Chapter 9
Freshwater Decapod Diversity and Conservation in Central America and the Caribbean

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Abstract This chapter provides an overview of the species diversity and conservation status of the freshwater decapods in Central America and the Caribbean islands that date back to the late 1800s in both areas. The majority of the early studies were on taxonomy but our knowledge of freshwater decapod ecology (especially of freshwater shrimps from some Caribbean islands) has increased substantially over the last four decades. Currently, 86 species of freshwater decapods are known from Central America and the Caribbean. Here the decapod fauna comprises two families of primary freshwater crabs (Pseudothelphusidae and Trichodactylidae), three families of freshwater shrimps (Atyidae, Palaemonidae and Xiphocarididae), and one family of crayfish (Cambaridae). Several species have been introduced to this region for aquaculture and have now established wild populations. We also provide a list of Central American and Caribbean freshwater decapods that host parasites. To date, the conservation status of 43 % of all freshwater decapods in the region has been assessed using the IUCN Red List protocols; 5 % of these species are endangered or Critically Endangered, and two species (*Cambarellus alvarezi* and *C. chihuahuae*) are likely extinct. Cuba is the country with the most Vulnerable species (7 spp.), while Bermuda (2 spp.) and

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Barbados (1 sp.) have Critically Endangered species. The biodiversity of the freshwater decapod fauna of this region is still incompletely known despite recent efforts, and much more data need to be collected on species that are already known to be threatened with extinction, and on species that are too poorly known to assess. The high diversity of amphidromus caridean shrimps makes them especially vulnerable to threats from the modification of natural river systems such as the construction of dams for hydroelectric power or for water supply.

Keywords Latin America · Neotropics · Isthmus · Biodiversity · Conservation assessment · Decapoda

9.1 Introduction

Studies on the freshwater decapods of Central America and the Caribbean date back to the late 1800s. As in most areas of scientific research in Latin America, initial studies were carried out by scientists based outside of the region who relied museum specimens and material submitted to them by local naturalists. Today, in both regions, locally based researchers are leading the way.

9.1.1 Freshwater Decapod Research in Central America

Mary Jane Rathbun was the first author to describe species of freshwater crabs from Central America (Rathbun 1893), based on material from Nicaragua, Costa Rica, and Cuba, and specimens deposited in the collections of the United States National Museum. Rathbun (1896) revised the freshwater crabs of America and described two species of pseudothelphusid crabs from Costa Rica, which were sent to her by Mr. José Fidel Tristan from the Museo Nacional de Costa Rica. Rathbun (1898) concluded in the section about the distribution of Pseudothelphusinae: "Costa Rica has yielded the greatest number of species of any one region. This is due not to the superabundance of species in this State, but to the diligence of collectors, Mr. J. Fid Tristan and his colleagues of the National Museum of Costa Rica, at San José, and Mr. H. Pittier, of the Physical-Geographic Institute of Costa Rica, also in San José." During this early phase of exploration, Pesta (1931) published the results of the Austrian expedition to Costa Rica, which was carried out between March and September 1930, that included freshwater crabs and two freshwater shrimps (one palaemonid and one atyid) (Pesta 1931).

After this early period, decades passed by with no published information on freshwater decapods in the region. The second period of freshwater decapod research started with the description of a new genus of the family Atyidae by Alejandro Villalobos F. (Mexico) who obtained specimens from Dr. Fenner A. Chace of the Smithsonian Institution, and described *Archaeatya chacei* from Isla del Coco, an island located roughly 500 km off the Pacific coast of Costa Rica (Villalobos 1959). A few years later, Alfred E. Smalley (1963) from Tulane University, New Orleans, Louisiana, U.S.A., revised the genus *Potimirim* (Decapoda: Atyidae) from Central America and examined specimens from Nicaragua, Costa Rica, and Jamaica. Smalley (1964a, b) revised the freshwater crabs of Costa Rica (Pseudothelphusidae) and described their gonopods (Smalley 1964a); he also described two river crabs from Nicaragua (Smalley 1964b). Later, Smalley (1970) erected a new genus (*Phrygiopilus*) from Guatemala to accommodate two new species and provided an identification key for the Central American pseudothelphusids (Smalley 1970).

Important contributions on the river crabs of Central America were published by Richard Bott from the Forschungsinstitut Senckenberg, Frankfurt a.M., Germany. Bott (1956) revised material collected by A. Zilcher during his expedition to El Salvador in 1951 together with specimens from El Salvador and Honduras. Bott (1967, 1968) revised the pseudothelphusids of eastern Central America (including Costa Rica) based on material deposited in several European museums.

Gerhard Pretzmann of the Naurhistorisches Museum in Vienna, Austria published a great deal on the freshwater crabs of Central America. Pretzmann (1975) revised the genus *Pomatocarcinus* based on material from Guatemala, Nicaragua, and Panama. Pretzmann (1978, 1980) later revised the freshwater crabs of Central America and Mexico based on specimens collected by Ivo Poglayen-Neuwall from Costa Rica, Guatemala, Honduras, Nicaragua, and Panama. In the 1980s, other authors published studies of freshwater decapods: Abele and Kim (1984) described the endemic freshwater shrimp species *Macrobrachium cocoensis* and five other species of river shrimps from the Isla del Coco.

The decapod fauna of the subterranean waters of Central America was studied by Horton H. Hobbs III (Wittenberg University, Ohio, U.S.A., and the Smithsonian Institution, Washington D.C., U.S.A.) and Gilberto Rodríguez (Instituto Venezolano de Investigaciones Científicas, Caracas, Venezuela). These carcinologists described species inhabiting Central American caves in Belize (Hobbs Jr 1986), Costa Rica (Hobbs III 1991), and Guatemala (Rodríguez and Hobbs 1989, 1990). Reviews of troglobitic decapod crustaceans and their biogeography in the Americas were published by Hobbs et al. (1977) and Hobbs III (1994).

While all the above-mentioned studies were carried out by colleagues from the U.S.A. or Europe, Carlos R. Villalobos from the Escuela de Biología, Universidad de Costa Rica, was the first carcinologist from Central America to publish on freshwater decapods when he described two freshwater crabs from Costa Rica, *Ptychophallus costaricensis* and *Potamocarcinus nicaraguensis* (=*Potamocarcinus nicaraguensis* Rathbun 1893) (Villalobos 1974; Villalobos and Burgos 1975).

The study of freshwater decapods from Central America during the past few decades has expanded from taxonomic works to now including ecological and molecular studies. In 2010 a new species of pseudothelphusid (*Allacanthos yawi* Magalhães et al. 2010) was described from southern Costa Rica, Lara et al. (2013) studied the species diversity and distribution of river crabs inhabiting the basin of the río Grande de Térraba on the Pacific slope of Costa Rica, and Wehrtmann et al.

(2010) provided information on reproduction in pseudothelphusid crabs. A number of publications have focused on freshwater shrimps from the region: Alvarez Ruiz et al. (1996) and Lara and Wehrtmann (2009) described the reproduction in *Macrobrachium carcinus* from Costa Rica, and provided information on the diversity, abundance, and distribution of river shrimps in the largest river basin of Costa Rica (Lara and Wehrtmann 2011). Recently, Pileggi et al. (2014) presented a molecular perspective on the transisthmian *Macrobrachium* species and concluded that all sibling species studied by them were valid taxonomic entities, but not all sibling pairs formed natural groups.

9.1.2 Freshwater Decapod Research in the Caribbean

Research on freshwater decapods in the Caribbean dates back to the 1800s that were followed by major faunistic studies in the mid-1900s. The early reports included partial lists of freshwater decapods for Puerto Rico (Gundlach 1887–1894) and Dominica (Pocock 1889). The decapod fauna of the other islands remained poorly studied until the mid- 1900s when Curacao was included in the work by Chace and Holthuis (1948). Chace and Hobbs (1969) provided the first comprehensive review of freshwater decapods in the Caribbean, with particular emphasis on Dominica, and this study remains a valuable source of information for carcinologists interested in the decapod fauna of all islands.

Research on the biology and ecology of freshwater decapods in the Caribbean has increased rapidly during recent years, with several studies describing their role in aquatic ecosystems, as part of food webs and in processing organic matter. One of the most studied locations is El Yunque National Forest in Puerto Rico, with research focusing on ecological interactions among decapod and non-decapod species (Pringle et al. 1993; Crowl and Covich 1994; Pringle 1996; March et al. 1998, 2002; Johnson and Covich 2000; Cook et al. 2008a, b; Covich et al. 2009; Hein et al. 2011), the effects of natural and anthropogenic disturbances on the populations (Covich et al. 1991, 1996, 2003, 2006; March et al. 1998, 2003; Benstead et al. 1999; 2000; Greathouse et al. 2005; 2006; Hein et al. 2011), and nutrient recycling (Covich and McDowell 1996; Pyron et al. 1999; Crowl et al. 2001, 2006; March et al. 2001; March and Pringle 2003; Wright and Covich 2005; Cross et al. 2008; Benstead et al. 2010). All species of freshwater shrimps are amphidromous and their migratory behavior in the Caribbean has been studied in detail in Puerto Rico (Benstead et al. 1999) and Guadeloupe (Fièvet et al. 1999).

Caribbean freshwater decapods are widespread and many species are found living sympatrically. Recent genetic studies have assessed several aspects of decapod biology. Taxon cycling with sequential expansions and contractions of distributional ranges was supported by studies with *Atya* (Atyidae) in Puerto Rico, where most species studied undergo regional population expansions. Genetic studies (Cook et al. 2008a) on the Puerto Rican freshwater crab *Epilobocera sinuatifrons* (Pseudothelphusidae), a non-migratory species, suggested shallow but significant genetic isolation among populations, which were intermediate between highly divergent populations (e.g., terrestrial specialists) and highly connected populations (e.g., migratory shrimp; Cook et al. 2008b).

9.2 Regional Diversity of Freshwater Decapods

Three groups of freshwater decapods are found in the region: crayfish, shrimps, and crabs. Freshwater crayfish species are represented in the Neotropics by two families: Cambaridae (48 spp.) and Parastacidae (16 spp.) (Crandall and Buhay 2008). Representatives of five (sub) families of caridean shrimps have been reported to occur in the Neotropics (De Grave et al. 2008): Alpheidae (1 sp.), Atyidae (19 spp.), Palaemonidae (83 spp.), Euryrhynchinae (4 spp.), and Xiphocarididae (2 spp.). There are 312 species of primary freshwater crabs in the Neotropics in two families: Pseudothelphusidae (262 species) and Trichodactylidae (51 species) (Yeo et al. 2008). Cumberlidge et al. (2014) updated the available information about the biodiversity of freshwater crabs in the Neotropics and concluded that there are 313 species of pseudothelphusid and trichodactylid freshwater crabs. Overall, the Neotropics harbor a total of 485 freshwater decapods, which makes this region one of the most diverse areas, especially considering the biodiversity of freshwater crabs.

9.2.1 Central American Freshwater Decapod Diversity

Our knowledge of freshwater decapods inhabiting the Central American region stems principally from studies in Costa Rica, Guatemala, and Panama, although some information on freshwater crabs is available from other countries in the region (see this Sect. 9.1.1). Overall, the Central American region has 86 species of freshwater decapods, while the Caribbean has 61 species (Fig. 9.1).

Astacidea. Roughly 10 % of the 638 currently known freshwater crayfish species occur in the Neotropics (Crandall and Buhay 2008). However, reports of crayfish from Central America are scarce (Table 9.1) (Alvarez and Villalobos 2016): *Procambarus (Austrocambarus) pilosimanus* has been reported to occur in northern Guatemala and Belize by Villalobos-Figueroa (1955, 1983), Villalobos (1982), Hobbs (1989), and Alvarez and Villalobos (2015). *Procambarus* (*A.*) *williamsoni* is known to occur in Guatemala and Honduras (Alvarez and Villalobos 2016), and *P.* (*A.*) *llamasi* is found in northern Guatemala (Alvarez et al. 2007; Barba-Macías et al. 2015). Considering the similarities of these species, a closer examination of the morphology and the genetics of the material reported for Central America is highly recommended (JL Villalobos pers. comm.). A fourth species, *Procambarus* (*Scapulicambarus*) *clarkii* was introduced into Costa Rica in 1966 (Huner 1977). Torres and Álvarez (2012) compared the genetic variability of the

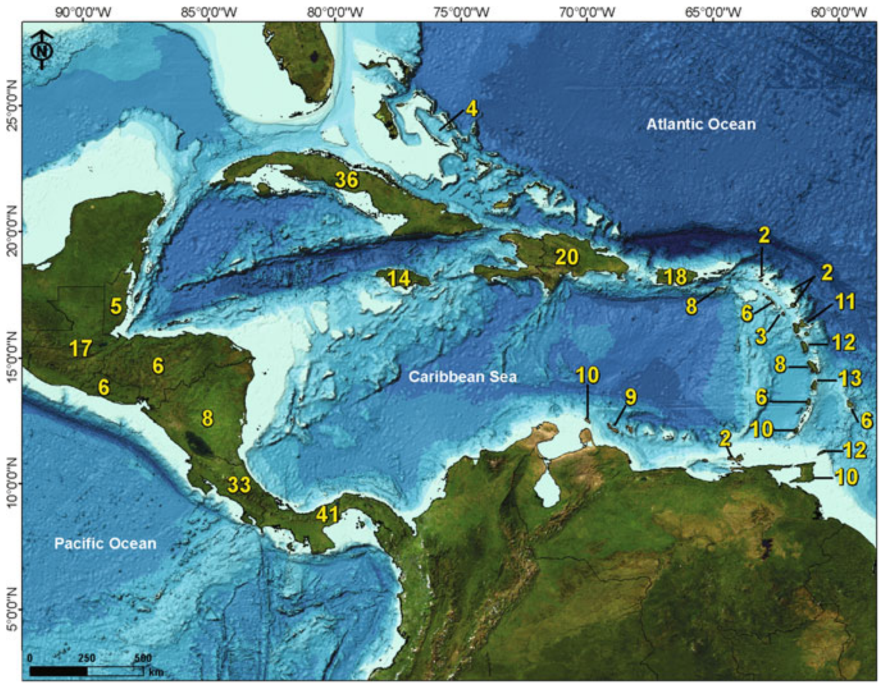

Fig. 9.1 Geographical distribution of the freshwater decapods from Central America from Belize to Panama (Astacidea, Atyidae, Palaemonidae, Pseudothelphusidae, and Trichodactylidae) and from the Caribbean to the Greater and Lesser Antilles (Atyidae, Astacidea, Grapsidae, Palaemonidae, Pseudothelphusidae, Trichodactylidae, and Xiphocarididae). *Numbers* represent the number of species per island/region. (*Background map source* The GEBCO_2014 Grid, version 20150318, http://www.gebco.net)

Costa Rican *P.* (*S.*) *clarkii* population with that of specimens of this species living in Mexico and concluded that the genetic variation of the native and introduced populations was equally low in both. *Cherax quadricarinatus* is also present in Costa Rica in the northwestern Pacific drainage near Guanacaste (RL Lara, pers. comm.). This species is native to freshwater habitats in northern Australia and Papua New Guinea and has been translocated worldwide due to its suitability for aquaculture (Ahyong and Yeo 2007).

Atyidae. According to a recent global assessment of freshwater shrimps (De Grave et al. 2015), atyid shrimps comprise 443 species (58.1 % of all the freshwater shrimp fauna) of which 37 % of atyid species are threatened with extinction. Atyid shrimps are widely distributed in Central America and are a common element of the freshwater decapod fauna (Table 9.1) (Smalley 1963; Hobbs and Hart 1982). The Atyidae in the region are represented by six genera (*Atya*, *Jonga*, *Micratya*, *Neorhynchoplax*, *Potimirim* and *Typhlatya*) with eleven species. The most speciose genera in Central America are *Atya* (*A. crassa*, *A. innocuous*, *A. margaritacea*, *A. scabra*) and *Potimirim* (*P. americana*, *P. glabra*, *P. poeyi* and *P. potimirim*).

Table 9.1 Presence/absence of freshwater decapod families in Central America and the Caribbean

Country/decapod family		Atyidae	Astacidea	Palaemonidae	Pseudothelphusidae	Trichodactylidae	Xiphocarididae	Selected references
Central America	Nicaragua	X	–	X	X	X	–	Rathbun (1893); Smalley (1964c); Pretzmann (1980); Rodriguez (1982); Magalhães and Türkay (2008)
	Honduras	X	X	X	X	–	–	Pretzmann (1980); Rodriguez (1982); Alvarez et al. (2005); Alvarez and Villalobos (2016)
	Guatemala	X	X	X	X	–	–	Pretzmann (1980); Rodriguez (1982)
	Panama	X	–	X	X	X	–	Rathbun (1893); Rathbun (1912); Pretzmann (1980); Rodriguez (1982); Magalhães and Türkay (1996, 2008); Magalhães et al. (2013)
	Costa Rica	X	X	X	X	–	–	Hobbs Jr (1986); Magalhães et al. (2015)
	Belize	X	X	X	X	–	–	Rathbun (1893); Rodriguez (1982); Hobbs Jr (1986); Magalhães and Türkay (1996, 2008)
	El Salvador	X	–	X	X	X	–	Holthuis (1954); Bott (1956); Rodriguez (1982)
Greater Antilles	Cuba	X	X	X	X	–	X	Chace and Hobbs (1969); Holthuis (1977); Rodriguez (1982); Hobbs (1984); Navarro-Pacheco et al. (1998); Juarrero (1993; 1999); Capolongo and Pretzmann (2002); Capolongo (2003); Rodríguez and Magalhães (2005)
	Hispaniola	X	–	X	X	–	X	Rodriguez (1982); Rodríguez and Williams (1995); Pérez-Gelabert (2008)
	Bahamas	X	–	X	–	–	–	Alvarez et al. (2005)
	Jamaica	X	–	X	–	–	X	Hart (1961); Schubart and Koller (2005)
	Puerto Rico	X	–	X	X	–	X	Chace and Hobbs (1969); Karge et al. (2013); Pérez-Reyes et al. (2013)

(continued)

Table 9.1 (continued)

Country/decapod family		Atyidae	Astacidea	Palaemonidae	Pseudothelphusidae	Trichodactylidae	Xiphocarididae	Selected references
Lesser Antilles	Trinidad	X	–	X	X	X	X	Rodríguez (1992); Rodríguez and López (2003)
	Guadeloupe	X	–	X	X	–	X	Rodriguez (1982); Fièvet et al. (1999)
	Martinique	X	–	X	X	–		Rodríguez and López (2003)
	Margarita	–	–	–	X	–	–	Rodríguez and López (2003)
	Dominica	X	–	X	X	–	X	Chace and Hobbs (1969); Rodriguez (1982); Rodríguez and López (2003); Bass (2004a, 2007)
	Saint Lucia	X	–	X	X	–	X	Barnish (1984); Thorpe and Lloyd (1999); Rodríguez and López (2003)
	Curacao	X	–	X	–	–	X	Debrot (2003)
	Antigua and Barbuda	X	–	X	–	–	–	Bass (2005)
	Barbados	X	X	X	X	–	–	Hobbs and Hart (1982); Felix (1991); Bass (2003a)
	Grenada	X	–	X	X	–	X	Hobbs and Hart (1982); Bass (2004b)
	U.S. Virgin Islands	X	–	X	X	–	X	Chace and Hobbs (1969); Hobbs and Hart (1982); Nemeth and Platenberg (2007)
	St. Vincent	X	–	X	X	–	X	Hobbs and Hart (1982); Rodriguez (1982); Rodríguez and López (2003);
	Tobago	X	–	X	X	–	X	Hynes (1971); Maitland et al. (2002); Bass (2003b)
	Saint Kitts and Nevis	X	–	X	–	–	X	Chace and Hobbs (1969); Bass (2006)
	Montserrat	X	–	X	–	–	–	Hobbs and Hart (1982)

Three species of *Atya* (*A. crassa*, *A. innocuous* and *A. scabra*) are found on both the Pacific and Atlantic coasts of Central America, while the fourth species (*A. margaritacea*) is restricted to the Pacific slope from Baja California southward to Peru (Hobbs and Hart 1982; Snyder et al. 2011). *Neorhynchoplax kempi* is native to Iraq, and may have been introduced into the Panama Canal along with an exotic aquarium plant (Abele 1972). The only reported troglobitic species from Central America is *Typhlatya utilaensis* from Utila Island, Honduras (Alvarez et al. 2005). Recently, Torati et al. (2011) surveyed 17 locations on several islands of the Bocas del Toro archipelago and the adjacent mainland of Panama, and provided information of the distribution of freshwater shrimps on a more regional scale. These authors documented the variability of the color pattern of five atyid species encountered in their study area (*A. scabra*, *J. serrei*, *M. poeyi*, *P. glabra*, and *P. potimirim*), and noted the extremely high color variability in *P. glabra*. The molecular phylogeny of shrimps of the genus *Potimirim* was studied by Torati and Mantelatto (2012) based on several atyid species from Central America (*J. serrei*, *M. poeyi*, *P. americana*, *P. glabra*, *P. potimirim*) and revealed *P. americana* to be the most basal species.

Palaemonidae. This family is one of the two dominant freshwater shrimp families worldwide and comprises 300 species (39.3 % of all currently known freshwater shrimp species), and 14.8 % of species of palaemonid freshwater shrimps are threatened with extinction (De Grave et al. 2015). In Central America (Table 9.1), several palaemonid species live in brackish water. For example, Lara and Wehrtmann (2011) reported the presence of *Palaemon gracilis* and *P. hancocki* from the estuarine zone at the mouth of the river Grande de Térraba on the Pacific slope of Costa Rica. Only palaemonid species of the genus *Macrobrachium* are widely distributed in the freshwater habitats of the region. Although the highest diversity of *Macrobrachium* is located in the Indo-Pacific region, more than 55 valid species out of the currently recognized 300 species (De Grave et al. 2015) are found in The Americas, which highlights the geographical importance of this region for the Palaemonidae (Holthuis 1952; Pileggi et al. 2014). So far, 13 species of *Macrobrachium* have been reported from Central America (Holthuis 1952; Lara and Wehrtmann 2011): *M. acanthurus*, *M. americanum*, *M. carcinus*, *M. cocoense*, *M. crenulatum*, *M. digueti*, *M. hancocki*, *M. heterochirus*, *M. occidentale*, *M. olfersi*, *M. panamense*, *M. rathbunae*, and *P. tenellum*. An additional species, *M. amazonicum*, has been reported to occur in Nicaragua and Costa Rica, but so far no specimens have been deposited in collections (Vergamini et al. 2011). In addition, *M. rosenbergii* has been introduced in Costa Rica for aquaculture (I.S. Wehrtmann, pers. commun.), but wild populations of this species have not yet been found. The only endemic species of freshwater shrimps in Costa Rica is *M. cocoense* from the Pacific island of Isla de Coco (Abele and Kim 1984). The geographic distribution of the genus *Macrobrachium* is generally confined to the Pacific or Caribbean slopes of Central America (Valencia and Campos 2007), with eight species on the Pacific slope (*M. digueti*, *M. hancocki*, *M. occidentale*, *M. olfersi*, *M. panamense*, *M. rathbunae*, *P. tenellum*, and *M. cocoense* from Isla del Coco), and five species on the Caribbean slope (*M. acanthurus*, *M. carcinus*, *M. crenulatum*, *M. heterochirus*, and *M. olfersi*). If confirmed, *M. amazonicum* would be the sixth species known from the Caribbean slope. Only *M. olfersii* has been reported from both the Pacific and Caribbean slopes of Central America (Anger 2013; Pileggi et al. 2014). The raising of the Isthmus of Panama about 3.1 million years ago (Keigwin 1978; Coates et al. 1992; Coates and Obando 1996; Anger 2013) has thus contributed to the formation of two distinct species groups on both sides of the landbridge (see Lessios 2008). However, despite of the geographic separation, some of the species on different sides of the country are extremely difficult to tell apart and were called “sibling species” by Knowlton (1993). Holthuis (1952) also referred to similar-looking pairs of species of *Macrobrachium* from the Caribbean and Pacific slopes as “sister species”. Pileggi et al. (2014) assessed the relationship among the transisthmian sister species of *Macrobrachium* in a molecular phylogenetic context and confirmed all species to be valid, and that the following pairs of sibling species formed natural monophyletic groups (the first species is from the Pacific drainage, the second from the Caribbean slope): *Macrobrachium occidentale* – *M. heterochirus*, *M. americanum* – *M. carcinus*, *M. digueti* – *M. olfersii*, *M. hancocki* – *M. crenulatum*, and *M. tenellum* – *M. acanthurus*. Many *Macrobrachium* species are known for their amphidromous migrations (Bauer 2013) with larval development occurring in estuarine waters, while the adults inhabit freshwater habitats. Other *Macrobrachium* species are hololimnetic inland species, and their life cycle includes an abbreviated and lecithotrophic mode of larval development (Anger 2013; Bauer 2013). In Central America, all *Macrobrachium* species have an extended larval development, and their larvae need estuarine waters for successful development (Anger 2013). As far as we know, hololimnetic inland species are absent in Central America.

Pseudothelphusidae and Trichodactylidae. There are five families of primary freshwater crabs worldwide (Cumberlidge and Ng 2009) with more than 1306 species (Yeo et al. 2008; Cumberlidge 2015). Two of these families, the Trichodactylidae (51 species) and the Pseudothelphusidae (278 species) are endemic to the Neotropics. Representatives of both these primary freshwater crab families occur in Central America (Table 9.1) (Yeo et al. 2008; Cumberlidge et al. 2014), making a total of 50 species for this region (Pseudothelphusidae, 47 species) and Trichodactylidae (3 species) (Magalhães et al. 2015; C. Magalhães, unpubl. data). Central American pseudothelphusids belong to 12 genera. The most speciose genus is *Ptychopallus* (13 species from Costa Rica and Panama), followed by *Potamocarcinus* (8 species from Costa Rica, Guatemala, El Salvador, Honduras, Nicaragua, and Panama), and *Zilchia* (5 species from Belize, Guatemala and Honduras). Several genera are known only from either one or two countries: *Achlidon* (Costa Rica), *Camptophallus* (Nicaragua), *Spirocarcinus* (Panama), *Allacanthos* (Costa Rica and Panama), *Hypolobocera* (Panama and South America), and *Phrygiopilus* (Guatemala and Mexico). Panama (18 species) and Costa Rica (12 species) harbor the most diverse freshwater crab fauna in the region. However, the freshwater decapod fauna of these countries is the most studied in Central America, and future surveys in the other countries of the region are likely to discover several more new species (Yeo et al. 2008). The three species of trichodactylids from the region are *Trichodactylus quinquedentatus* and *Poppiana dentata* from Nicaragua, and *Melocarcinus meekei* from Panama (Magalhães and Türkay 2008; Magalhães et al. 2013).

Xiphocarididae. *Xiphocaris elongata* is widely distributed in the Caribbean (Chace and Hobbs 1969; also: see Sect. 9.2.2.) but has not been reported to occur in Central America (Table 9.1).

9.2.2 Caribbean Freshwater Decapod Diversity

Many species of Caribbean freshwater decapods live exclusively in freshwater and are completely independent of the marine environment, while other species (usually carideans) are tolerant of high salinities and have larval stages that need to develop in sea water (Bauer 2011a, b, 2013). These life cycle strategies add to the complexity of explaining how (and when) freshwater species reached the islands they are found on today. The more than 61 species of freshwater decapods found in the Antilles belong to seven families: Atyidae, Cambaridae, Grapsidae, Palaemonidae, Xiphocarididae Pseudothelphusidae, and Trichodactylidae (Table 9.1) (Chace and Hobbs 1969; Crandall and Buhay 2008; Cumberlidge et al. 2014). More species are found in the Greater Antilles than the Lesser Antilles probably because the wider variety of aquatic habitats in the Greater Antilles has resulted in more diversification (Fig. 9.1) (Pérez-Reyes et al. 2013). The islands in the Caribbean are classified in three categories: volcanic or coral origin islands with sediment uplift. These islands include: the Greater Antilles (Cuba, Hispaniola, Puerto Rico, Jamaica), and the Lesser Antilles (Dominica, Montserrat, Saint Lucia, Saint Thomas, Saint John, Tortola, Grenada, Saint Vincent, Guadeloupe, Martinique, Nevis, and Saint Kitts). Islands of volcanic or coral origin have a steep topography with elevations that range from as high as 3000 m (Pico Duarte, Dominican Republic) to 45 m below sea level (Enriquillo Lake, Dominican Republic, Hispaniola) (Kennedy et al. 2006). These island of volcanic or coral origin are forested and receive abundant rainfall, especially at higher elevations and during the rainy season (May–November) (Heartsill-Scalley et al. 2007). The streams and rivers of these islands typically have rocky substrates that increases the diversity of habitats (Smith et al. 2003). Trinidad and Tobago are continental islands on the continental shelf that belong to the northwestern South American transitional zone (Weeks et al. 1971, Morrone 2006). Other Caribbean islands (Aruba, Bonaire, Curaçao, Guadeloupe's Grand Terre, Antigua, Barbuda, Saint Martin, Anguilla, Barbados, Cayman Islands, and Saint Croix) have been formed by sediment uplift and have a flat low-lying topography, lack lush dense forests, and rainfall is low (Bass 2003b). Here the streams are intermittent or ephemeral and streambeds are typically composed by mud and silt (Bass 2003b).

Freshwater decapods are diverse and very common in both the island streams as well as in the coastal continental creeks and rivers. Streams on islands are dominated by species of freshwater decapods that fill the same ecological roles as the insects, amphipods, or isopods that dominate continental and temperate streams (Boulton et al. 2008). Freshwater shrimps found in streams and rivers on Caribbean islands live in all parts from river mouths to high altitude headwater streams. They have complex life cycles, and those species whose larval stages need to develop in marine or estuarine environments have migratory behavior (Bauer 2011a, b; Bauer 2013). Adult amphidromous shrimp mature and reproduce in freshwater, and females release larvae that move downstream to estuaries where they develop further and migrate back upstream as juveniles. The larvae of marine species of decapods are transported over wide areas by oceanic surface currents (Cook et al. 2008b, 2009; Page et al. 2008), and represents a stock for streams in Caribbean islands. Molecular and phylogenic analyses of species of freshwater shrimps from the Antilles and Central America (Cook et al. 2008b, 2009, 2012; Page et al. 2008, 2013) indicate that the amphidromous species of shrimp in the Caribbean share a common genetic pool.

Astacidea. All species of crayfish found in the Greater Antilles are endemic to their islands, and probably reached there by overseas dispersal on floating logs from Central America to the Greater Antilles (Hobbs 1984; Hobbs III 1994; Crandall and Buhay 2008). This is supported by experimental evidence that indicates that some species of crayfish are tolerant to changes in salinity and to drought (surviving for long periods buried in soil) (McClain and Romaire 2007). Three species of crayfish are found in the Greater Antilles: *Procambarus atkinsoni*, *P. cubensis* (with 2 subspecies), and *P. niveus*, and all are endemic to Cuba (Hobbs 1984; Sinclair et al. 2004). *Procambarus cubensis cubensis* has a widespread distribution in Cuba, *P. cubensis rivalis* is found in the western part of the island, *P. atkinsoni* is restricted to Isla de Pinos, and *Procabarus niveus* is a troglobitic species with a limited distribution in the western provinces. Several species of crayfishes have been introduced for aquaculture to Jamaica (*Cherax quadricarinata*), the Bahamas (*C. quadricarinata*), Hispaniola (Haiti and Dominican Republic), (*Procambarus clarkii*, *Pacifastacus leniusculus*), to Puerto Rico (*C. quadricarinatus*), and to islands in the Lesser Antilles (Williams et al. 2001; Kairo et al. 2003; Neal et al. 2009; Pienkowski et al. 2015).

Atyidae. Nineteen species of atyid shrimps are found in Antillean islands, 11 of which are endemic to these Caribbean islands: *Atya lanipes*, *A. brachyrhinus*, *Typhlatya garciai*, *T. monae*, *T. consobrina*, *T. elenae*, *T. garciadebrasi*, *T. iliffei*, *T. taina*, *T. kakuki*, and *Micratya cooki*. Eight species are found in freshwater streams and rivers in both Central America and the Caribbean islands: *Atya innocuous*, *A. scabra*, *Jonga serrei*, *Micratya poeyi*, *Potimirim americana*, *P. mexicana*, *P. potimirim*, and *P. glabra* (Bass 2003a, b, 2004a, b, 2005, 2006, 2007; Pérez-Reyes et al. 2013). *Atya lanipes* is the most basal and morphologically less specialized species of the *Atya* in the region and is found in Cuba, Jamaica, La Hispaniola, Puerto Rico and U.S. Virgin Islands (Hobbs and Hart 1982). The troglobitic genus *Typhlatya* is represented in the Antilles by seven species, five of which are endemic to Cuba (*T. garciai*, *T. consobrina*, *T. elenae*, *T. garciadebrasi*, and *T. taina*), one (*T. iliffei*) is endemic to Bermuda (Hunter et al. 2008), and one (*T. monae*) is found in Puerto Rico, Curacao, Hispaniola, and Barbuda (Botello et al.

2013). In addition, *Typhlatya kakuki*, from the Bahamas was described by Alvarez et al. (2005) (which closely resembles species from Cuba). Other taxa of freshwater shrimps from the region include *Micratya cooki* from Puerto Rico (Karge et al. 2013), and a potential new species of *Potimirim* sp. from Puerto Rico that is currently being described (F. L. Mantelatto pers. com.).

Pseudothelphusidae and Trichodactylidae. The freshwater crabs of the Caribbean belong to two families: Pseudothelphusidae and Trichodactylidae. The pseudothelphusids generally prefer higher altitude streams, but in this region these crabs are found in low altitude rivers throughout the aquatic ecosystems up to headwater streams at 3000 m above sea level, and most species can breathe air and are semiterrestrial in habit (Rodríguez 1992; Rodríguez and Magalhães 2005). Five genera of pseudothelphusids (out of 40) belonging to 15 species are found in the Caribbean (*Epilobocera*, *Neoepilobocera Rodriguezus*, *Guinotia*, and *Pseudothelphusa*) (Cumberlidge et al. 2014). Cuba has the highest diversity of pseudothelphusids in the region with two genera (*Epilobocera* and *Neoepilobocera*) and nine species (Capolongo 2003; 2005). Hispaniola (Haiti and Dominican Republic) has two species, *Epilobocera haytensis* (which has a wide distribution in the Dominican Republic and Haiti,) and *E. wetherbeei* (which is restricted to high altitude localities up to 2300 m above sea level in the island). *Epilobocera sinuatifrons* is found in Puerto Rico and Saint Croix (Chace and Hobbs 1969; Cook et al. 2008a), and this distribution implies a common origin on the Puerto Rico Bank (at a time when Puerto Rico and Saint Croix were part of a single land mass), that became separated recently when sea levels rose following the end of the most recent Ice Age about 10000 years ago (Larue 1994). The most recent status about the populations of *E. sinuatifrons* in Puerto Rico was described by Cook et al. (2008a) who reported genetic divergence in the populations from different rivers in the island, but their isolation may be recent because this species has not experienced a population expansion or a bottleneck. Trinidad and Tobago have two species of pseudothelphusids, the South American continental species *Rodriguezus garmani* and the endemic species *Microthelphusa odaelkae* (Cumberlidge et al. 2014).

The trichodactylid freshwater crabs live in lakes and lowland streams in tropical South America, but a few species are found in Mexico and Central America (Nicaragua), and the range of one mainland species (*Poppiana dentata*) extends to Trinidad (Rodríguez 1992), which is the only trichodactylid found on any Caribbean island (Cumberlidge et al. 2014).

Palaemonidae. The 16 species of Caribbean palaemonid freshwater shrimps live in fresh water and brackish water, and 12 species are found in West Indian freshwater habitats. The troglobitic genus *Troglocubanus* is endemic to Cuba (*Troglocubanus calcis*, *T. eigenmanni*, *T. gibarensis*, and *T. inermis*) and to Jamaica (*T. jamaicensis*) (Hobbs III 1994; Hobbs et al. 1994). The troglobitic species *Macrobrachium lucifugum* is found in caves and sinkholes in Cuba, Hispaniola, Barbados, Curacao, and Jamaica (Juarrero 1999; Debrot 2003; Anger 2013), and the range of the continental species *Macrobrachium jelskii* includes Trinidad and Tobago (Bass 2003b, 2004b), islands that are closest to the continent. In South America *M. jelskii* is found in Suriname, Venezuela, Brazil, Peru

Paraguay, and Argentina, Five species of *Macrobrachium (M. acanthurus*, *M. carcinus*, *M. crenulatum*, *M. heterochirus*, and *M. faustinum)* are distributed throughout Central America and the Caribbean Islands (Pérez-Reyes et al. 2013). *Palaemon pandaliformis* is common in brackish waters in Cuba, Saint Kitts and Nevis, Tobago, Saint Lucia, Puerto Rico, and Barbados (Pérez-Reyes et al. 2013). The presence of the Asian species *Macrobrachium rosenbergii* in several Caribbean islands is likely the result of the introduction of this species for aquaculture and its subsequent release or escape (Anger 2013).

Xiphocarididae. Caribbean freshwaters are inhabited by two species of xiphocarids: *Xiphocaris gomezi* and *X. elongata*, that are distinguished by their retention of primitive characters of the exopods of their pereiopods (Chace and Hobbs 1969). *Xiphocaris gomezi* is endemic to Cuba and is known from shallow pools with a high density of organic matter at three high altitude localities (600 m above sea level) where it lives sympatrically with *X. elongata*, *A. lanipes*, and species of *Macrobrachium* (Juarrero 1993; Navarro-Pacheco et al. 1998; De Grave 2013). *Xiphocaris elongata* has a widespread distribution in the Antilles and occurs in large numbers in streams and rivers draining into low-altitude valleys near river mouths, where they tolerate daily fluctuations in salinity. Populations of *X. elongata* that live in headwaters are predated by palaemonid shrimp, pseudothephusid crabs, and freshwater fishes. Populations of *X. elongata* that are heavily predated by fish have evolved a longer rostrum (>5 mm) that presumably deters attacks by predators (Ocasio-Torres et al. 2014, 2015).

9.2.3 Species that Are Vectors of Parasites

In many regions of the Caribbean and Central America freshwater decapods are not only an important component of the stream ecosystem (Covich and McDowell 1996), they are also part of the diet of the local human communities (Wehrtmann et al. 2014). The potential for the spread of parasites and diseases increases along with increasing aquaculture of decapods with the introduction of non-native freshwater organisms. For example, when bopyrids infect juvenile shrimp it slows their growth, while trematodes such as *Paragonimus*, the human lung fluke, infect mammal definitive hosts that feed on freshwater crabs.

Paragonimiasis. Paragonimiasis is a foodborne parasitic zoonosis caused by lung flukes of the genus *Paragonimus* (Fürst et al. 2012). Species of *Paragonimus* are parasites of wild carnivores, domestic carnivores, and humans. Carnivores and humans acquire the disease when they eat uncooked/undercooked crustaceans that are infected with lung fluke metacercariae. Once the parasite has been ingested it migrates from the intestine to the lungs where it develops into encysted resident adult worms (Acha and Szyfres 2003). Humans with paragonimiasis can develop additional medical complications if parasites migrate to different organs besides the lungs, including the brain (Procop 2009). *Paragonimus* species are highly evolved parasites with a complex life cycle that involves three hosts: a snail, a crustacean, and a mammal (Doanh et al. 2013). *Paragonimus mexicanus*, reported from Colima, Mexico, and *P. caliensis* from Colombia are important pathogens in Central and South America (Brenes et al. 1985; Calvopiña et al. 2014). Freshwater crabs serve as the second intermediate host of *Paragonimus* and are infected by cercariae that then develop inside crabs into metacercariae, the most infective stage for mammals. *Paragonimus mexicanus* has been found in 14 out of the 278 species of Pseudothelphusidae (Lamothe-Argimedo 1995), while *P. caliensis* has been found in four species of freshwater crabs (Rodríguez and Magalhães 2005) (Table 9.2). The incidence of *P. mexicanus* in endemic areas of the parasite from Mexico to Panama is very high and 85 % of the studied crabs (*Ptychophalus tristani*) were infected with *Paragonimus* metacercariae (Monge et al. 1985).

The life cycle of *Paragonimus* requires two intermediate hosts (one snail, one crustacean), and a final definitive host (a mammal) (Calvopiña et al. 2014). Eggs of the adult parasites are released by the mammal host into a freshwater body where they hatch after 2–3 weeks and release a miracidium that infects a snail. Inside the snail the miracidia develop into cercariae that are then released into the water where crabs (and crayfish) become infected (Calvopiña et al. 2014).

In Latin America, *Paragonimus* infections in humans are associated with the ingestion of raw or undercooked freshwater crabs in traditional dishes such as the locally called “ceviche”, where crabs are marinated in citrus juice that does not kill the parasites (Blair et al. 2008). The spread of the parasite in Central America is enabled by commercial or artisanal fishermen who import crabs from areas where the parasite is endemic.

Bopyrids. Epicaridean isopods (bopyrids) are ectoparasites of other crustaceans that live in the gill chambers of their crustacean hosts where they gain entry to the body and either sterilize them completely, or reduce the rate of gametogenesis (Beck 1980) and reduce the rate of respiration and the metabolic rate in general (Chaplin-Ebanks and Curran 2007). In the Caribbean and Central America the isopod *Probopyrus pandalicola* infects freshwater shrimps of the genera *Macrobrachium* and *Palaemon* (Kensley and Schotte 1989; Bunkley-Williams and Williams 1998) (Table 9.2). *Probopyrus pandalicola* hatches as an epicaridium larva that swims and attaches to a copepod (the intermediate host) where the larva molt and metamorphosize into an infective stage (cryptoniscus) that leaves the copepod host and infects the final host (a shrimp) (Cash and Bauer 1993). Inside the shrimp the first larval parasite stage (cryptoniscus) is a female that then develops into a dwarf male that lives attached to a female. The parasite then increases in size until it compresses and atrophies the gills and internal organs (Schuldt and Rodrigues-Capítulo 1985). These infections end in the production of thousands of bopyrid larvae and the death of the crustacean host that failed to reach maturity.

The effect of bopyrids varies from species to species. Female parasites feed on host haemolymph by piercing a blood sinus usually on the inside wall of the gill chamber where the parasite consumes up to 25 % of the host’s haemolymph in a day (Lester 2005). As a result of this blood removal, the parasite sequesters the host’s energy intake and lowers the host’s egg production (Anderson 1977). Parasitized shrimps have less energy to capture food and migrate to breeding sites

Table 9.2 Species of freshwater decapods from Central America and the Caribbean that host parasites

	Parasite	Host	Localities	Reference
Crustacea: Isopoda	*Probopyrus pandalicola* (Packard, 1879)	*Macrobrachium acanthurus* *Macrobrachium amazonicum* *Macrobrachium boneli* *Macrobrachium carcinus* *Macrobrachium faustinum* *Macrobrachium ohione* *Macrobrachium olfersii* *Macrobrachium surinamicum* *Palaemon pandaliformis*	Cuba, La Hispaniola, Puerto Rico, Virgin Islands, Panama, Costa Rica, Nicaragua, Martinique, Curacao	Bunkley-Williams and Williams (1998) Kensley and Schotte (1989)
Platyhelminthes: Trematoda	*Paragonimus mexicanus* Miyazaki and Ishii, 1968	*Odonotelphusa maxillipes* *Potamocarcinus magnus* *Pseudothelphusa belliana* *Pseudothelphusa dilatata* *Pseudothelphusa nayaritae* *Pseudothelphusa propinqua* *Pseudothelphusa terrestris* *Ptychophalus coclensis* *Ptychophalus costaricensis* *Ptychophalus richmondi* *Ptychophalus tristani* *Ptychophalus tumimanus* *Raddaus bocourti* *Raddaus tuberculatus*	Mexico, Costa Rica, Guatemala, Panama, Honduras, Nicaragua	Brenes et al. (1985) Calvopiña et al. (2014) Lamothe-Argimedo (1995) Monge et al. (1985) Rodríguez and Magalhães (2005) Vélez et al. (2003)
Platyhelminthes: Trematoda	*Paragonimus caliensis*	*Pseudothelphusa dilatata* *Potamocarcinus magnus* *Ptychophalus exilipes* *Ptychophalus tristani*	Costa Rica, Panama	Rodríguez and Magalhães (2005)

(Somers and Kirkwood 1991) and suffer reductions in their fecundity and structural changes in their appendages (Anderson 1977; Calado et al. 2008; Williams and Boyko 2012).

Bopyrids cause castrations, stunting, the lack of development of secondary sexual characteristics, and increased mortality to their shrimp and crab hosts, and have direct and indirect effects on crustacean fisheries (De Castro 1985). A high prevalence of bopyrids in commercial species results in financial losses from stunting and mortality of crabs and shrimps.

9.3 Conservation Status

A total of 130 decapod species have been reported from freshwater ecosystems in Central America (86 spp.) and the Caribbean (61 spp.). Most species are still poorly studied beyond their taxonomy and distribution. According to the IUCN Red List, the conservation status of only 53.8 % of all decapod species in the region is known (Table 9.3), and the remaining species (46.2 %) are too poorly known to assess (Data Deficient). Three species (*Atya brachyrhinus*, *Procaris chacei*, *Typhlatya iliffei*) are threatened with extinction (Critically Endangered), two species (*Macrobrachium occidentale*, *Troglocubanus eigenmanni*) are Near Threatened, and none are extinct.

The number of threatened species (Vulnerable (VU) and Critically Endangered (CR)) varies among countries. Bermuda has two species that are CR and Barbados has one species that is CR. The highest number of VU species are found in Cuba (7 species), Guatemala (4 species), and Costa Rica (2 species). *Thyphlatya* has 5 species of threatened species, *Troglocubanus* has 4 species, and *Epilobocera* has 2 species. The remaining genera are represented by single threatened species. Cuba, El Salvador, Guatemala, and Margarita all have one species that is assessed as not currently threatened (Near-Threatened NT), but that may become threatened in the future if threat levels were to increase.

Almost half (46.2 %) of the freshwater decapods from Central America and the Caribbean are too poorly known to assess (Data Deficient) (Table 9.3). On a global scale, the level of data deficiency of freshwater shrimps is 37.0 % (De Grave et al. 2015), 49.1 % for freshwater crabs (Cumberlidge et al. 2009), and 21.2 % for

Table 9.3 Conservation status of the 130 freshwater decapod species so far reported for Central America and the Caribbean

Status	%
Not evaluated	22.0
Data Deficient	24.2
Least Concern	38.6
Vulnerable	11.4
Endangered	0.0
Critically Endangered	2.3
Near Threatened	1.5
Extinct	0.0

crayfish (Richman et al. 2015). Clearly, more studies are needed to fill these knowledge gaps and to provide sufficient information for a more complete assessment of the extinction risks of the freshwater decapod fauna in Central America and the Caribbean.

9.4 Threats and Conservation Issues

Like all freshwater fauna, decapods face a series of threats associated with changes in their environment. Here we focus on three major impacts from the large diversity of anthropogenic activities that result in ecosystem degradation and loss of fauna. First, loss of access to the ocean for freshwater species is important for island and coastal decapod populations; second, changes in land use cover (including urbanization) have led to the degradation of freshwater ecosystems, and third, fishing has had a major impact on decapod populations.

9.4.1 Loss of Ocean Connectivity

Connectivity with the oceans is a key aspect of ecosystem integrity for freshwater ecosystems. Hydrologic connectivity refers to the water-mediated movement of matter, energy, or organisms among components of the landscape (Pringle 2001). For stream and river ecosystems longitudinal connectivity joins downstream ecosystems including estuaries with upstream ecosystems. The free movement of decapods up and down stream networks is a key factor in conserving the long-term stability of populations of freshwater decapods in Central America and the Caribbean because it allows for the completion of life cycles in migratory species and facilitates genetic exchange between populations. Although there are primary freshwater species in the region, a number of species of decapods are secondary freshwater (amphidromous) species whose adult populations live in freshwater ecosystems but whose eggs and larval stages require salt or brackish water to develop into juveniles. Newly hatched larvae migrate downstream to marine environments where they grow into juveniles, which then migrate back into freshwater to complete their life cycle.

River damming is one of the main drivers of longitudinal connectivity loss in rivers. In temperate regions the negative effects of dams on species such as anadromous fish like salmon that migrate annually upstream to spawn are well known, and has both economic and conservation importance (Zabel and Williams 2002). In tropical areas, less is known about the effects of dams and other in-channel structures on freshwater organisms, despite the fact that many decapods and over 200 species of fish are diadromous (Milton 2009). Builders of dams across tropical rivers that include fish ladders for migratory fish to navigate the obstruction base their design on the needs of anadromous fish such as salmon, that are often still impassable for many other native freshwater species (McCully 1996). Dams block the downstream movement of the larvae of amphidromous tropical decapods, and the reservoir and water intakes become a major source of larval mortality (Benstead et al. 1999). Similarly, juvenile shrimps migrating upstream are able to climb over waterfalls and small dams with water flowing over vertical walls, but large dams are impervious migratory barriers for juvenile shrimps.

Connectivity of freshwater ecosystems with the ocean creates a particularly complex conservation problem, because most protected areas are not designed to protect entire watersheds. In Puerto Rico protected areas are either located on the upper parts of the mountains (e.g., El Yunque National Forest) or in the lowlands (e.g., Guánica State Forest). The importance of these reserves for the conservation of native decapods will depend on the location of the large dams that are built downstream from them, because of dams, reserves only partially protect decapod populations. All watersheds with a large dam on them (dam wall of >30 m) lack native fish and shrimp in their upper reaches (Holmquist et al. 1998; Cooney and Kwak 2013). Although large dams have drastic effects on amphidromous decapod populations, small dams and water intakes are a major conservation threat due to the high incidence of larval mortality.

El Yunque National Forest is one of the best-protected areas in Puerto Rico. The upper parts of El Yunque had been under some type of protection for over 200 years because the Spanish Crown set aside the mountains as a source of wood. The lowlands in Puerto Rico are heavily urbanized, but most rivers lack major dams. However, the rivers draining El Yunque are important sources of water for human consumption and at least 60 % of the runoff is diverted toward municipal facilities to be used as drinking water (Crook et al. 2007). Studies of migratory shrimp larvae show a clear nocturnal migration by the shrimp and that there is a high larval mortality due to water abstraction. Water abstraction in one of the main watersheds draining El Yunque accounts for between 30 and 60 % of decapod larval mortality, depending on the amount of water extracted (Benstead et al. 1999). Given the preference for shrimps to migrate at night, larval mortality could be greatly reduced by simple management practices that could include stopping water extraction for a few hours each night.

9.4.2 Land Cover and Land Use

A major cause of ecosystem degradation and a threat to decapod conservation is the conversion of land use from natural vegetation to agricultural use or urban development. Changing land use alters the water physicochemistry and habitat characteristics of freshwater ecosystems and creates new conditions that are often adverse for native biota. The sediment delivery rates of streams affect channel morphology and substrate composition (Chin 2006), the physicochemical characteristics of the stream water are often affected by nutrient loads from nearby agricultural activities (Herlihy et al. 1998; Jones et al. 2001). Urbanization is perhaps the most extreme type of land use conversion because urban freshwaters often carry large solute loads, have altered geomorphologies, and are often inhabited by exotic species (Walsh et al. 2005). The effects of changes in land cover use on freshwater decapod populations clearly can follow complex pathways, with numerous indirect effects and unknown mechanisms.

Freshwater macroinvertebrate assemblages change their abundance and species composition in response to changes introduced by inland use (Maloney and Weller 2011), but decapods do not seem to follow this general response. In Puerto Rico, shrimp assemblages are abundant and diverse in forested, agricultural, and urban streams and do not show evidence of assemblage degradation (Kwak et al. 2007). Comparisons of shrimp assemblages in watersheds with different levels of urbanization in Puerto Rico showed similar decapod species composition and densities, and appeared to unaffected by watershed land use (Pérez-Reyes et al. 2016). The loss of species richness and abundance of freshwater shrimps (*Atya lanipes*, *A. innocous*, *A. scabra*, *Macrobrachium carcinus*) in urban streams on tropical islands such as Puerto Rico is the result of a series of human stressors that have degraded decapod habitat (Pérez-Reyes et al. 2016).

The migratory behavior and the vulnerability of decapod populations to the loss of connectivity of their home streams with the ocean are more important than land use changes when explaining the presence of decapods at a particular location. Urban streams that keep a connection with the ocean maintain their shrimp assemblages (Pérez-Reyes et al. 2016) but both urban and forest streams above large dams are likely to be either completely devoid of shrimps or only have relic populations (Fig. 9.2).

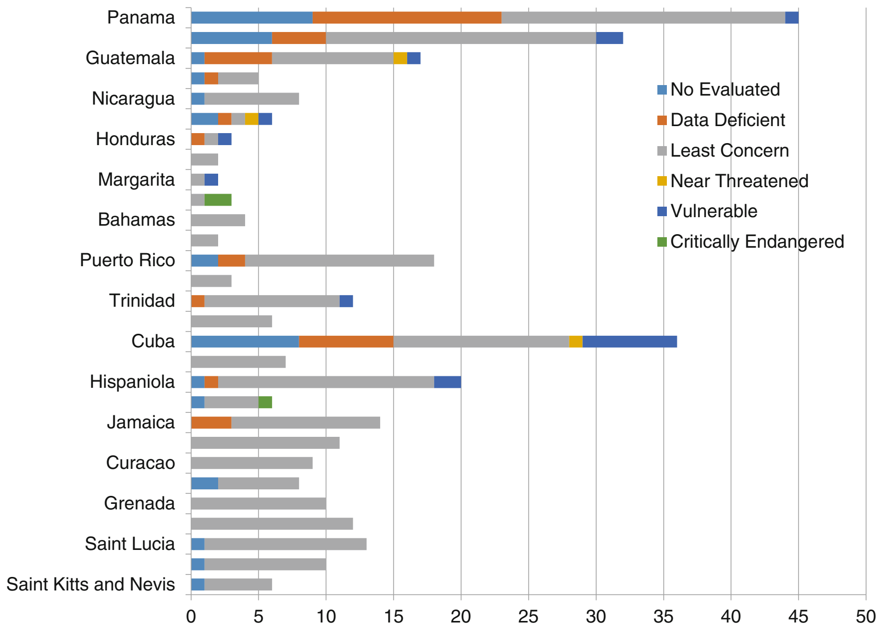

Fig. 9.2 Percentage of freshwater decapod species in each of the IUCN Red List categories (Least Concern, Near Threatened, Vulnerable, and Critically Endangered) for Central America and Caribbean countries

9.4.3 Fishery Impacts

In Central America as well as in the Caribbean freshwater decapods are an important source of protein for humans, and the harvesting of these crustaceans is a common practice, making overharvesting an important conservation issue. Traditional harvesting techniques involve either the use of traps, or snorkeling and harpooning of individuals. The almost complete lack of fishery data is a major problem when trying to assess the impact of the exploitation of shrimps and crabs inhabiting freshwater habitats. Shrimps (*Macrobrachium* spp.) are the main targets of recreational fisheries in the region (Figs. 9.3 and 9.4) and in rural areas are harvested for personal consumption and for restaurants (I. S. Wehrtmann, pers. obs. in Costa Rica). The impacts of the recreational fisheries on populations of *M. olfersi* in lowland Neotropical streams in Costa Rica revealed a sharp decline (87 %) in relative abundance between recent and historical data, and one possible explanation for the observed decrease was direct harvesting of adult shrimps (Snyder et al. 2013). An assessment of the recreational fishery of freshwater shrimps is urgently needed in order to develop adequate management protocols and to obtain a better understanding of the impact and sustainability of local fishing activities on the populations of freshwater shrimps and crabs.

Fig. 9.3 Typical bamboo trap for *Macrobrachium* used in an artisanal fishery in northern Costa Rica (Photo courtesy of R. L. Lara)

Fig. 9.4 Wooden container for maintaining live specimens of *Macrobrachium carcinus* caught in northern Costa Rica (Photo courtesy of R. L. Lara)

Harvesting of freshwater shrimp in Costa Rica may include the illegal poisoning of river sections with chlorine bleach or even stronger chemicals, which kill not only shrimps and other macroinvertebrates but also smaller fishes; the consumption of these fishes may lead to serious health consequences, especially for children (Greathouse et al. 2005; J. Picado, pers. comm. from Costa Rica). Studies on the impacts of these illegal chemical releases on ecosystems are scarce. Greathouse et al. (2005) documented ecosystem structure, function, and biotic interactions three months after a chlorine bleach poisoning event in a stream in Puerto Rico, and found a rapid recovery of the habitat and the organisms in it. Shrimp abundances after three months were either unchanged or even greater, but the effect of repeated poisoning of the same stream is unknown, and may have severe impacts on the ecosystem and the abundance of the shrimps and other organisms living there.

9.5 Perspectives

A series of recent publications have addressed the diversity, conservation status, threats, and conservation actions on a global scale for freshwater crabs (Cumberlidge et al. 2009, 2014), crayfish (Richman et al. 2015), and freshwater shrimps (De Grave et al. 2015). Here we provide a regional view of the diversity and conservation of freshwater decapods in Central America and the Caribbean, which is certainly not completed and needs to be continued. For example, the freshwater decapods in Honduras and Nicaragua in Central America and in Haiti/Dominican Republic in the Caribbean are still poorly studied, and intensive biotic surveys in these areas are needed to extend our knowledge on the decapod fauna. Species discovery rates over time of freshwater shrimps (De Grave et al. 2008) and freshwater crabs (Yeo et al. 2008) are still climbing steeply and show no sign of flattening out (except perhaps for the trichodactylid freshwater crabs), and additional sampling will provide valuable data on the distribution of known species, and discover a number of new species. For example the freshwater crab *Allacanthos yawi* (Magalhães et al. 2010) was recently described from the Pacific slope of Costa Rica whose freshwater decapod fauna is relatively well-studied (Magalhães et al. 2015).

An improved assessment of the freshwater decapod fauna in Central America and the Caribbean faces a major obstacle given the current lack of experienced taxonomists (Pearson et al. 2011). It is necessary therefore to increase our efforts to train more students in the identification of freshwater decapods, to establish collaborations with experienced taxonomists outside the region, and to organize regional workshops to bring together young scientists and students interested in the topic.

Support to regional museums is also critical. Collected material needs to be deposited in official museum-based collections, preferably located directly in the region. Museum collections are cornerstones of traditional taxonomy and systematics and they also play a critical role in studies of the effects of environmental changes on organisms over time. However, these contributions have been widely unappreciated by decision makers, resulting in insufficient financial support for their maintenance and improvement (Suarez and Tsutsui 2004). Not surprisingly, only a few countries in Central America and the Caribbean have museums with zoological collections maintained by a curator and technical staff (Alonso-Eguíalis et al. 2014a). As a consequence many valuable specimens are simply stored in laboratories and offices and are inaccessible to taxonomists which impedes biodiversity studies in the region. There is clearly a need to develop a regional plan for the inclusion and curation of all preserved specimens of freshwater decapods currently in unofficial collections.

Our understanding of the true diversity of the freshwater decapod fauna of Central America and the Caribbean would be greatly enhanced by studies that combine taxonomic and molecular techniques. Several widespread freshwater species in Central America and the Caribbean include morphologically variable specimens from different parts of the range but species boundaries are difficult to identify (Pileggi et al. 2014) and these taxa may prove to represent species complexes comprising one or more cryptic species.

Pollution, climate change, human disturbance, invasive species, modification of natural ecosystems, and mining represent the greatest threats to species of caridean shrimps from Central America and the Caribbean that are threatened with extinction (De Grave et al. 2015). In addition, the modification of natural river systems by

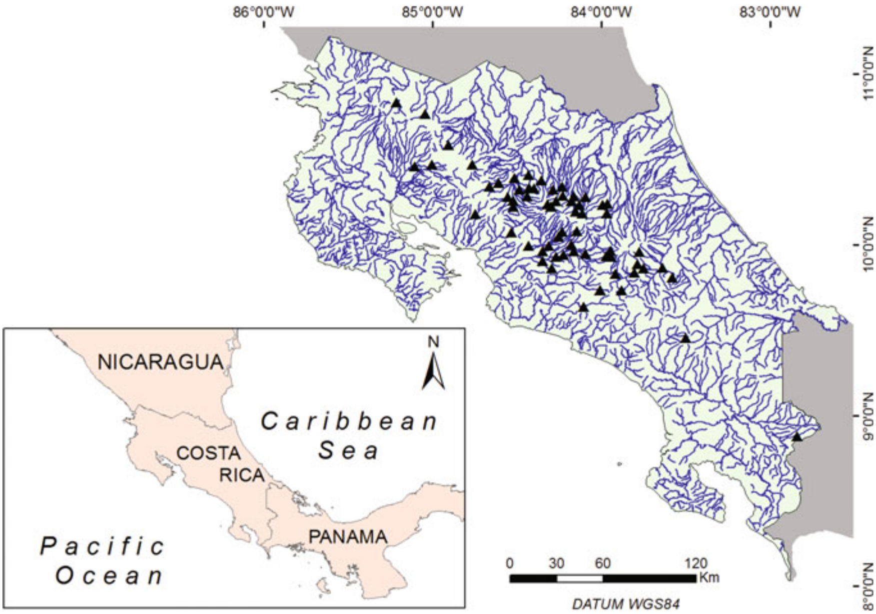

Fig. 9.5 Location of existing hydroelectric plants in Costa Rica (excluding those under construction or at the planning stage).

constructing dams across rivers to either generate hydroelectric power or to create a reservoir is a serious problem for migratory amphidromous decapods such as species of *Macrobrachium* and species of atyids. Figure 9.5 shows the distribution of 75 hydroelectric projects in Costa Rica, excluding those which are under construction and/or in progress. The dams block the migratory routes of migratory amphidromous shrimps, and represent a major threat to these freshwater decapods (March et al. 2003; Lara and Wehrtmann 2011; De Grave et al. 2015). In México the construction of small permanent barriers across waterways has been shown to have had a negative impact on the upstream movement of the migratory freshwater shrimp *M. tenellum* (Rodríguez-Uribe et al. 2014). It is known that the construction of dams and reservoirs blocks migratory pathways of freshwater animals and significantly alters their distribution and abundance in many parts of the world; the impact of such barriers on freshwater decapods of Central America and the Caribbean is still poorly understood (Holmquist et al. 1998; March et al. 2003; Rodríguez-Uribe et al. 2014). There is clearly a need to develop research projects aimed at obtaining a better understanding of the migratory patterns of palaemonid and atyid shrimps in Central America and the Caribbean and to develop protocols that can mitigate this problem (De Grave et al. 2015). There is also a need for a closer interaction between scientists and decision makers to ensure that the threats to migratory species of amphidromous shrimps are taken into account in management plans.

The literature on freshwater decapods in Central America and the Caribbean is dominated by taxonomic studies, while their ecology and physiology is poorly understood. There is a need for more studies on the impact of climate change on freshwater ecosystems and the organisms that live there, because climate change has been identified as a significant threat with a potentially high impact (De Grave et al. 2015). Such studies should also include monitoring programs to detect medium and long-term changes in the populations of freshwater decapods (Snyder et al. 2013).

Finally, we strongly recommend network building among scientists in Central America and the Caribbean and elsewhere (such as the Mesoamerican network for freshwater macroinvertebrates) aimed at facilitating the exchange of information and development of joint projects (Alonso-EguíaLis et al. 2014b). Also needed is an open-access library with a database that includes unpublished data from environmental impact studies, and more international and/or regional conferences, small meetings, and training workshops that provide opportunities to discuss current problems and possible collaborations.

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