AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. (2013)

Published online in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.2350

Conservation status of the inland aquatic crustaceans in the Yucatan Peninsula, Mexico: shortcomings of a protection strategy

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ABSTRACT

1. The Yucatan Peninsula (YP), Mexico, is a large karstic Neotropical system hosting a highly diverse crustacean fauna related to epigean and subterranean aquatic habitats. There are more than 40 hypogean endemic species, thus qualifying as a subterranean biodiversity hotspot.

2. In view of the relevance of both the YP karstic aquifer and its related crustacean fauna, the spatial distribution of 212 species from 1165 geo-referenced records of the inland aquatic crustaceans were analysed in relation to the geographic coverage of protected natural areas (PNAs) of the YP. The data analysed were obtained from sources including the authors' own observations, published literature, and institutional and government databases.

3. The YP is an area with a high biodiversity of continental crustaceans and is also an important area of endemism worldwide. However, most of the crustacean fauna is at risk. Only 18.5% of the crustacean species recorded in the YP and only 3.2% of the endemic forms are distributed within the limits of a protected area. In addition, only five of the 48 endemic species are listed in the Mexican Official Standard (NOM-059-2010) and none of them occurs in a protected area.

4. The groups with the highest endemism are the Remipedia and Ostracoda, each with two known YP endemic species. Peracarids are also highly endemic in the YP (62%), followed by Copepoda (27%), Decapoda (18%), and Branchiopoda (1.5%).

5. Currently, the areas of most concern, owing to high tourist pressures, are the 'Corridor Tulum - Puerto Morelos' and the 'Ring of Cenotes', both having significant numbers of endemic forms. A revision of the PNAs' management programmes to incorporate aquatic ecosystems and biota, the expansion of selected PNAs to provide protection to critical unprotected areas, and increased research activities focused on the aquatic fauna are recommended actions.

Received 21 September 2012; Revised 08 January 2013; Accepted 30 January 2013

KEY WORDS: groundwater; conservation evaluation; invertebrates; crustaceans; biodiversity; protected areas

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INTRODUCTION

The Yucatan Peninsula (YP) is an immense limestone platform in south-eastern Mexico, covering 450 000 km^2 and bordered by the Gulf of Mexico and the Caribbean Sea. It is considered a clearly defined biotic province in the Neotropical region (Morrone, 2005). This large karstic system includes a variety of epigean and subterranean aquatic systems. Epigean systems, which are locally called 'cenotes' or water-filled sinkholes, are the main source of fresh water in the region and represent the habitat for many aquatic species with a restricted distribution (Schmitter-Soto *et al.*, 2002; Alcocer and Bernal-Brooks, 2010; Pérez *et al.*, 2011). Extensive networks of submerged subterranean cave passages extend from cenotes, especially those along the central part of the Caribbean coast. In this area, more than 1000 km of underwater cave passages have been surveyed including the 303 km long Sistema Sac-Actun, the longest underwater cave system known on Earth (QRSS, 2013). Many cenotes, even those far inland, have a surface layer of fresh water underlain by sea water (Suárez-Morales and Rivera-Arriaga, 1998) some having a halocline at depths of 60+ m separating fresh water above from salt water below. In the north-west part of the YP, a 180 km diameter semicircle of sinkholes, known as the 'Ring of Cenotes', marks the edge of the Chicxulub impact crater where a large meteorite struck at the end of the Cretaceous period, 65 million years ago (Schmitter-Soto *et al.*, 2002; Pérez *et al.*, 2011).

Because of the characteristic physiographic features of the YP and its geological history involving successive waves of marine invasions and regressions (Suárez-Morales *et al.*, 2004), this region has a highly diverse native aquatic biota as well as high levels of endemism of vertebrate and invertebrate taxa (*v. gr.* teleosts, decapods, amphipods, copepods). It has therefore been considered a clearly defined biotic province (Morrone, 2005).

Crustaceans are one of the most successful zoological groups, both in terms of number of living species recorded (Brusca and Brusca, 1990; Martin and Davis, 2001) and the diversity of habitats they colonized (Boxshall and Halsey, 2004). The knowledge of inland aquatic crustaceans of the YP includes mainly amphipods and isopods (Rocha *et al.*, 2008), decapods (López-Mejía, 2008; Villalobos-Hiriart and Álvarez, 2008), cladocerans (Suárez-Morales and Elías-Gutiérrez, 1992; Elías-Gutiérrez *et al.*, 1999; Elías-Gutiérrez, 2006), and copepods (Fiers *et al.*, 1996, 2000; Suárez-Morales *et al.*, 1996; Suárez-Morales and Reid, 1998, 2003; Rocha *et al.*, 2000). Many of these crustacean species dwell in groundwater habitats and caves of the YP. A diverse crustacean fauna (43 species) is known from the fragile anchialine habitats (Yager, 1987; Iliffe, 1992, 1993; Mejía-Ortíz *et al.*, 2006; Suárez-Morales *et al.*, 2006; Suárez-Morales and Iliffe, 2007; Álvarez *et al.*, 2012; Neiber *et al.*, 2012). In temperate latitudes both the diversity of the stygobiotic fauna and endemism are relatively low (Martin *et al.*, 2009). According to a general estimation of endemism related to subterranean karstic waters, areas with at least 20 obligate subterranean species are considered to be biodiversity hotspots (Culver and Sket, 2000). Hence, the YP could be deemed as one of the foremost sites of endemic crustaceans worldwide.

In order to protect this diverse flora, fauna, and habitats, up to 60 protected natural areas (PNAs) have been created in the YP (Table 1). The PNA system represents a national environmental strategy aimed to promote the conservation of biodiversity and natural resources. It was created by a federal decree setting basic management strategies in the General Law of Ecological Balance and Environmental Protection (LGEEPA, 1988). Overall, the PNAs represent 12% of the total area of the YP (Bezaury-Creel *et al.*, 2007) and almost 13% of the national territory. The PNAs are categorized following diverse criteria and operate at different levels (CONANP, 2012). The criteria used to categorize the PNAs and the main features of each of the main categories are presented in a subsequent section.

Based on the available information of the inland aquatic crustaceans recorded from the YP and on the coverage and distribution of the PNAs in this area, the role of the PNA in protecting and conserving this unique and highly diverse group of aquatic invertebrates and their habitats was determined.

Definition and regulations of the PNAs:

According to the General Law of Ecological Balance and Environmental Protection (LGEEPA,

Table 1. Features and coverage of Protected Natural Areas (PNAs) of the Yucatan Peninsula. CAM: Campeche, QROO: Quintana Roo, TAB: Tabasco, YUC: Yucatan. ZSEC: Zones Subjected to Ecological Conservation, BR: Biosphere Reserve, APFF: Area for Protection of Flora and Fauna, GRRS: Garden of Regeneration and Recuperation of Species, UP: Urban Park, SR: State Reserve, ES: Experimental Station, NP: National Park, NTP: Natural Park, ZEP: Zone of Ecological Preservation, ER: Ecological Reserve, BZER: Buffer Zone of Ecological Reserve, NM: Natural Monument, NR: Natural Reserve, SP: State Park, SCHV: Area of Scenic, Cultural or Historic Value, PR: Private Reserve *terrestrial and marine areas, **exclusively marine areas

Type	State	Name	Category	Area (ha)
State	CAM	Balam-Kin	ZSEC	99,135
State	CAM	Balam-Ku	ZSEC	406,993
Federal	CAM	Calakmul	BR	723,185
Federal	CAM	Laguna de Términos*	APFF	705,016
Federal	CAM	Los Petenes*	BR	282,857
Municipal	CAM	Laguna Ik	GRRS	28,743
Municipal	CAM	Salto Grande	UP	1,577
State	QROO	Balamán Káax	SR	128,390
State	QROO	El Tangaro	ZSEC	848
State	QROO	Kabah	UP	41
State	QROO	Laguna de Chancanaab	NTP	13
State	QROO	Laguna de Manatí	ZSEC	201
State	QROO	Mario Molina Pasquel	SR	1,589
State	QROO	Refugio Estatal de Flora y Fauna Laguna Colombia	ZSEC	1,526
State	QROO	Refugio Estatal de Flora y Fauna Sistema Lagunar Chacmochuch	ZSEC	1,897
State	QROO	San Felipe Bacalar	ES	0
State	QROO	Santuario de la Tortuga Marina Xcacel-Xcacelito*	ZSEC	361
State	QROO	Santuario del Manatí, Bahía de Chetumal*	ZSEC	277,212
Federal	QROO	Arrecife de Puerto Morelos*	NP	9,066
Federal	QROO	Arrecifes de Cozumel*	NP	11,987
Federal	QROO	Arrecifes de Sian Ka'an*	BR	34,927
Federal	QROO	Arrecifes de Xcalak*	NP	17,949
Federal	QROO	Banco Chinchorro*	BR	144,360
Federal	QROO	Costa Occ. de I. Mujeres, Pta. Cancún y Pt.*	NP	8,673
Federal	QROO	Isla Contoy*	NP	5,126
Federal	QROO	Sian Ka'an*	BR	528,147
Federal	QROO	Tulum	NP	664
Federal	QROO	Uaymil*	APFF	89,118
Federal	QROO	Yum Balam	APFF	154,052
Municipal	QROO	Jurídica Poniente	ZEP	22
Municipal	QROO	Zona Occidental de Microcuencas	ZSEC	11,437
	QROO	Manglares de Nichupte	APFF	4,257
	QROO	Tiburón Ballena**	BR	145,988
State	TAB	Agua Blanca	SP	1,878
State	TAB	Cañón de Usumacinta	SP	46,128
State	TAB	Cascadas de Reforma	ER	5,583
State	TAB	Centro de Interpretación de la Naturaleza	BZER	1,516
State	TAB	Gruta del cerro Coconá	NM	285
State	TAB	Laguna de las Ilusiones	ER	176
State	TAB	Laguna del Camarón	ZSEC	50
State	TAB	Parque Ecológico de la Chontalpa	ER	304
State	TAB	Parque Ecológico Laguna La Lima	ER	21
State	TAB	Río Playa	ER	709
State	TAB	Yu-Balcah	ZSEC	576
Federal	TAB	Pantanos de Centla	BR	30,2706
	TAB	Sierra Madrigal	NR	0
	TAB	Sierra Tijualpa		0
State	YUC	Kabah	SP	996
State	YUC	Lagunas de Yalahau	SP	5,419
State	YUC	Reserva de Dzilam	ZSEC	68,377
State	YUC	Reserva El Palmar	ZSEC	49,065
State	YUC	San Bautista Tabi y Anexa Zac Nicte	SCHV	1,420
Federal	YUC	Dzibilchaltún	NP	539
Federal	YUC	Otoch Ma'ax Yetel Kooh	APFF	5,367
Federal	YUC	Ría Celestún*	BR	81,482
Federal	YUC	Ría Lagartos	BR	60,347
Municipal	YUC	Bioparque Xla'kaj (Pueblo Antiguo)	ZSEC	25
Municipal	YUC	Cuxtal	ZSEC	10,405
Private	YUC	Zapotal	PR	0
Federal	YUC	Arrecife Alacranes*	NP	333,768
			Total area	4,802,520

1988), protected areas are divided into a number of categories classified according to their physiography, ecological features, socioeconomy, and intended uses. Natural areas under federal jurisdiction include Biosphere Reserves, National Parks, Natural Monuments, Natural Protected Areas, and Wildlife Sanctuaries. Other areas of state and municipality jurisdiction are State Ecological Reserves, State Parks, Historic Gardens, Areas of Ecological Preservation, and Municipality Urban Parks or Gardens. Finally, another category includes private conservation areas. These areas are selected following various criteria and features. (1) Biosphere reserves constitute relevant biogeographic areas, representing one or more pristine ecosystems or important habitats that require preservation and/or restoration. They contain species representative of national biodiversity, including those considered endemic, threatened or endangered. In their core zone no use of resources is permitted. (2) National Parks also represent biogeographically important areas involving at least one ecosystem with particular relevance for their scenic beauty, or scientific, educational, recreational, and historical value, or for the existence of a special flora and/or fauna. They are suitable for tourism development. Their core areas can be managed. (3) Natural Monuments contain one or more natural elements, consisting of places or objects that are unique or exceptional for their aesthetic, historic or scientific value. They do not have the variety of ecosystems and the minimum area required to be included in other management categories. (4) The areas for the protection of natural resources are aimed to preserve and protect the soil, catchment, water, and natural resources related to forest lands and are suitable for forestry; this category is applied to areas not covered by other protection categories. These PNAs can belong to the federal or state spheres. (5) Protection areas for flora and fauna contain unique habitats whose balance and preservation is deemed essential for the existence, protection and development of particular biotas or species of flora and fauna. These can be under federal or state jurisdiction. (6) Sanctuaries are established in areas characterized by exceptionally diverse flora or fauna, or by the presence of species, sub-species or with a restricted habitat distribution. These areas cover ravines, meadows, caves, sinkholes, creeks, or other topographical or geographical units that need to be preserved or protected. (7) Private areas are voluntarily dedicated to conservation by landowners; they can have any of the features and biological elements of the other categories and they provide environmental services or promote the local conservation of natural resources in compliance with the objectives of the General Law of Ecological Balance and Environmental Protection (LGEEPA, 1988).

As a rule, the operation of PNAs is regulated by the management programme for the Regulation of Protected Areas (RANP), according to the features, legal status, goals, and needs of the PNA (LGEEPA, 1988). Each management programme contains an analytical outline of the sociology, economy, ecology, and legal framework of the area. This information allows the development of specific strategies to achieve the conservation of ecosystems and their biodiversity through protection, sustainable use, adequate management, and restoration. This process encourages an adequate use of the natural resources and supports productive activities, thus promoting an improved quality of life within local populations. Many of these plans focus on rural and indigenous communities settled in or near these protected areas and include them in long-term goals and scenarios.

METHODS

Several sources of information were consulted in order to compile a basic data set on the crustacean species recorded from the YP. One of the most recent was the set of databases generated from projects supported by the Mexican National Commission for Biodiversity (CONABIO) and made available through their website (Herrera-Silveira, 1997; Maeda-Martínez, 1999; Álvarez and Villalobos Hiriart, 2002; Vásquez-Yeomans *et al.*, 2005; Elías-Gutiérrez, 2006; Batllori-Sampedro *et al.*, 2007). Local listings and species distributions were also compiled and analysed from a number of publications (Iliffe, 1992; Suárez-Morales and Elías-Gutiérrez, 1992; Suárez-Morales and Reid, 2003; Maeda-Martínez *et al.*, 2005; Álvarez and

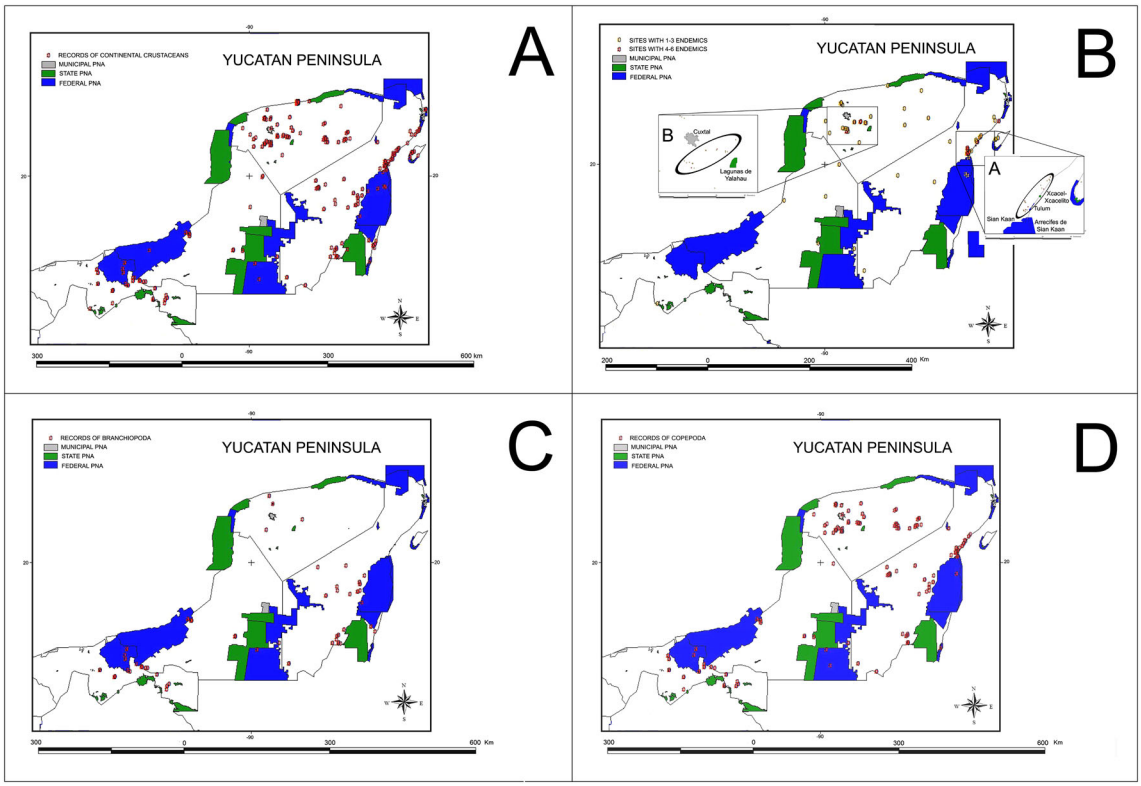

Figure 1. Protected natural areas (PNAs) in the Yucatan Peninsula emphasizing three different government levels (federal, state, municipality) and geo-referenced distribution records of inland crustacean taxa. (A) All continental crustacean taxa; (B) distribution of endemic crustacean taxa in the YP indicating sites with 1–3 and 4–6 endemic species; two critical areas of endemism adjacent to existing PNAs are highlighted, one in the northern sector of the YP (A) and the other in the Tulum area (B); (C) Branchiopoda; (D) Copepoda.

Iliffe, 2008; López-Mejía, 2008; Rocha *et al.*, 2008; Villalobos-Hiriart and Álvarez, 2008) of which all records of inland aquatic crustaceans distributed in the YP and Tabasco were selected. Overall, the database contains 212 species that were assigned to six groups as follows: Branchiopoda, 63; Ostracoda, 2; Copepoda, 61; Peracarida, 24; Decapoda, 60; and Remipedia, 2, totalling 1165 regional records. These data were ordered using ArcView 3.2 GIS software for mapping the PNAs and the crustacean records in order to superimpose all records of the different groups in relation to the coverage and distribution of the PNAs in the YP. In this way, the management plans of the YP PNAs were reviewed in order to determine the effectiveness of protection of inland aquatic areas.

RESULTS

From the distribution data collected, the PNAs were mapped in relation to the geo-referenced records of 212 species belonging to six different groups of crustaceans (Figures 1, 2). Of all the species of crustaceans recorded in the YP, only 39 (Branchiopoda, 18; Copepoda, 11; Peracarida, 9; Decapoda, 1) occur within any PNA, thus representing only 18.5% of the total records. The remaining 81.5% inhabit unprotected areas. Figure 1(B) shows the distribution of the species deemed to be endemic to the YP and their protection status with reference to the location of PNAs. There are 48 species of endemic freshwater crustaceans distributed in the YP (22.43% of the species recorded) (Appendix). Many of these endemic species have a restricted distribution; up to 25 are known from a single locality. Only seven are found within the limits of any of the PNAs; these include three species of Copepoda (*Acanthocyclops rebecae*, *Diacyclops ecabensis*, *Halicyclops caneki*), one of Peracarida (the amphipod *Bahadzia bozanici*) and three of Decapoda (*Procambarus maya*, *Procaris mexicana*,

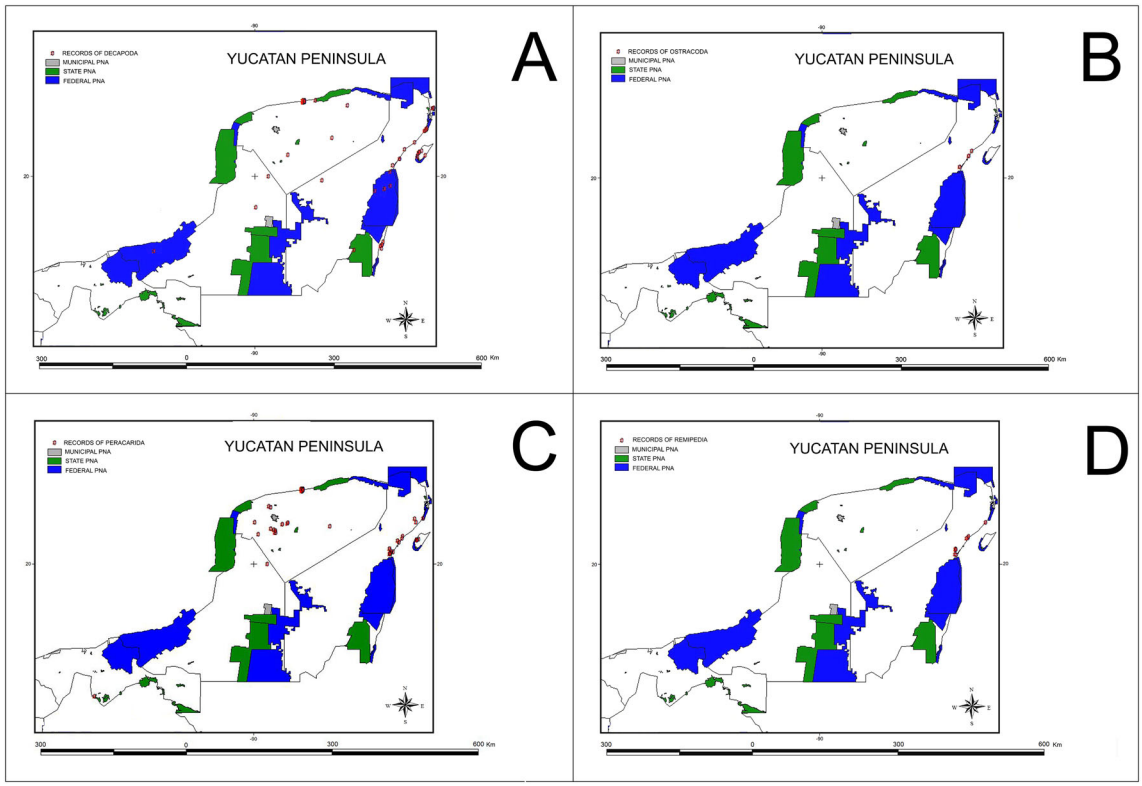

Figure 2. Protected natural areas (PNAs) in the Yucatan Peninsula and geo-referenced distribution records of inland crustacean taxa: (A) Decapoda; (B) Ostracoda; (C) Peracarida; (D) Remipedia.

Yagerocaris cozumel). In addition, only the endemic peracarids *Antromysis* (*Antromysis*) *cenotensis* (threatened) and *Creaseriella anops* (threatened) and the decapods *Creaseria morleyi* (endangered), *Typhlatya campecheae* (endangered), *T. mitchelli* (endangered), and *T. pearsei* (endangered) are within any of the categories provided by the Mexican Official Standard NOM-059-2010 (SEMARNAT, 2010), but none of them occurs within a PNA. Only two endemic species, the decapods *P. maya* and *Procambarus llamasi*, are included in the IUCN lists (IUCN, 2012), the former in the Least Concern category and the latter as Data Deficient.

The Branchiopoda constitute 14.3% of all species records in the YP (Figure 1(C)), only 18 of the 63 branchiopod species occur within the area of a PNA. Only one species is deemed as an endemic form in the YP: *Alona pectinata*, known from a site adjacent to the Biosphere Reserve of Calakmul. The rest of the branchiopod records are distributed mainly in the central part of Quintana Roo and near the border of Tabasco and Campeche. Records of Ostracoda (0.5%, Figure 2(B)) were relatively scarce in the YP. This group contains two endemic species known from three sites (Appendix).

Records of Copepoda are widely distributed in the YP (Figure 1(D)), but mainly in the northern sector of the YP and along the eastern coast of the peninsula, as well as some records in the states of Campeche and Tabasco. Copepod records represented 31.9% of the total crustacean data analysed; this group includes 61 species of which 11 are distributed within a PNA. Up to 17 copepod species are endemic to the YP (Appendix); however, only three are within the area of a PNA. The remaining endemic species are found at locations associated with non-protected areas along the central eastern coast and the northern YP. Among these species, there are three members of the YP endemic genus *Prehendocyclops*.

The Peracarida (Figure 2(C)) accounted for 10.7% of total crustacean records and are represented by 24 species of amphipods, isopods, tanaids, mysids, and thermosbaenaceans. The

group has a high proportion of endemic forms; about 62.5% (15 spp.) of the peracarid species distributed in the YP are endemic to this region (Appendix). Only the amphipod *B. bozanici* is distributed within a PNA (Cozumel Reefs), while other species are distributed primarily in the 'Ring of Cenotes' and in the Tulum area, along the eastern coast of the YP (Figure 2(C)).

The Decapoda represented up to 41.5% of the total crustacean records (Figure 2(A)). Many decapod records are from contiguous locations; thus, the geographical distribution of records involves relatively small areas. Sixty decapod species are distributed in the YP, nine of which occur within the limits of a few PNAs. There are 11 endemic species of decapods in the YP (18%) (Appendix) of which three: *P. maya* (Sian Ka'an), *P. mexicana*, and *Y. cozumel* (Cozumel Reefs) are known to dwell within the limits of a PNA in the YP. The remaining eight endemic decapods are known only from unprotected areas.

Records of Remipedia (0.9%, Figure 2(D)) were relatively scarce in the YP, the group is represented entirely by endemic forms (Appendix). There are only two species of remipedes; their distribution is restricted to eight localities, six of which are currently used for tourist diving. These species are not under any protection status. Records are mainly from the central sector of the eastern coast of the YP.

DISCUSSION

It is well known that the processes of perturbation and transformation of tropical ecosystems, particularly forests and mangroves, has now reached alarming levels. According to FAO (2001) Mexico has one of the highest deforestation rates (0.46×10^6 ha y^{-1}). A high percentage of the original forest vegetation of the YP disappeared in the last decades of the 20th century (Sánchez-Aguilar and Rebollar-Domínguez, 1999; Rueda, 2010). Consequently, inland aquatic systems and their biota have been significantly affected by deforestation, while the rapid urban and touristic development along the Caribbean coast of the YP also poses a serious risk for these fragile systems. Salinization of inland waters, pollution of subterranean aquifers, invasions by alien species, stream degradation, and surface wetlands loss are among the main factors threatening the freshwater Crustacea worldwide (Reid *et al.*, 2002; Wood *et al.*, 2008). At least one of these factors is related to the current conditions of most inland aquatic systems of the YP and their highly diverse biota. The proper management of these ecosystems is essential to ensure the supply and quality of water in the region (Schmitter-Soto *et al.*, 2002). So, there are reasons to consider the karstic system of the YP as an 'imperiled ark of biodiversity' (Clements *et al.*, 2006).

The most threatened species in the processes leading to the erosion of biodiversity are: (i) species whose distributions are restricted to small areas, (ii) species restricted to specific sites, and (iii) species with low population sizes (Rabinowitz, 1981). About 22% of the crustaceans inhabiting inland waters of the YP can be placed in at least one of these categories, which makes them a highly vulnerable group facing extinction processes by human perturbation, primarily habitat loss (Covich *et al.*, 2010). Despite their ecological importance as a group, crustaceans have not attracted much, if any, particular concern in terms of conservation (Reid *et al.*, 2002); consequently, the group has not been taken into account when developing management plans for the PNAs in the region. Another factor related to the lack of attention to the crustacean fauna is that the group does not generally include flagship or charismatic species used in seeking financial support for conservation actions (Walpole and Leader-Williams, 2002). In addition, even the flagship species-based strategies have serious limitations in protecting regional biotas in natural reserves (Andelman and Fagan, 2000).

Protected areas are an effective means to protect tropical biodiversity (Bruner *et al.*, 2001), but no protection is possible if a significant part of the biota is left outside their limits. Overall, only 14.5% of the freshwater crustacean species that are considered endemic in the YP region (seven of 48 endemic species) are distributed within a PNA, while the rest are primarily distributed in areas of sinkholes and submerged caves with a high tourism pressure (e.g. Ring of Cenotes and the Tulum-Puerto Morelos corridor) (Figure 1(B)). The three PNAs protecting these endemic species

(Sian Ka'an Biosphere Reserve, Tulum National Park, and Cozumel Reef) have management programmes, but the invertebrate aquatic biota is not explicitly mentioned or protected, so it is expected that these and other aquatic fauna will not be effectively managed. The only programme containing a section specifically aimed at managing aquatic biota is the Cozumel Reef Park, a coral reef zone with a narrow strip of land including mangrove swamps, lagoons, and sinkholes. Its management plan focuses on the protection of fish and amphibians inhabiting these systems, but the endemic stygobiotic forms are not mentioned. In other PNA programmes, the aquatic sub-component is only treated within a social development framework, which implies exclusive management for human use. This approach overlooks the ecological processes occurring in aquatic ecosystems and their connection to the functioning of adjacent coastal ecosystems, such as mangroves and coral reefs. Moreover, the faunal lists included in such programmes focus on vertebrates and ignore many other animal groups. The lack of knowledge or monitoring of aquatic invertebrates is a factor leading to inadvertent loss of the habitat of epigean and subterranean crustaceans worldwide (Wood *et al.*, 2008); however, the basic taxonomy and ecology of local faunas are under active investigation in many parts of the world, including the YP. The need to expand protection and management to the entire biodiversity of the PNAs should be supported by studies aimed at describing the biological diversity in protected areas of the YP, which has already been done for two biosphere reserves: Sian Ka'an (Navarro and Robinson, 1990; Navarro and Suárez-Morales, 1992) and Banco Chinchorro (Suárez-Morales and Camarena-Luhrs, 2003). These works compile lists of various groups of crustaceans and other invertebrates that have been overlooked and might substantiate existing and potential PNAs.

The preliminary management programme of Tulum National Park covers one of the most important regions in the YP; it includes one of the main areas of cenotes and associated groundwater systems (Tulum-Puerto Morelos) and contains a high number of endemic crustaceans. Although both the National Park and hundreds of cenotes are within this polygon, no specific strategy has been proposed for the management or conservation of these fragile ecosystems. In addition, cenotes are under strong tourist pressure; some of them, such as Cenotes Cristal, Aktun Ha, Calavera, Mojarras, 27 Steps and others have a unique crustacean fauna (Suárez-Morales *et al.*, 1996) but are under the control of local landowners with a limited economic incentive or knowledge to implement local conservation programmes (Langpap, 2006). This area in particular has a wide variety of unique cave fauna, including at least 27 endemic stygobiotic species of crustaceans with a restricted distribution or known from a single site only (Suárez-Morales *et al.*, 1996; Suárez-Morales and Reid, 2003).

Another important zone for the YP crustacean fauna is the 'Ring of Cenotes'. In this area, up to 18 crustacean species with restricted distribution or known from a single site have been recorded, but none of them occurs within the limits of a PNA. This area also includes important sites for endemic fish species, some of them classed as vulnerable because of the reduction and isolation of their distribution areas (Schmitter-Soto *et al.*, 2002). This region is under high pressure from tourism and as it is regulated by the landowners it is thought to be highly vulnerable to habitat loss.

One group of particular interest is the remipedes, considered by some researchers as the most ancestral living forms among the Crustacea; their evolution and biogeography has been actively studied since their discovery in the Caribbean (the Bahamas, Turks and Caicos Islands, Cuba, Dominican Republic, and cenotes in the YP), the Canary Islands and Australia (Yager, 1987; Martin and Davis, 2001; Álvarez and Iliffe, 2008; Neiber *et al.*, 2012). The two remipede species of the YP are known only from unprotected areas and there are probably more cryptic species in these complex subterranean systems. According to Neiber *et al.* (2011), sympatry is the rule rather than the exception for this group. At present, sympatric species of Remipedia are known from nine localities, many of which host four to six other crustacean taxa. Hence, there are more remipede species at risk in the YP; it is most likely that a similar situation is true for cryptic species of other crustacean groups.

Of the 48 endemic species of inland crustaceans of the YP, only two peracarids and two decapods

are categorized within the NOM-059-2010 criteria (SEMARNAT, 2010), but none of these species is distributed within the limits of any PNA in the YP. Except for *T. campecheae*, all other species are considered widespread in the YP (Álvarez and Iliffe, 2008; SEMARNAT, 2010). Culver and Sket (2000) stated that the Walsingham caves in Bermuda (29 species) and the Triadou Wells in France (28) host the highest number of endemic crustaceans. Our data confirm that the number of endemic crustaceans found in the YP, including subterranean and anchialine habitats (more than 40 species) is the highest known worldwide, certainly qualifying the YP as a world hotspot for subterranean biodiversity.

Based on this evidence, there are at least two areas of the YP that are highly relevant in terms of number of crustacean endemics and their restricted geographic distribution: one is the Ring of Cenotes and the other is in the Tulum area (Figure 1(B)). These selected areas include locations that are adjacent to existing PNAs; both could be protected if the adjacent PNAs were expanded. The present data will help to support such a proposal to the CONANP.

CONCLUSIONS AND RECOMMENDATIONS

The current coverage of PNAs in the YP is clearly ineffective in providing protection to the epigean and subterranean inland crustacean fauna. This is a result of failure to cover areas that include the distributional range of most endemic and non-endemic species and ignoring the crustaceans and other aquatic fauna in the creation and development of the PNAs' management plans, thus excluding them from any type of conservation or protection. It is recommended that all PNA management plans be revised to include a section for aquatic ecosystems management.

At present the areas of most concern, owing to high tourist pressures, are the Corridor Tulum - Puerto Morelos Cenotes and the Ring of Cenotes, both having a high crustacean biodiversity including significant numbers of endemic forms. In these cases, management proposals of PNAs should incorporate general regulations for the conservation of habitats, including waste management plans in areas related to water bodies, and strict control of tourist wastes such as sunscreen lotions and insect repellents. In some open water cenotes, large numbers of the epigean fish *Astyanax mexicanus* have learned to follow tourist divers into caves where they voraciously consume any crustacean illuminated by the diver's light beam, thus effectively sterilizing the cave habitat of stygobiotic fauna (Iliffe, pers. obs.). Incentive policies (Michael, 2003; Langpap, 2006) should be explored as an option to promote the preservation of the aquatic habitats on private land in the YP. Owing to the relevance of the karst aquifers worldwide, full assessments of risks and vulnerability should be supported as part of an effective protection strategy (Escolero *et al.*, 2002; Andreo *et al.*, 2006). The epikarst should be protected as a whole system, rather than individual sites (Pipan *et al.*, 2010), because of its ecological role and as a water source.

Studies of the aquatic fauna should be expanded to increase knowledge of their reproduction and ecology, while water quality investigations should document natural conditions in their habitat. Considering the very small percentage of cenotes and underwater caves that have been scientifically investigated, it is highly likely that further biospeleological diving investigations will result in the discovery of new endemic stygobionts. Finally, many crustacean species should be re-evaluated to allow their inclusion in the NOM-059-2010 (SEMARNAT, 2010) in order to provide some protection and thus favour their management and conservation.

ACKNOWLEDGEMENTS

This work is based on the results and efforts developed by many colleagues that have studied the various crustacean taxa in the Yucatan Peninsula. We appreciate their work and we hope that this analysis will encourage new, expanded surveys on this group of invertebrates. We thank the CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad) and the CONANP for granting access to their databases and PNA maps. A previous version of this work was greatly improved following the comments and suggestions from two anonymous reviewers and from the AQC Chief Editor, Professor Philip J Boon.

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APPENDIX GROUP DISTRIBUTION AND PROTECTION STATUS OF INLAND CRUSTACEAN SPECIES IN THE YUCATAN PENINSULA. *ENDEMIC SPECIES; NA: NOT APPLICABLE

Species	Status of protection
Branchiopoda	
Acroperus harpae	NA
Alona costata	NA
Alona davidi	NA
Alona karua	NA
Alona ossianni	NA
*Alona pectinata**	NA
Alona pseudoverrucosa	NA
Alona sarasinorum	NA
Alona setulosa	NA
Bosmina hagmanni	NA
Bosmina tubicen	NA
Camptocercus dadayi	NA
Ceriodaphnia cornuta	NA
Ceriodaphnia dubia	NA
Ceriodaphnia laticaudata	NA
Ceriodaphnia pulchella	NA
Ceriodaphnia rigaudi	NA
Chydorus brevilabris	NA
Chydorus nitidilus	NA
Chydorus ventricosus	NA
Diaphanosoma bergamini	NA
Diaphanosoma brevireme	NA
Disparalona hamata	NA
Dunhevedia americana	NA
Ephemeroporus barroisi	NA
Ephemeroporus tridentatus	NA
Eulimnadia belki	NA
Euryalona orientalis	NA
Graptoleberis testudinaria	NA
Grimaldina brazzai	NA
Guernella raphaelis	NA
Ilyocryptus gouldeni	NA
Ilyocryptus paranaensis inarmatus	NA
Ilyocryptus spinifer	NA
Kurzia latissima	NA
Latonopsis australis	NA
Leptestheria complexmanus	NA
Leydigia striata	NA
Leydigiopsis brevirostris	NA
Macrothrix elegans	NA
Macrothrix marthae	NA
Macrothrix paulensis	NA
Macrothrix spinosa	NA
Moina dumonti	NA
Moina micrura	NA
Moinodaphnia macleayi	NA
Notoalona globulosa	NA
Onchobunops tuberculatus	NA
Oxyurella ciliata	NA
Oxyurella longicaudis	NA
Picripleuroxus denticulatus	NA
Picripleuroxus quasidenticulatus	NA
Pleuroxus unispinus	NA
Pleuroxus varidentatus	NA
Pseudosida ramosa	NA
Pseudosida variabilis	NA
Sarsilatona serricauda	NA
Scapholeberis armata	NA
Simocephalus latirostris	NA
Simocephalus mixtus	NA
Simocephalus semiserratus	NA
Simocephalus serrulatus	NA
Streptocephalus texanus	NA
Ostracoda	
*Danielopolina mexicana**	NA
*Spelaeoecia mayan**	NA
Copepoda	
*Acanthocyclops rebecae**	NA
Acanthocyclops robustus	NA
Acanthocyclops smithae	NA
Amphiascoides walteri	NA
Arctodiaptomus dorsalis	NA
Attheyella pilosa	NA
*Balinella yucatanensis**	NA
Cletocamptus cf. *deitersi*	NA
*Diacyclops chakan**	NA
*Diacyclops ecabensis**	NA
*Diacyclops pilosus**	NA
*Diacyclops puuc**	NA
Ectocyclops herbsti	NA
Ectocyclops phaleratus	NA
Eucyclops agilis	NA
Eucyclops bondi	NA
Eucyclops breviramatus	NA
Eucyclops conrowae	NA
Eucyclops leptacanthus	NA
Eucyclops prionophorus	NA
*Exumella tsonot**	NA
*Halicyclops caneki**	NA
*Halicyclops cenoticola**	NA
Halicyclops magniceps	NA
Homocyclops ater	NA
Leptodiaptomus novamexicanus	NA
Macrocyclops albidus	NA
Mastigodiaptomus albuquerquensis	NA
*Mastigodiaptomus maya**	NA
Mastigodiaptomus nesus	NA
*Mastigodiaptomus reidae**	NA
Mastigodiaptomus texensis	NA
Mesocyclops brasilianus	NA
*Mesocyclops chaci**	NA
Mesocyclops edax	NA

(*Continues*)

Table 1. Continued

(*Continues*)

Table 1. Continued

Species	Status of protection
Mesocyclops evadomingoi	NA
Mesocyclops longisetus curvatus	NA
Mesocyclops longisetus s.str.	NA
Mesocyclops pescei	NA
Mesocyclops reidae	NA
Mesocyclops thermocyclopoides	NA
*Mesocyclops yutsil**	NA
Microcyclops anceps	NA
Microcyclops ceibaensis	NA
Microcyclops dubitabilis	NA
*Microcyclops echinatus**	NA
Microcyclops rubellus	NA
Neutrocyclops brevifurca	NA
Nitokra pusilla	NA
Nitokra spinipes	NA
Osphranticum labronectum	NA
Paracyclops fimbriatus	NA
Parapseudoleptomesochra botosaneanui	NA
*Prehendocyclops abbreviatus**	NA
*Prehendocyclops boxshalli**	NA
*Prehendocyclops monchenkoi**	NA
Prionodiaptomus colombiensis	NA
Pseudodiaptomus marshi	NA
Schizopera tobae cubana	NA
Thermocyclops inversus	NA
Thermocyclops tenuis	NA
Peracarida	
*Antromysis (A.) cenotensis**	THREATENED NOM-059
*Bahadzia bozanici**	NA
*Bahadzia setodactylus**	NA
*Cirolana (Anopsilana) yucatana**	NA
*Creaseriella anops**	THREATENED NOM-059
Cymodoce ruetzleri	NA
Dynamenella angulata	NA
Erichsonella floridana	NA
Excorallana tricornis	NA
*Haptolana bowmani**	NA
*Haptolana yunca**	NA
Hargeria rapax	NA
*Mayaweckelia cenoticola**	NA
*Mayaweckelia yucatanensis**	NA
*Metacirolana mayana**	NA
*Mexigidiella tabescensis**	NA
Paracerceis caudata	NA
Quadrivisio lutzi	NA
Rocinela signata	NA
*Stygiomysis cokei**	NA
Stygiomysis holthuisi	NA
*Tulumella unidens**	NA
*Tuluweckelia cernua**	NA
*Yucatalana robustispina**	NA
Decapoda	
*Agostocaris bozanici**	NA
Alpheus amblyonyx	NA
Alpheus armatus	NA
Alpheus armillatus	NA
Alpheus candei	NA
Alpheus formosus	NA
Alpheus heterochaelis	NA
Alpheus normanni	NA
Alpheus schmitti	NA
Alpheus viridari	NA
Brachycarpus biunguiculatus	NA
*Calliasmata nohochi**	NA
Callinectes sapidus	NA
*Creaseria morleyi**	THREATENED NOM-059
Farfantepenaeus brasiliensis	NA
Farfantepenaeus notialis	NA
Hippolyte zostericola	NA
Latreutes fucorum	NA
Leander tenuicornis	NA
Libinia emarginata	NA
Macrobrachium acanthurus	NA
Macrobrachium carcinus	NA
Macrocoeloma trispinosum	NA
Metapenaeopsis goodei	NA
Palaemon floridanus	NA
Palaemon northropi	NA
Palaemonetes pugio	NA
Periclimenaeus bermudensis	NA
Periclimenaeus caraibicus	NA
Periclimenes americanus	NA
Periclimenes iridescens	NA
Periclimenes yucatanicus	NA
Pitho picteti	NA
Portunus gibbesii	NA
Procambarus llamasi	IUCN LEAST CONCERN
*Procambarus maya**	IUCN DATA DEFICIENT
*Procaris mexicana**	NA
Processa bermudensis	NA
Processa wheeleri	NA
Prunum amabile	NA
Prunum apicinum	NA
Prunum carneum	NA
Prunum guttatum	NA
Prunum pruinosum	NA
Rhithropanopeus harrisii	NA
Sicyonia laevigata	NA
Sicyonia parri	NA
Sicyonia typica	NA
Synalpheus brooksi	NA
Synalpheus dominicensis	NA
Synalpheus filidigitus	NA
Thor dobkini	NA
Thor manningi	NA
Tozeuma carolinense	NA
*Triacanthoneus akumalensis**	NA
*Typhlatya campecheae**	ENDANGERED NOM-059
*Typhlatya dzilamensis**	NA
*Typhlatya mitchelli**	THREATENED NOM-059
*Typhlatya pearsei**	THREATENED NOM-059
*Yagerocaris cozumel**	NA
Remipedia	
*Speleonectes tulumensis**	NA
*Speleonectes fuchscockburni**	NA

(*Continues*)