second Ramsar site, the Sarstoon Temash National Park is located within the coastal plains. At least 15 minor watersheds drain parts of this geographical region (Boles *et al.* 2008). The offshore cays and atolls form part of Belize's Barrier Reef System, which contains the longest barrier reef in the Western Hemisphere extending for 280 km and covering an estimated area of 1,400 km^2 (McField and Bood 2007). Sandy cays and mangrove forests characterize this region. Finally, the Maya Mountains region is characterized by montane and submontane broadleaf forest over soils derived from sedimentary, igneous and metamorphic rocks. The western part of the Maya Mountains is characterized by rolling karst hills

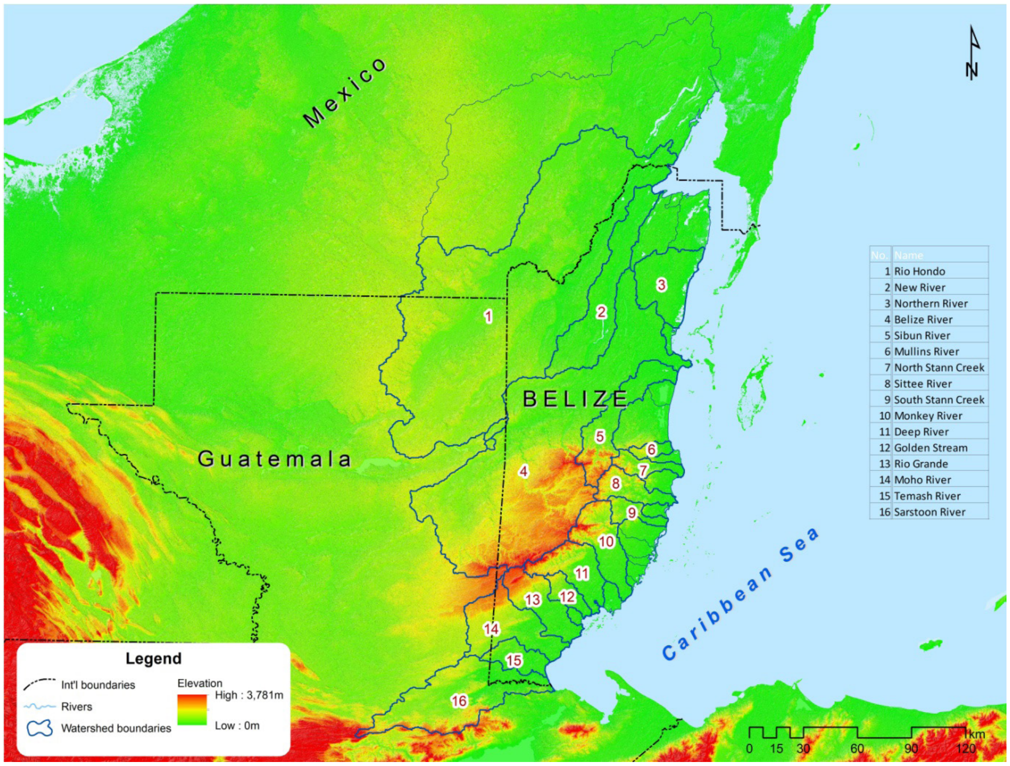

Figure 1: Major watersheds of Belize including transboundary areas (Prepared by Emil Cherrington)

and a vast network of subterranean caves. The Mountain Pine Ridge, an upland savanna is also part of this geographical region. Overall, the Maya Mountains geographical region is of primary importance to maintaining the health and integrity of Belize's freshwater resources, as this is where the headwaters for most of Belize's central and southern watersheds originate (Boles *et al*. 2008).

The central and southern watersheds comprise all but three of Belize's 16 major watersheds (Figure 1). Several of these watersheds, namely the Rio Hondo, Belize River, Moho River, Sarstoon River and Temash River watersheds, include transboundary sections in Mexico and/or Guatemala (Figure 1). In their entirety, the major watersheds of Belize cover an overall area of 47,393 km^2 or just over twice Belize's land area (Cherrington *et al.* 2014), and are part of a regional drainage system of approximately 50 principal watersheds that discharge into lagoons connected to the Caribbean Sea (Boles *et al*. 2008). Belize is at the geographical center of a drainage basin that directly or indirectly affects the Mesoamerican Barrier Reef System (MBRS). Apart from the major watersheds, Belize also has a series of small coastal tidal creek watersheds. With the exception of one small section of land in the Maya Mountains, all of Belize's watersheds flow into the Caribbean Sea. The rivers associated with Belize's watersheds are only one part of an estimated 4,000 permanent and seasonal water bodies throughout the country that also include karstic lakes, oxbow lakes, abandoned channels, freshwater lagoons, wetlands, swamps and brackish water marshes (Boles *et al.* 2008). These water bodies have been characterized into four ecological drainage units and 46 aquatic ecosystems on the basis of variation in major abiotic conditions, such as salinity and altitude, which are considered important drivers of biological variation (Esselman *et al.* 2005). The diversity of aquatic ecosystems generally increases along a gradient from north to south reflecting the environmental heterogeneity present in the central and southern regions, particularly in geology and topography (Esselman *et al.* 2005).

While the aquatic ecosystems of Belize are numerous and diverse, and there have been some advances in freshwater research in the country since Esselman and Boles (2001) reviewed the status and future needs of limnological research in the country, many gaps still exist, particularly regarding macroinvertebrates. Research on Belize's freshwater resources remains a priority, as highlighted in the National Environmental and Natural Resources Management Research Agenda (University of Belize Environmental Research Institute 2010 and 2014).

1.3. State of knowledge about the freshwater macroinvertebrates of Belize

Knowledge about the presence and distribution of macroinvertebrates of Belize is poor relative to that held for many other countries in Central America. While collections have been made from freshwaters in Belize since at least the turn of the 20^{th} century, few of the groups have been studied systematically: comprehensive countrywide reviews do not exist for any of the major taxonomic groups, although reviews have been completed for some individual families (see below). There is little if any published information about the Annelida, Blattodea, Collembola, Lepidoptera, Neuroptera, Nematoda, Nematomorpha, Orthoptera, Platyhelminthes or Trombidiformes (Hydrachnidia). Of the groups that have attracted research attention, the Diptera that are important vectors of human disease have been considered most thoroughly, along with the Odonata and byrrhoid Coleoptera. Important contributions to the accumulated knowledge of a variety of groups in Belize have been made as a result of the collecting campaigns undertaken at the beginning of the 20^{th} century by J. J. White and since the 1970's by William Shepard and Vincent Resh. More recently, collections have been made by Robert Sites, David Baumgardner, Ed Boles and Rachael Carrie, whose multi-taxon material variously awaits examination, is under examination or has been deposited in entomological collections primarily in the United States and United Kingdom.

1.3.1. Taxonomic studies

Summarized below is information available for each of the major taxonomic groups. While few comprehensive reviews of the macroinvertebrates of Belize exist, a checklist that summarizes published and grey literature for many of the groups has been compiled (Carrie 2014). Unless otherwise stated, the quantification below of known taxa within each of the major taxonomic groups reflects information contained within this checklist and it should be consulted for a full list of relevant works. It is important to note, that this checklist is an evolving resource and not an exhaustive review of the literature.

Phylum Nematoda – Knowledge about nematodes associated with freshwaters in Belize is very scarce. While this group has been encountered as prey items of fish and crocodiles during gut analysis (Stafford *et al.* 2003, Cochran 2008), and *Paratrichosoma* spp has been observed parasitizing the ventral scales of the latter (Stafford *et al.* 2003, Tellez and Paquet-Durand 2011), there have been no systematic studies of this group.

Phylum Nematomorpha – Only one nematomorph species has been reported in Belize, *Neochordodes chordodides*, from a total of 22 species known from Central America (Schmidt-Rhaesa and Menzel 2005).

Phylum Platyhelminthes – Although this group is often observed in freshwaters in Belize, published information is limited to the distributional records of Planariidae in the south of the country (Carrie *et al.* accepted).

Phylum Annelida – Information about annelids associated with freshwaters in Belize is scarce. Hirudinea belonging to the Glossiphoniidae family have been reported (Carrie *et al.* accepted), and members of Oligochaeta and Polychaeta have been observed (Boles 1998, Carrie *et al.* accepted). However, with the exception of two species (*Limnodrilus bulbphallus* and *L. profundicola*) reported by Block and Goodnight (1972) there appears to be no published information about the generic or specific identity of the annelids associated with the freshwaters of Belize.

Filo Arthropoda

Subfilo Chelicerata

Clase Arachnida

Orden Trombidiformes – (Hydrachnidia) – Water mites have been encountered in streams during surveys in southern Belize (Carrie *et al.* accepted) and have been recorded as prey items during gut analysis (Greenfield *et al.* 1983, Cochran 2008). Yet, there are no published records detailing the identity of water mites present (Goldschmidt 2007).

Subphylum Crustacea

Class Ostracoda – Ostracodes have been encountered in freshwaters in Belize (Greenfield *et al.* 1983, Carrie *et al.* accepted). While they have not been systematically studied, Perez *et al.* (2011) listed 29 species collected from freshwater and brackish habitats in and around the Yucatán peninsula, including five freshwater sites located in northern Belize.

Class Malacostraca

Order Amphipoda – Records exist for marine members of this group. However, there are no known published freshwater records for Belize.

Order Isopoda – 'Isopoda' was noted as observed during research in the Sibun River (Boles 1998), but there are no known published freshwater records for Belize.

Order Decapoda – Records have been found in the literature for two families of shrimp in Belize: Atyidae and Palaemonidae. The latter includes the troglobitic shrimp *Macrobrachium catonium* (Hobbs and Hobbs Jr. 1995) while for the Atyidae, *Potimirim mexicana* was recorded in the 1950s (Holthuis 1954). One crab family, Pseudothelphusidae, has been reported in the literature, comprising records of two troglobitic crabs: *Potamocarcinus aspoekorum* (Hobbs 1994) and *Typhlopseudothelphusa acanthochela* (Rodriguez and Hobbs Jr. 1989). Like both shrimp families, crabs are commonly encountered during stream surveys but their identity does not appear to have been documented at a resolution finer than family-level (Boles 1998, Carrie *et al*. accepted). The invasive crayfish *Procambarus clarkii* has also been noted as present in Belize (Hernandez *et al.* 2008) and records of the native crayfish *Procambarus pilosimanus* exist for surface waters and caves (Hobbs 1994).

Subphylum Hexapoda

Class Collembola – Although this group has been encountered during research in streams (Carrie *et al.*, accepted), published details of generic and species identity appear restricted to a few non-aquatic troglobitic species (Soto-Adames and Taylor 2013).

Class Insecta

In the grey and published literature, there are records of 79 families in ten orders of insects associated completely, or partly, with freshwaters in Belize (as listed in Carrie 2014). The Odonata are probably the best documented. The most diverse orders are the Diptera, Coleoptera, Trichoptera and Odonata.

Order Ephemeroptera – Existing knowledge about the Ephemeroptera of Belize is not well-documented. McCafferty (1984) published one of the first Ephemeropteran records, but a comprehensive countrywide review has yet to be published. At present, formal records exist for eight families (Baetidae, Caenidae, Euthyplocidae, Heptageniidae, Isonychiidae, Leptophlebiidae, Leptohyphidae and Polymitarcyidae), comprising 18 genera and 23 species (McCafferty and Jacobus 2014). Of these, one is endemic: *Latineosus cayo* was first collected by David Baumgardner in the Cayo District in Central Belize (Sun and McCafferty 2008) and *Latineosus* sp. has subsequently been collected from a number of streams in the south of the country (Carrie 2014). At least two additional families (Oligoneuriidae and Siphlonuridae) and more than nine additional genera have been collected during research in Belize (Boles 1998, Carrie 2014). A comprehensive review of the Ephemeroptera is currently underway. It includes specimens taken across the country by numerous collectors since the 1970's and it will significantly increase the published number of taxa known from the country.

Order Odonata – Knowledge about the Odonata is probably the best documented of all of the freshwater insects, thanks primarily to the research of Tineke Boomsma and Sidney Dunkle who extended the work of J.J. White in the 1930's, and subsequent research undertaken during the 1980's and early 1990's (see Boomsma and Dunkle 1996 and references therein). Boomsma and Dunkle's comprehensive study (1996), listed 67 Zygopteran and 107 Anisopteran species in 63 genera. Subsequent work and revisions to nomenclature have raised the current species count to 181. These species represent 64 genera in twelve families (Aeshnidae, Gomphidae, Libellulidae, Calopterygidae, Coenagrionidae, Lestidae, Megapodagrionidae, Perilestidae, Platystictidae, Polythoridae, Protoneuridae and Pseudostigmatidae), of which the Libellulidae and Gomphidae are the most diverse. Two gomphid species are endemic to Belize – *Erpetogomphus leptophis* and *Epigomphus maya*. Since records of Corduliidae exist in the grey literature (Boles 1998), this family count may be increased if and when retained specimens are confirmed. It is important to note that many of the extant Odonate records for the country relate to adult forms, and in some cases the larvae have yet to be described.

Order Orthoptera – Orthoptera have been collected from marginal habitats during freshwater surveys (Boles 1998, Carrie *et al*. accepted). Yet, while numerous records exist for terrestrial members of this group, a solitary *Cornops aquaticum* collected in 1968 from the Stann Creek, appears to be the only aquatic species-level information published (Adis *et al*. 2007).

Order Plecoptera – *Anacroneuria* (Perlidae) is the sole generic member of this group present in Belize. Stark and Kondratieff (2004) listed five species records collected between 1960 and the 1990's, many by William Shepard, after whom one species - *Anacroneuria shepardi* is named. The total number of records almost certainly reflects limited sampling effort and taxonomic attention, rather than a paucity of diversity. Furthermore, as for the Odonates, knowledge of most of the species recorded as present is limited to their aerial forms, which have not been related to aquatic life-stages (Stark and Kondratieff 2004).

Order Blattodea – Individuals from this group have been encountered in forested streams in southern Belize (Carrie *et al*. accepted). However, there appears to be no published information about the identity of freshwater associated species for the country.

Order Hemiptera – Existing knowledge about the Hemiptera of Belize is not well-documented. Fragmented records (grey and published) have been found for 18 genera in 11 families (Belostomatidae, Corixidae, Gelastocoridae, Gerridae, Hydrometridae, Mesoveliidae, Naucoridae, Nepidae, Notonectidae, Potamocoridae and Veliidae). Nine species-level records have been published of which two describe Hemiptera endemic to Belize: *Rhagovelia chac*, a Veliid bug (Polhemus and Chordas 2010) and *Potamocoris isbiru* a bug in the family Potamocoridae which resulted in the synonymization of the two known genera *Potamocoris* and *Coleopterocoris* (Polhemus and Carrie 2013). The earliest collections appear to have been made at the turn of the 20th century (for Hydrometridae) (Drake and Lauck 1959), and a number of genus-level observations have been made as a result of incidental collections during studies of other macroinvertebrate groups (Spangler and Santiago-Fragoso 1992). Although a comprehensive countrywide review of the aquatic Hemiptera has not been completed, a species-level review of the Naucoridae and Potamocoridae of Belize is underway, and it will include new species descriptions.

Order Coleoptera – Published records for aquatic Coleoptera in Belize are scattered, but records have been found in the grey and published literature for 14 families (Dryopidae, Dytiscidae, Elmidae, Eulichidae, Gyrinidae, Hydrophilidae, Limnichidae, Lutrochidae, Sphaeriusidae, Noteridae, Psephenidae, Ptilodactylidae, Scirtidae and Staphylinidae), 29 genera and around 34 species. Additional records include as yet undescribed species and genera. While a systematic countrywide review of the aquatic Coleoptera has not been completed, important contributions to knowledge about Elmidae have been made by Paul Spangler and colleagues (Spangler and Perkins 1989, Spangler and Santiago-Fragoso 1992), and by William Shepard whose collections between the early 1990's and the present have also resulted in a review of the Dryopidae, Lutrochidae, Psephenidae and Ptilodactylidae (Shepard 2004). Most recently, Shepard's collections have enabled the description of new Psephenid genera and several new species, including *Belicinus rhomboideus* (Arce-Perez *et al.* 2012), *Psephenops spiniparameri and Psephenops shepardi* (Arce-Perez and Novelo-Gutierrez 2013) –which occur throughout Belize.

Order Neuroptera – Published information about this group is scarce for Belize. One solitary species-level record for *Sisyra nocturna* has been found in the literature (Flint Jr and Mathis 2006).

Order Megaloptera – Corydalidae is the sole representative of this group in Belize. Published records exist for one species, *Corydalus luteus* (Contreras-Ramos 2011). While formal records have not been published for *Chloronia,* larvae from the genus have been collected during research in the south of the country (Carrie 2014).

Order Trichoptera – The Trichoptera of Belize are very poorly known. Species records are scattered and a comprehensive review of existing literature and as yet unexamined specimens is long overdue. The Hydroptilidae has received perhaps the most research attention (Kelley 1983, Bueno-Soria and Santiago-Fragoso 1997, Flint *et al.* 1999, Keth 2003) and as a result, the ten species of this family listed for Belize account for 1/3rd of all species-level Trichoptera records. Only around 30 species, in 18 genera and 11 families (Calamoceratidae, Ecnomidae, Glossosomatidae, Helicopsychidae, Hydrobiosidae, Hydropsychidae, Hydroptilidae, Leptoceridae, Odontoceridae, Philopotamidae and Polycentropodidae) have been recognized in published literature, although additional taxa are known to occur, including Xiphocentronidae and possibly Lepidostomatidae (Carrie 2014). Larval specimens collected from streams in the south of the country are currently being identified to the lowest taxonomic resolution possible.

Order Lepidoptera – There is limited accumulated knowledge about freshwater-associated Lepidoptera in Belize. No published species-level records are available for the Neotropical taxa known to have truly aquatic larvae. Observations are mentioned in the grey literature only and they are limited to the Crambidae (probably *Petrophila*) (Boles 1998, Carrie 2013).

Order Diptera – Accumulated knowledge about the water-associated Diptera is perhaps the most limited for Belize, given the vast amount of species in this group. Gaps in knowledge about taxon identity and the varying requirements of different life-stages render existing literature somewhat inaccessible. For example, Williams (1971) listed 31 species of Tabanidae known from Belize as a result of collected adult material. Yet, it is not clear if all of these species are associated with water in their larval stages. Therefore, the information presented here is almost certainly far from complete. Published and grey records exist for at least 15 families (Athericidae, Blephariceridae, Cecidomyiidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Dolichopodidae, Empididae, Limoniidae, Psychodidae, Simuliidae, Stratiomyidae, Tabanidae and Tipulidae), which have some association with freshwaters in Belize. Of those, the best-documented are taxa that have been the focus of research attention because they are vectors of human disease, or have been collected during research about other vectors of human disease (*e.g.* most of the Tabanidae reported by Williams in 1971). For instance, and building on the previous work of Lewis and Garnham (1960), Shelley *et al.* (2002) detailed the identity and distribution and provided a taxonomic key for 12 *Simulium* species (Simuliidae), that have become known as a result of research to establish the dispersal potential of human onchocerciasis from Guatemala to Belize. A further two species records from this family are provided by Hernández-Triana *et al.* (2012). Over 110 species of Culicidae, which are assumed to have aquatic larvae, are listed (Meerman and Clabaugh 2014). Other groups for which species-level information is available include the Ceratopogonidae (Guillermo-Ferreira and Vilela 2013) and Chironomidae (Resh 1976, Vinogradova *et al.* 2009, Pérez *et al.* 2013), although presented knowledge about the latter is sometimes regional and not necessarily reflective of species presence in Belize.

Phylum Mollusca – With few exceptions, knowledge about the freshwater mollusc fauna of Belize is particularly poor. The early work on molluscs by Morelet (1849, 1851), Crooke and Fisher (1870-1902) and Von Martens (1890-1901) probably remains the most comprehensive available for the region. Updates for Belize have been made by Paraense's collections across Central America in the 1960's and 70's, which included six species of Planorbinae snail (Paraense 2003). Annotated descriptions are provided for three – *Biomphalaria helophila*, *B. obstructa*, and *Drepanotrema lucidium* in Paraense (2003). Combined, these works detail eight Planorbinae species in three genera, all originating from ponds in the Belize District. A solitary species-level record for Ancylinae from a pond in central Belize has been found in the grey literature - *Hebetancylus excentricus* (Meerman and Clabaugh 2014). Ancylinae have also been observed with some frequency in streams in southern Belize (Carrie *et al.* accepted), but their specific taxonomic identity, along with that of one Planorbinae specimen, has yet to be resolved. Three species of Ampullariidae are known from Belize, including *Pomacea belizensis*, which may be endemic (Thompson 2011). Pachychilidae and Thiaridae are commonly encountered in at least the south of the country (Dourson 2009, Carrie *et al.* accepted). The former probably includes at least five different species (Dourson 2009), although assigning identity to members of the Mesoamerican Pachychilidae based on shell characteristics is problematic (Gomez 2009). The Belizean Thiaridae appears to comprise two invasive species: *Melanoides tuberculata* and *Tarebia granifera* (Meerman 2010). A published account of *Mexinauta princeps* (Physidae) exists for the north of the country (Thompson 2011). Hydrobiidae also occurs: *Pyrgophorus coronatus* has been collected from the Pulltrouser Swamp in northern Belize but additional records beyond family-level are very limited and restricted to the grey literature (Meerman and Clabaugh 2014). Of the bivalves, while Sphaeriidae and Unionidae are present, recent records are presented only at the family-level (Carrie *et al.* accepted).

Taxonomic collections

There are no centrally curated collections of freshwater macroinvertebrates in Belize. Some of the material collected has been donated to relevant experts and/or deposited in entomological collections primarily in the United States and United Kingdom, including those at the Texas A & M University, the Smithsonian Institute in Washington, DC, the Essig Museum of Entomology in Berkeley, California and the Natural History Museum in London. While many collected specimens remain in Belize, they are distributed among organizations, institutions and private collectors. The development of a formal and centralized collection in which these and newly collected material can be deposited is an urgent need.

1.3.2. Ecological Studies

Very few ecological studies have focused on the composition, structure and factors controlling freshwater macroinvertebrate assemblages in Belize. A handful of doctoral studies have been conducted in the country's central and southern rivers and streams (Gonzalez 1980, Boles 1998, Buck 2012, Carrie 2013). Other doctoral and postdoctoral research has focused attention on the ecology of specific taxon groups, such as Anopheline communities particularly, although not exclusively, in wetlands in northern Belize (*e.g.* Rejmankova *et al.* 1993, Roberts *et al.* 2002, Achee 2004, Grieco *et al.* 2006), or specific communities, like the stygobiont fauna characterizing caves (Reddell and Veni 1996, Wynne and Pleytez 2005). Below is a brief summary of some of the macroinvertebrate-related knowledge that has emerged from ecological studies conducted in freshwaters in Belize.

In common with many other tropical rivers and streams (Jacobsen *et al.* 2008), the limited research undertaken indicates that lotic communities are dominated by insect taxa comprised of a rich Ephemeropteran, Dipteran, Trichopteran and Coleopteran fauna (Gonzalez 1980, Boles 1998, Carrie 2013). A descriptive longitudinal study of the Sibun River watershed in central Belize indicated highest taxa richness occurred in the upper, forested headwaters (particularly for Ephemeroptera and Trichoptera: Hydroptilidae), and in the mid-reach sections impacted by agriculture and gravel mining, where Ephemeropteran and Coleopteran families were numerically important (Boles 1998). Ephemeroptera and Trichoptera were also encountered in abundance in forested, agricultural and mined sections of the Swasey Branch of the Monkey River system in southern Belize, compared to numbers encountered in samples collected from neighboring streams (Carrie *et al.* accepted). While probably reflecting disturbance, elevated macroinvertebrate abundance in the Swasey Branch may also reflect the naturally phosphate-enriched waters identified by Esselman *et al*. (2006), which appear to be linked to the Santa Rosa Group geology. Anecdotal information about macroinvertebrate abundance from other rivers draining this geology gives some support for this hypothesis, and it provides an interesting line of enquiry for future trophic research.

Geological influence was identified as an important determinant of community composition in streams in the south of Belize, particularly the influence of a limestone gradient (Carrie *et al.* accepted). This study revealed non-insect macroinvertebrates, especially the Pachychild snail, to be important faunal components of stream assemblages draining calcareous geologies, and paleo-archaeological studies suggest this gastropod family has been abundant in lotic systems in Belize since at least the pre-Hispanic era (Covich 2000, Healy *et al.* 1990). Research in the 1970's suggests other Gastropoda, particularly Planorbidae, may form an important component of the non-insect taxa in central parts of the country, where they appeared to fluctuate in relative importance seasonally (Gonzalez 1980).

Long-term studies of the macroinvertebrate fauna have not been undertaken in Belize. Nonetheless, there is limited evidence of wet/dry seasonality in some assemblages. Although differences among seasons were not quantified, Gonzalez (1980) described a general decline in the abundance and family richness of all major taxonomic groups sampled from the Belize River, during the wet season relative to the dry, with the exception of Gastropoda and Oligochaeta. Concurring with this general finding, Carrie *et al.* (accepted) quantified a significant difference in the composition of the assemblages sampled in southern streams, at the beginning and end of the dry seasons. Furthermore, there was some evidence that seasonality was more pronounced in streams draining calcareous than silicate geologies, although the authors concede this may be a statistical rather than ecological effect. Differences reflected an increase in insect taxa characteristic of both erosional and depositional habitats at the end of the dry, and a decrease in the relative importance of Gomphidae and the Pachychild snail. Carrie *et al*. (accepted) speculate that habitat availability, gathering activity (by humans), and macroinvertebrate life history strategies may be possible causes. In so doing, they draw attention to the near absence of research investigating life histories, emergence activity and other aspects of macroinvertebrate phenology in Belize. An important exception is research regarding *Anopheles* (Diptera: Culicidae).

As in many other locations (*e.g.* Puerto Rico, Costa Rica), Culicidae research in Belize has been driven by epidemiological need: to develop interventions to control vectors of human disease. Subsequently, larval development times, survival rates and adult lifespan have been documented for some species that are abundant in northern Belize (Grieco *et al.* 2003), along with life history strategies related to seasonality. For example, knowledge accumulated by various research in a range of freshwater habitats across the country, has revealed high variability in seasonal densities among Anopheline species, and geographical seasonal variation among *A. darlingi*. Seasonal variation has been related to flexibility in oviposition site selection among and within species, and links between the stability of preferred breeding habitats, rainfall and water levels (see Achee *et al.* 2006 and references therein). Such factors may help explain seasonal variance in the distributional range of *A. darlingi*, since its dispersal range from riversides appears to increase during the wet season compared to the dry (Roberts *et al.* 2002).

One aspect of Culicidae research that has received attention in Belize relates to larval habitat preference and the influence of land-use and human activities on habitat condition. Early research revealed immature *A. darlingi* to be positively associated with lotic environments and particularly with shaded riverine habitats and floating debris mats (Manguin *et al.* 1996). Other species have been linked to marshland with sparse macrophytes and cyanobacterial mats (*A. albimanus*), and marshlands densely vegetated by tall macrophyte species (*A. vestitipennis*) (Rejmánková *et al.* 2013). Building on such work, John Grieco, Kevin Pope and colleagues, related abundance of *A. vestitipennis* to phosphate application on agricultural land in close proximity to marshland, because of observed correlations between phosphate additions and increased *Typha* growth - a favored larval habitat of this species (Pope *et al.* 2005, Grieco *et al.* 2006). Similar epidemiologically-based research about Tabanidae (Williams 1971) and Simuliidae (Shelley *et al.* 2002) has generated ecological knowledge about the habitat preferences and/or country-wide distribution of adults and larvae of these two families respectively.

Anelopheline-related research has demonstrated the gains that can be made for disease control by advances in ecological knowledge. Yet, the 'dichotomy' Rejmankova *et al.* (2013) identified as existing between epidemiological and ecological research, is not often bridged. The authors urge that medical research becomes more ecologically oriented and in the same vein, ecologists should explore the opportunities and knowledge to be gained from researching other potential vector groups, such as the invasive *Melanoides* snail and the Planorbidae.

The byrrhoid Coleoptera (Dryopidae, Elmidae, Lutrochidae, Psephenidae and Ptilodactylidae) have also received ecological research attention. In a qualitative study that considered the distribution of these families throughout the country, Shepard (2004) found the highest taxon richness and the highest number of taxa per stream were present on the eastern slope of the Maya Mountains, where streams drain watersheds encompassing the full altitudinal range of the country (0 - 1,120m a.s.l.), are highly dissected and can be high gradient. Lowest numbers were found in the northern part of the country where water bodies are few, and those present are mainly swamps, stagnant or large, slow-flowing low-gradient rivers. Shelley *et al.* (2002) found similar general patterns of distribution in Simuliidae larvae, with none sampled from the northern karstic lowlands and greatest abundances observed in the fast-flowing streams and cascades that characterize the higher regions of the Maya Mountains.

1.3.3. State of conservation

Belize's freshwater ecosystems are currently facing alteration and degradation from a number of threats. Primary amongst these are threats from anthropogenic activities such as deforestation, large-scale agriculture, mining, hydroelectricity generation, water extraction for human-use and consumption, and pollution from various point and diffuse sources (Boles *et al.* 2008). Of particular concern are the predicted impacts of climate change, especially when it is considered that they exacerbate the threats mentioned above. Underlying these threats are the demographic, social, economic and political factors that Kay and Avella (2010) discuss, with the demographic factors representing those for which more systematized data exists.

Brief consideration of the latest figures publicly available from the Statistical Institute of Belize for example, shows that Belize has a young, growing population. The total population in the 2010 census was 322,453 compared to 248,916 in 2000, representing a 30 percent increase in the country's population over a period of 10 years, or an estimated average annual growth of three percent. This population is almost evenly distributed between rural and urban communities with the rural population slightly higher and growing at approximately the same rate as the national average from 2000-2010. In terms of population structure, the 2010 census figures show that 64 percent of the country's population was below 30. Although population growth is not the only significant driver of anthropogenic impacts on Belize's freshwater resources, it is one of the most important, especially because the country's population is so young and hence, major decreases in population growth cannot be expected in the near future. Belize is a country with an economy that is heavily reliant on the use of its natural resources, and as the country's population continues to grow, pressure will increase on the resource base.

One of the country's largest natural assets is its forest; Belize is the most forested country in Mesoamerica (FAO 2010, CATHALAC 2011) with approximately 60 percent forest cover and an average annual deforestation rate of approximately 0.6 percent (Cherrington *et al.* 2010). However, despite a historically low deforestation rate, recent analysis of forest cover for the 2010-2012 period showed that the rate of deforestation is increasing at a faster rate than historically (Cherrington *et al.* 2012). Land-use change scenarios indicate that by 2050, forest cover in Belize could decline by approximately 23 percent relative to 2010 figures (Cherrington *et al.* 2014). This is not surprising given population increase, large public and external debt, and lack of, or poorly enforced environmental policies, laws and regulations. All these factors have been driving the country towards an increase in the use and liquidation of natural assets for income and foreign exchange generation, with the main driver of deforestation being an increase in agriculture, particularly at the commercial-scale (Garcia *et al.* 2011). Current deforestation hot spots include the northeastern portion of the country, Central Belize, especially within and around the Central Belize Corridor, and eastern Stann Creek (Cherrington *et al.* 2012).

Almost all deforestation in Belize has been in broadleaf forests and from 2010-2012, approximately 98 percent of deforestation occurred within 12 major and 6 minor watersheds. Deforestation in the Belize River watershed (the most populated), by far exceeded deforestation in any other in this time period, while earlier losses were most noticeable in the watersheds of the New River in the north and the Moho River in the south (Cherrington *et al.* 2010, Cherrington *et al.* 2012). Apart from deforestation, that is due largely to land clearance for agricultural purposes, freshwater systems also experience additional agricultural impacts. Some of these include pollution from runoff, altered flows due to water abstraction for irrigation, and erosion from land clearing. However, at this time there is very little quantification of the extent of these impacts on macroinvertebrates, other freshwater biodiversity, and on overall water quality. There is also little systematized and/or readily available information on the impacts of mining in rivers, although dredging and extraction of gravel occurs widely (Boles *et al.* 2008).

Of the rivers in Belize, the one that may be subject to the greatest cumulative impact is the Macal River. This river system is the only one on which large dams have been constructed: namely, the Chalillo, Mollejon and Vaca dams. Environmental compliance plans for these dams require monitoring of the river for various impacts and pollutants, including mercury. However, to our knowledge, no robust, long-term monitoring program exists in association with dam operations, or if it does any data collected are not readily available, nor regularly published. There are many other threats to Belize's freshwater systems including those from emerging industries such as the petroleum industry, non-agricultural pollution sources and localized extractive uses. Legal and illegal gold mining occurs in the rivers of the Chiquibul Forest in the Maya Mountains for example, and environmental change associated with these activities needs to be studied in detail.

Despite the paucity of research that quantifies the impacts of prevailing stressors on the country's freshwater systems, one area for which new data has been modelled, is predicted climate change impacts. Cherrington *et al.* (2014) examined more than a dozen latest-generation downscaled global climate models to indicate that rainfall patterns have the potential to fluctuate from 25 percent below the historical norm, to almost 24 percent above. When land use change scenarios that included increased deforestation were considered alongside climate change predictions it was revealed that, runoff in the Belize River watershed could potentially increase by approximately 85 percent under wetter climate conditions. However, if the rate of deforestation was reduced, increase in runoff for this same watershed could potentially be less than half that amount (37 percent). Further analysis revealed that if the climate became drier, runoff could decrease by around 12 percent under increased deforestation scenarios, or decrease by more than three times that (40 percent) if deforestation is reduced. Importantly, under all scenarios examined, erosion was predicted to increase in most of the major watersheds (Cherrington *et al.* 2014).

The urban population in Belize is heavily dependent on rivers as their primary water source and supplying this need accounts for approximately half of all water abstraction from rivers in the country. Although many rural populations depend on rain and well water for drinking, others rely on rivers and associated waters such as in-stream springs, either directly, or after water has been pumped to homes or rudimentary water systems. Rivers are also relied upon by many rural communities for bathing, washing clothes and dishes, varied cultural and customary uses and for agricultural needs (Carrie 2013). Threats to water security from the potential impacts of climate change including drought and changes to water quality are therefore an important consideration for the entire Belizean population (Boles *et al.* 2008) and conservation efforts that promote the sustainable-use of freshwaters need to be redoubled.

There are no specific efforts for macroinvertebrate conservation in Belize and macroinvertebrates are usually conspicuous only by their absence from assessments of aquatic fauna and other macroinvertebrates, as assessments undertaken in Ramsar sites reveal (Meerman *et al.* 2003). Conservation efforts have mostly focused more generally on freshwater systems, but these are often localized and not sustained. Community riparian reforestation, river clean-ups, and outreach campaigns take place often to highlight the importance of the ecosystems, but these are not currently replicated at a national scale. Of interest however, is that across the board and as evidenced by several conservation planning efforts at the landscape level, freshwater systems have consistently been identified by stakeholders as key conservation targets (Boles *et al.* 2008). For example, the Conservation Action Plan for the Maya Mountain Marine Corridor targets freshwater systems for conservation based on several key attributes that include water quality and biological communities such as macroinvertebrate assemblages; the Maya Mountain Massif Conservation Action Plan identifies aquatic and riparian systems as a key conservation target (Boles *et al.* 2008), and more recently, in the ongoing conservation action planning process for the Central Belize Corridor, freshwater systems were also identified by stakeholders as one of the primary conservation targets (UB ERI, unpubl.). It therefore appears certain that Belizeans value healthy freshwater systems. However, the mechanisms, networks and finances to sustain freshwater conservation efforts and roll them out at a national-scale are still poor.

One mechanism that is an exception, and which remains the country's most effective and important conservation effort for freshwaters, is the National Protected Areas System (NPAS), and an associated protected areas management regime that includes their co-management by government and non-governmental partners. Belize has a total of 98 protected areas and these include two Ramsar sites, 16 archaeological sites (Wildtracks 2013). Protected areas account for over a third of Belize's land surface (Kay and Avella 2010) and feature two large forest blocks that comprise part of the Selva Maya in the north and the Maya Mountain Massif in the west and south (Wildtracks 2013). These forest blocks, as well as several individual protected areas, are critical to the protection of a large proportion of Belize's most important watersheds. The Maya Mountain Massif is particularly important because of its function protecting the headwaters of the country's central and southern watersheds. One of the strongest pieces of evidence that attests to the effectiveness of the NPAS for maintaining freshwater resources is that from 1980-2010, approximately 85 percent of deforestation occurred outside protected areas with that figure rising to approximately 94 percent between 2010-2012 (Cherrington *et al.* 2010, 2012).

Recent work based on the use of fish species distribution models has indicated the potential for a freshwater protected areas network for Belize that includes the transboundary portions of the country's watersheds. Half of the resulting potential network is already contained within existing protected areas (Esselman and Allan 2011). But for now, expansion of Belize's NPAS to fully accommodate a freshwater protected areas network remains a research concept. Attempts to integrate such a network within the existing NPAS would surely reap benefits for freshwater ecosystems, not least because the gaps in protection that were identified have a direct relationship with activities in distant locations that have the potential to influence downstream habitats and biota (Esselman and Allan 2011). The value of acknowledging the highly connected nature of freshwater ecosystems can be emphasized by considering some of the challenges faced by the NPAS. Within the Maya Mountains for example, especially in the Chiquibul Forest, illegal incursions result in activities, like gold-panning and deforestation that put the integrity of Belize's rivers and their headwaters at risk. Belize's Ramsar sites, which together comprise approximately 18,000 ha of protected wetlands, approximately 17, 000 ha of which are in the Sarstoon Temash National Park, have suffered from infrastructural development. The Sarstoon Temash National Park is also currently under oil exploration and therefore, the impacts associated with the development of the oil industry cannot be ignored. Belize's mix of public sector-civil society management partnerships has been crucial in addressing the challenges faced in managing the NPAS by providing a voice that highlights the importance of the country's freshwater resources, and calling for tools and mechanisms with which they can be assessed and managed (Boles *et al.* 2008). Belizeans however must unite in their efforts such that the work can be localized but always with a vision and goals for freshwater conservation that are national and system-wide in scope and reach.

1.4. The use of macroinvertebrates as bioindicators of water quality in Belize

Knowledge about the response of macroinvertebrates to environmental change associated with natural and human disturbance is very limited for Belize. In fact, and although the use of macroinvertebrate assemblages as bioindicators has been considered in Belize for at least the past two decades, no research on this subject has yet been published. The earliest work to consider macroinvertebrate assemblages as bioindicators was a single watershed study in central Belize, which provided descriptive baseline information about primarily insect taxa sampled from erosional habitats (Boles 1998). The assemblage was found to include a sufficiently rich Ephemeropteran and Trichopteran fauna to support bio-assessment work. Qualitative assessment of faunal composition indicated that ecological integrity was most altered in the mid-reaches of the Sibun River watershed, and in sections adjacent to the Hummingbird Highway.

More recently, research undertaken in streams in the south of the country attempted to quantify the response of commonly-used macroinvertebrate metrics to categories of human disturbance (Carrie 2013). However, and despite attempts to control for the potentially confounding effects of natural variation using coarse-scale categories of geology, stream size and altitude, Carrie (2013) was unable to demonstrate that tested family-level macroinvertebrate metrics could consistently discriminate change associated with anthropogenic activities. This finding was considered to reflect limitations imposed by natural patterns of disturbance, and the relatively low-level of disturbance effects: significant predictable changes in family and EPT richness, and the BMWP-CR and ASPT-CR scores were only observed where the disturbance gradient was greatest and when it was strongly collinear with the natural upstream-downstream gradient. Consistent and significant variation was not observed where disturbance was presumed to be lower and when it did not correspond closely with a natural gradient of longitudinal change, although non-significant trends, including a reduction in BMWP-CR, ASPT-CR and EPT scores, were observed at these sites. This research was conducted in well-forested watersheds with a low population density. Thus, although there was evidence of anthropogenic environmental change, influence on family-level assemblages appeared to be subtle: a similar observation was made for the fishes of the region (Esselman and Allan 2010). Importantly, the study indicated the potential utility of family-level macroinvertebrate metrics for monitoring large-scale effects in Belize, because they were responsive to coarse-scale environmental change (*i.e.* that originating from collinear natural and anthropogenic variation).

1.5. Legal and regulatory framework for the development and use of macroinvertebrates in environmental assessment

Belize has responded to fragmented legislation related to the use and protection of freshwater systems and the riparian zone, and the scattered responsibility for enforcement among government agencies that has resulted in a history of minimal regulation and non-enforcement, by gazetting in 2011 the National Integrated Water Resources Act (2010). This piece of legislation was informed by policy that explicitly addressed challenges Belize is predicted to face from climate change. The Act seeks to consolidate approaches to the controlled allocation and sustainable use and protection of water resources under the guiding principles of social equity, use efficiency, and sustainability (Global Water Partnership 2000).

Under this legislation, the National Integrated Water Resources Authority (NIWRA) has been established to coordinate and assist in regulating the water sector, which is currently governed by numerous departments and agencies including Belize Water Services Ltd., Belize Electricity Ltd., the Belize National Emergency Management Organization, the Ministry of Health, Ministry of Natural Resources and Agriculture, and the Ministry of Forestry, Fisheries and Sustainable Development. It also seeks to harmonize the use of existing legislation in relation to water resources, including the Environmental Protection Act (1992 and amendments) and associated regulations which give requirements for developing Environmental Impact Assessments, for identifying waters that are ecologically or socially vulnerable to the impacts of domestic effluent and for setting effluent limits, standards and concentrations, and supporting pollution regulation and environmental monitoring.

The National Integrated Water Resources Act (2010) requires the development of a National Water Resources Management Master Plan, to outline objectives for the development, conservation and use of water resources in Belize and requires in particular the identification of Water Quality Control Areas and development of subsequent Water Quality Control Plans. Current effort is focused on groundwater resources and water allocation, but clearly this overarching legislation provides a framework of opportunity that could serve as a vehicle for the development and implementation of biomonitoring approaches. These approaches are already being advocated in the draft implementation framework of the National Biodiversity Monitoring Program (NBMP). The University of Belize Environmental Research Institute (UB ERI) is coordinating the development of the NBMP as part of the implementation of Belize's National Protected Areas System Plan and through a participatory consultation process involving government agencies and non-governmental organizations (NGO's) across the country.

1.6. Future Perspectives

More than a decade has passed since Esselman & Boles stated that "gaps in knowledge surpass strides made to document the country's water resources" (2001) to introduce their review of limnological research in Belize. In making that statement, the authors sought to instill urgency to document baseline ecological condition before changes associated with predicted population increase resulted in degradation. While this statement remains true today for the macroinvertebrate component of the freshwater fauna, despite the important advances in knowledge detailed in the preceding sections, commitment to progressing and enabling macroinvertebrate research has never been greater, at every level in Belize. For example, the UB ERI is actively supporting bioassessment-related research with international and local partners, especially local NGO's, by collaborating in an attempt to secure the resources necessary to characterize macroinvertebrate assemblages at the national-scale, so they can serve as a baseline against which future changes (anthropogenic and natural) can be assessed. Since it was established in 2010, the UB ERI has been instrumental in coordinating research and collaborative efforts for research, based on priorities outlined in a National Environmental and Natural Resources

Research Agenda, and instituting mechanisms to mentor and lead Belizeans in environmental research. Some recommendations for prioritizing macroinvertebrate-related research and advancing their use in the management of Belize's natural resources are given below.

Taxonomy and natural history - Knowledge about the taxonomy and natural history of the Annelida, Blattodea, Collembola, Lepidoptera, Neuroptera, Nematoda, Nematomorpha, Orthoptera, Platyhelminthes and Trombidiformes (Hydrachnidia) associated with freshwaters is lacking entirely. Research is required not only to understand the identity and distribution of these taxonomic groups, and to expand knowledge of all others, but also to identify the importance and conservation status of both invasive and native macroinvertebrates present in Belize. That reviews are underway to document the identity and distribution of Ephemeroptera, Naucoridae and Potamocoridae (Hemiptera) is encouraging, and this effort should serve as inspiration for the systematic country-wide review of other taxonomic groups, particularly the Trichoptera, for which very little is known. DNA sequence-based approaches (*e.g.* Hajibabaei *et al.* 2011, Sweeney *et al.* 2011) and larval rearing would enable immature and adult forms to be linked, and would add considerable value to this effort. It is urgent therefore that collected specimens awaiting examination be distributed to taxonomic experts, and equally as urgent that a centralized collection is established for the curation of specimens in Belize. Of particular need to facilitate future research and the practical use of macroinvertebrates as bio-assessment tools, are verified reference collections and taxonomic identification guides.

Macroinvertebrate ecology – This chapter clearly demonstrates that while knowledge has been generated about macroinvertebrate ecology by the above-described studies, there has been little quantitative research about the factors controlling macroinvertebrate assemblages in Belize. There has been limited research for example, dedicated to life history strategies, trophic interactions, the relevance of global ecological concepts and models, or the effects of natural disturbance including the hurricanes and wild-fires that sometimes sweep across parts of the country. Nor has much consideration been dedicated to headwater, drift, wetland, lotic, stygiobiont or phytotelmatic communities, or long-term investigations of inter- and intra-annual spatial and seasonal change.

Ranked 8th of 167 countries, Belize has been identified as one of those most vulnerable to the impacts of climate change (United Nations Environment Program 2011). Furthermore, and although the population density of Belize is one of the lowest in Central America, with an annual population growth rate typically above 2%, it is increasing faster than any other. Scenarios under climate change and increased population growth will increase pressure on freshwater-related ecosystem services. Thus, gaps in knowledge about macroinvertebrate ecology require urgent attention if a better understanding is to be gained of factors determining if and how future environmental change will impact the ecological structure and function underpinning the many freshwater-related ecosystem services upon which Belize relies.

Bio-assessment – Given the interest in developing bio-assessment capacity in Belize, future research to develop bio-assessment tools may be best conducted at the national-scale. Among other opportunities, this would enable 1) the full spectrum of natural and anthropogenic gradients to be reflected and replicated so interpretation of effect is not confounded by natural variation; 2) models to be developed that can account for continuous variation in natural environmental features and biological assemblages, against which change can be assessed; and 3) the selection of metrics responsive to existing and newly emerging stressors and their standardization for national-use through the development of locally-defined condition classification criteria (Boles 1998, Carrie 2013). Given that large parts of Belize are only moderately disturbed, bio-assessment work would benefit greatly from investigation of intra-familial and intra-generic variation in the response of macroinvertebrates to stressors, particularly in some of the Ephemeroptera (*e.g.* Leptophlebiidae, Heptageniidae) and Plecoptera (Perlidae: *Anacroneuria*). This may facilitate not only the detection of smaller-scale effects, but also enable metrics extrapolated from remote geographic regions to be fine-tuned for the general assessment of Belize's freshwaters, and allow stressor specific indicators to be identified.

Macroinvertebrates have the potential to provide an easy-to-use and cost-effective tool for freshwater management in Belize. Although further research is required to fully inform their practical use, if the potential of macroinvertebrates (and that of additional biological components such as the fishes), is to be realized, they must ultimately be formally recognized in legislative tools and by regulatory agencies as complementary to other monitoring and assessment approaches, as they are in other Mesoamerican countries (*e.g.* Costa Rica and Puerto Rico). Bio-assessment potential has been recognized by some non governmental organizations in Belize that are attempting to implement macroinvertebrate-based approaches at the local-scale. These organizations and their experiences could provide a valuable basis for the development of a network of groups collaborating towards a comprehensive approach to achieving freshwater work. Inspiration and guidance could be drawn from the Coral Reef Monitoring Network and Spawning Aggregations Group for example, that have enabled a number of advances in the management of marine resources. Macroinvertebrates can be particularly suitable for non-expert use, and work that seeks to facilitate use by non-governmental and community-based organizations and embrace their co-operation is much-needed given the responsibilities, enthusiasm and roles played by these groups in the use and management of freshwater resources

Finally, students at UB have been exposed to macroinvertebrate sampling and potential use in bio-assessment since the inception of the university in 2000; in the last six years, the use of more systematic approaches and quantitative techniques has been routinely taught to Natural Resource Management undergraduates through collaborative efforts with the Ya'axché Conservation Trust. Additional effort must be focused on mentoring graduates and enabling them to become the future of macroinvertebrate-based research and freshwater management in Belize.

1.7. Conclusion

Overall, knowledge about freshwater macroinvertebrates in Belize is relatively poor. However, more recently, through new and more coordinated approaches to research and monitoring, and the interest of protected areas managers across the country in freshwater resource management, Belize is not only starting to systematize what little knowledge exists on macroinvertebrate groups but is advocating their use for bio-assessment. Macroinvertebrates have already been included in a select list of indicators to be developed under the NBMP. However, before macroinvertebrate-based bio-assessment can be fully progressed, basic taxonomic, natural history and ecological research is needed as well as the establishment of support systems for research that include an in-country well-curated reference collection and development of taxonomic guides. Belize is small in size; therefore, in order to maximize and better leverage limited human and financial resources for macroinvertebrate work, collaborative efforts at a national scale may yield the best results. Capacity-building for this work in a new generation of Belizean biologists, natural resource managers and community groups will be key to the success of any future efforts.

1.8. Acknowledgements

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