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**Estimado Dr. Antonio Saldivar Moreno**  
**Director de Posgrado CONACyT**

Aunque es un programa de nueva creación, se cuenta ya con la colaboración de profesores investigadores de otras instituciones (el Núcleo Académico Ampliado), generando publicaciones acordes a las LGAC del programa (se anexan probatorios de lo anterior). Es importante mencionar que los profesores de las instituciones con las cuales se colabora, han manifestado su disposición e interés por participar en este programa de posgrado (se cuentan con las cartas compromiso, las cuales están disponibles en los documentos probatorios de la plataforma de esta convocatoria y en este mismo documento probatorio).

En este sentido, las LGAC se están viendo fortalecidas desde un inicio, lo cual impacta en el mejoramiento del desempeño académico y profesional de nuestros estudiantes, promoviendo la movilidad y cumpliendo con las exigencias de la calidad profesional del CONACyT.

ATENTAMENTE

DR. ADRIÁN CERVANTES MARTÍNEZ

**Universidad de Quintana Roo Unidad Académica Cozumel**

**Profesor-Investigador Tit. "A" SNI I**



# Using small drones to photo-identify Antillean manatees: a novel method for monitoring an endangered marine mammal in the Caribbean Sea

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**ABSTRACT:** Population assessments and species monitoring for many endangered marine megafauna are limited by the challenges of identifying and tracking individuals that live underwater in remote and sometimes inaccessible areas. Manatees can acquire scars from watercraft injury and other incidences that can be used to identify individuals. Here we describe a novel method for photo-identification of Antillean manatees *Trichechus manatus manatus* using aerial imagery captured during flights with a small multicopter drone. Between 2016 and 2017, we conducted 103 flights to detect and observe manatees in Belize, primarily at St. George's Caye (SGC) near the Belize Barrier Reef. Review of aerial videos from these flights resulted in 279 sightings of manatees (245 adults, 34 calves). High-resolution images of individual manatees were extracted and classified according to image quality and distinctiveness of individual manatees for photo-identification. High-quality images of manatees classified as sufficiently distinctive were used to create a catalog of 17 identifiable individuals. At SGC, 21% of all sighted adult manatees (N = 214) were considered photo-identifiable over time. We suggest that the method can be used for investigating individual site fidelity, habitat use, and behavior of manatee populations. Our photo-identification protocol has the potential to improve long-term monitoring of Antillean manatees in Belize and can be applied throughout clear, shallow waters in the Caribbean and elsewhere.

**KEY WORDS:** Drones · Trichechidae · Photo-ID · Manatee · *Trichechus manatus manatus*

## 1. INTRODUCTION

The Antillean manatee *Trichechus manatus manatus* is a subspecies of the West Indian manatee *T. manatus* and is considered Endangered by the IUCN (Self-Sullivan & Mignucci-Giannoni 2008) due to threats such as entanglement, poaching, watercraft collision, and habitat loss (Castelblanco-Martínez et al. 2012). In the Regional Management Plan for the

West Indian manatee (Quintana-Rizzo & Reynolds 2010), long-term and longitudinal studies of individually identifiable animals are recommended to determine the survival rates, reproduction rates, site fidelity, and movement patterns of manatee populations. However, the techniques typically used to identify individuals, such as capturing and tagging animals, are expensive, invasive, and require extensive effort. Devising affordable alternative methods

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RESEARCH ARTICLE

# Genetic structure of Mexican lionfish populations in the southwest Gulf of Mexico and the Caribbean Sea

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## Abstract

The recent expansion of the invasive lionfish throughout the Western Hemisphere is one of the most extensively studied aquatic invasions. Molecular studies have improved our understanding of larval dispersal, connectivity, and biogeographical barriers among lionfish populations, but none have included Mexican localities, an important area for the larval dispersal of *Pterois volitans* through the Western Caribbean and the Gulf of Mexico. Here, we present a genetic analysis of lionfishes collected along Mexican coasts, examining their connectivity with other Caribbean localities (Belize, Cuba, Puerto Rico) and the role of ocean currents on population structure. We collected 213 lionfish samples from seven locations comprising four countries. To evaluate genetic structure, mitochondrial control region and nuclear inter-simple sequence repeat markers were used. We found that lionfish collected along Mexican coasts show a similar haplotype composition (H02 followed by H01 and H04) to other Caribbean locations, and the H03 rare haplotype was not found. Haplotype composition in the southwest Gulf of Mexico suggests a discontinuity between the southern and northern areas of the Gulf of Mexico. The southern area clustered more strongly to the Caribbean region, and this is supported by the complexity of water circulation in the semi-enclosed region of the Gulf of Mexico. Mitochondrial genetic diversity parameters show small values, whereas nuclear markers produce medium to high values. Only nuclear markers highlighted significant genetic differentiation between the southwest Gulf of Mexico and Caribbean region, confirming a phylogeographic break between both regions. Separate analysis of Caribbean locations indicates restricted larval exchange between southern and northern regions of the Mesoamerican Barrier Reef System, potentially in response to regional oceanographic circulation.



## A new *Speleophria* (Copepoda, Misophrioida) from an anchialine cave of the Yucatán Peninsula with comments on the biogeography of the genus

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**ABSTRACT.**—Misophrioid copepods are hyperbenthic or anchialine forms whose known distributional patterns appear to have a Tethyan origin and subsequent vicariant processes. A new misophrioid copepod, *Speleophria germanyanezi* n. sp., collected from an anchialine cave in Cozumel Island, Yucatán Peninsula (YP), is described based on male and female specimens. This is the second report describing a misophrioid copepod species from the Yucatán Peninsula, harboring a remarkably diverse anchialine crustacean fauna. The new species is the sixth of this anchialine genus. It differs from its congeners by a combination of characters including: the armature of leg 4 exopod, 21-segmented female antennule, 24-segmented male antennule, both with moderate proximal expansion, the male with the terminal antennular segments distinctively elongate. The fifth leg distal segment is armed with 3 elements in the female, 4 in the male. The female genital double-somite is furnished with long, slender spinules. The other members of *Speleophria* are distributed in Europe (Croatia, Spain), Bermuda, and Australia. Relationships among species of *Speleophria* have revealed amphiatlantic pairs of sister taxa. The new species has little affinity with its regionally closest congener from Bermuda; it appears to be most closely related to the Croatian *S. mestrovi* and could be its western Atlantic counterpart. The different misophrioid fauna between the YP and Cozumel Island and the more recent emergence of Cozumel with respect to that of the YP plate suggests either an ancestral Tethyan-related independent colonization or a relatively recent local dispersal through deep-sea crevicular habitats before emergence of these land masses.

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Misophrioid copepods include deep-sea hyperbenthic, a bathypelagic, and many anchialine forms that have been reported from different geographic regions (Boxshall and Roe 1980, Boxshall 1983, 1987, Boxshall and Iliffe 1986, 1990, Huys 1988, Jaume and Boxshall 1995, 1996a,b, 1997, 1998, Boxshall and Jaume 2000, Jaume et al. 2001, Boxshall et al. 2014), including the Yucatán Peninsula (YP) (Boxshall et al. 2014).

# Is captive breeding a priority for manatee conservation in Mexico?

ALEJANDRO ORTEGA-ARGUETA and DELMA NATALY CASTELBLANCO-MARTÍNEZ

**Abstract** The Endangered Antillean manatee *Trichechus manatus manatus* is one of the most threatened aquatic mammal species in Mexico and the wider Caribbean region. The decline of this subspecies is mainly a result of historical exploitation and the impact of current coastal development. The conservation strategies adopted for the Antillean manatee include habitat protection, reduction of the most severe threats, and the rescue of stranded, orphaned or injured individuals and their management in captivity. This latter strategy has produced positive outcomes in some countries but has been the subject of controversy in others, including Mexico. We analyse the benefits and challenges associated with the management of captive manatees in Mexico, and the consequences of a lack of government policy and strategy for the post-rehabilitation release of individuals. We describe the evolution of this controversy from 1997–2017 in Mexico, analyse the consequences and implications for the conservation of the species, and propose an integrated management strategy that could address the issues raised. Although this strategy has been developed in the context of Mexico, it is applicable to management of this species across the Caribbean region.

**Keywords** Antillean manatee, captive breeding, captive management, decision-making, Mexico, post-rehabilitation release, threatened species recovery, *Trichechus manatus*

## Introduction

The Antillean manatee *Trichechus manatus manatus* is one of the most threatened aquatic mammal species across its range in eastern North, Central and South America. In Mexico, it occurs along the coasts of the Gulf of Mexico and the eastern Yucatan Peninsula (Colmenero-Rolón & Hoz, 1986; Morales-Vela & Olivera-Gómez, 1997) as two genetically distinct populations (Nourisson et al., 2011). An estimated 1,000–1,500 manatees inhabit Mexican waters (Castelblanco-Martínez et al., 2012).

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Threats to manatees include poaching, entanglement in fishing nets and habitat loss caused by intensive coastal development (Morales-Vela & Olivera-Gómez, 1997; Ortega-Ortiz et al., 2004). To address these threats, priority conservation strategies are being directed towards effective management for recovery (Quintana-Rizzo & Reynolds, 2010; SEMARNAT/CONANP, 2010). One of the management strategies is the rescue of injured or stranded manatees and their transfer to rehabilitation facilities. Although captive breeding of threatened species is a widespread conservation strategy (IUCN, 1998), it is not always feasible or justifiable as a management priority (Hunter et al., 2013). Decision-making in conservation needs to take into account complex social considerations and is subject to human emotion (Ainsworth et al., 2016), which can lead to erroneous or late decisions with unintended or unforeseen management outcomes (Wilson et al., 2009; Brook et al., 2014). In the management of threatened species, attention can be diverted to unnecessary or lower priority actions, with costly consequences in terms of funding and achievement of recovery goals (Pérez et al., 2012). Here we document a controversy surrounding the captive management and breeding of manatees in Mexico, examining whether captive breeding is a priority for manatee conservation. We describe the evolution of this controversy over 2 decades (1997–2017) and analyse the consequences of the decisions made and the implications for manatee conservation, and, to address these issues, propose an integrated management strategy that involves aspects of both in situ and ex situ conservation. Although this analysis was carried out in the context of Mexico, it is relevant and applicable to the management of this species across the wider Caribbean region.

## Conservation benefits of manatee management in captivity

Manatees can be injured or orphaned as a result of anthropogenic or natural events and become dependent on rescue and rehabilitation in appropriate facilities. Partnerships of government authorities with state and private zoos play an important role by providing the necessary veterinary care, husbandry and research opportunities. Such partnerships have been established successfully in the USA (including Puerto Rico), Brazil and Venezuela, where manatees have been held in captivity (Adimey et al., 2012; Normande

# Remarks on *Mastigodiptomus* (Calanoida: Diaptomidae) from Mexico using integrative taxonomy, with a key of identification and three new species

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## ABSTRACT

**Background:** In Mexico, species of four families of free-living calanoid copepods have been recorded as inhabitants of several freshwater systems. These families are Centropagidae, Temoridae, Pseudodiaptomidae and Diaptomidae. The genera *Leptodiptomus* and *Mastigodiptomus* are the most speciose diaptomid genera in Mexico, and they inhabit natural and artificial lakes, ephemeral ponds, springs, and caverns. *Leptodiptomus* is considered as an endemic Nearctic genus, whereas *Mastigodiptomus* is a widely distributed Neotropical genus in the southern USA, Mexico, the Caribbean Islands and Central America. Based on new and recent evidence, *Mastigodiptomus* diversity has been underestimated: six species of the genus were known before 2000. In this work three new *Mastigodiptomus* species have been described from different regions of Mexico by using integrative taxonomy. We also gave amended diagnosis of *M. nesus* Bowman (1986) and *M. patzcuarensis* s. str. (Kiefer, 1938).

**Methods:** In this work, the taxonomic status of the species was clarified using modern, integrative method based on the COI gene as a DNA marker, plus micro-structural analysis (based on SEM and light microscopy).

**Results:** Three new species of *Mastigodiptomus* were described based on genetic and morphological analyses: *M. alexei* sp. n., *M. ha* sp. n. and *M. cihuatlan* sp. n. Also amended description of *M. nesus*, morphological variation of *M. patzcuarensis* s. str., and a comparison of them with all known sequences within the genus are provided. These new findings show that in *Mastigodiptomus* differences in several cuticular microstructures of several appendages (such as the antennules, the fifth legs, or the urosomites of these copepods) agree with the interspecific genetic divergence >3% observed in sequences of the COI gene, and the integration of this information is a powerful tool in species delineation.

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Additional Information and  
Declarations can be found on  
page 40

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**Subjects** Biodiversity, Taxonomy, Freshwater Biology

**Keywords** COI gene, Freshwater, Barcodes, Zooplankton, Copepoda, Neotropical



# Vulnerability of Coastal Resort Cities to Mean Sea Level Rise in the Mexican Caribbean

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## ABSTRACT

We evaluated the potential economic impacts of increasing sea level rise (SLR) along the Mexican Caribbean where there are major gaps in our understanding of the mechanisms controlling flooding duration and frequency associated to future ecological and economic impacts. We determined the negative economic impact of SLR on infrastructure in the largest urban centers (Cancun, Isla Mujeres, Playa del Carmen, Puerto Morelos and Cozumel) in the state of Quintana Roo (Mexico) that are considered the largest tourism “hot spots” (resort cities) in the country. The tourism industry in this coastal area injects >8 billion dollars year<sup>-1</sup> to the Mexican economy. Our conservative economic assessment regarding the impact of SLR, under a 1 m scenario for all coastal cities is \$330 million USD. Further projections for worst scenarios (SLR >2 m) show a non-linear trend where the cost of inaction can reach up to \$1.4 billion USD (2 m SLR scenario) and \$2.3 billion USD (3 m SLR scenario). This potential loss of infrastructure, as construction cost, is staggering and represents a robust baseline to start evaluating with more detail future impacts of climate variability and change on the Mexican Caribbean coastline.

## KEYWORDS

Caribbean; coastal vulnerability; coastal urban center; tourism infrastructure; sea level rise

## Introduction

Coastal urban centers are historically vulnerable to flooding caused by both storms and sea level rise (SLR). Although these environmental risks are exacerbated by climate change (Chust et al. 2010; Cooper and Lemckert 2012; Kuhn, Tuladhar, and Corner 2011), it is estimated that more than half of the world population lives within 100 km of the coastline including 600 million people living along coastal regions located less than 10 m above sea level (McGranahan, Balk, and Anderson 2007). It is expected that by 2030, the coastal population exposed to SLR and coastal flooding will be 8 billion (Neumann et al. 2015). The specific geographic distribution of major urban centers varies around the world and depends, among other variables, on economic, cultural,

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## Short Note

Carlos Alberto Niño-Torres, Delma Nataly Castelblanco-Martínez, María del Pilar Blanco-Parra\* and Roberto Sánchez Okrucky

## Mandibular osteomyelitis in the bottlenose dolphin *Tursiops truncatus* (Montagu, 1821) (Odontoceti: Cetacea): first case in the Mexican Caribbean

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**Abstract:** Oral pathological conditions are common in mammals and have been relatively well documented for some wild groups, but are rarely reported in marine mammals. Here, we report for the Mexican Caribbean the first case of mandibular osteomyelitis in a free-ranging dolphin. A bottlenose dolphin *Tursiops truncatus* adult male (256.5 cm total length) was found stranded dead in the west coast of the State Reserve “Chetumal Bay Manatee Sanctuary”. Herein, we discuss some plausible explanations about the origin of this lesion to improve the knowledge about the species biology.

**Keywords:** cetacean; infectious disease; marine mammals; Mexican Caribbean; oral pathology; osteomyelitis; stranding.

Oral affections caused by pathological conditions are common in mammals (Fagan et al. 2005) and relatively well documented in some groups, especially in terrestrial

animals (Hoefs and Bunch 2001). Despite this, it is believed that osteomyelitis (spine, peripheral bones and mandibular osteomyelitis) is a common infection in dolphins (Sweeney and Ridgway 1975), there are few reports of this disease in this group (De Smet 1977, Brooks and Anderson 1998, Ramos et al. 2001, Montes et al. 2004, Van Bressemer et al. 2006, 2007a,b, Loch et al. 2011, Fettuccia et al. 2013). Due to the lack of information available about oral/dental lesions in cetaceans, Brooks and Anderson (1998) recommended to be alert and report any related case. Nevertheless, since that publication, few reports have been added.

The bottlenose dolphin *Tursiops truncatus* (Montagu, 1821) is the most common dolphin worldwide (Leatherwood and Reeves 1983). The species has a cosmopolitan distribution occurring principally in temperate and tropical waters, and is considered the most common cetacean in the Mexican Caribbean (Navarro 1992, Zacarías 1992, Niño-Torres et al. 2015). Despite its current categorization as Low Concern (LC) by the International Union for Conservation of Nature (IUCN) (Hammond et al. 2018), it has been suggested that several local populations/groups should be classified into the Data Deficient (DD) category. Mexican laws catalogued the bottlenose dolphin as subject to special protection (NOM-059-SEMARNAT 2010). Additionally, the species is listed in the Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2018).

The disease (mandibular osteomyelitis) is characterized by a severe deep bone infection (Antiabong et al. 2013), and its etiologic agents involve bacteria (culturable and non-culturable) established in the oral cavity (Moore and Moore 1994, Soto et al. 2014). Typically, the infection begins with gum damage and the entry of bacteria in the tooth socket that eventually spreads into the soft tissues reaching the jaw bone (Lang et al. 2009). Following the inflammatory process, necrotic tissues and pus fill the bone, and the infection gradually destroys the jaw (Sundqvist et al. 1979).

As part of the duties of the Marine Mammal Stranding Network of the State of Quintana Roo, a dead adult male

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Article

# Historical Zooplankton Composition Indicates Eutrophication Stages in a Neotropical Aquatic System: The Case of Lake Amatitlán, Central America

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**Abstract:** This paper presents a study of freshwater zooplankton biodiversity, deemed as a reliable indicator of water quality. The Guatemalan Lake Amatitlán, currently used as a water source, has shown signs of progressive eutrophication, with perceptible variations of the local zooplankton diversity. Biotic and abiotic parameters were determined at four sites of Lake Amatitlán (Este Centro, Oeste Centro, Bahía Playa de Oro, and Michatoya) in 2016 and 2017. The local composition, the species richness and abundance of zooplankton, and the system environmental parameters were analyzed during both years surveyed. Biological data suggesting eutrophication of this tropical system were obtained, including a high rotifer abundance (11 species: the rotifers *Brachionus havanaensis* (109 ind L<sup>-1</sup>) and *Keratella americana* (304 ind L<sup>-1</sup>) were the most abundant species in this lake). The presumably endemic diaptomid copepod species, *Mastigodiatomus amatitlanensis*, was absent in our samples, but we report the unprecedented occurrence of two Asian cyclopoid copepods (i.e., *Thermocyclops crassus* and *Mesocyclops thermocyclopoides*) for Lake Amatitlán and Guatemala. The presence of larger zooplankters like adults and immature copepods (i.e., *Arctodiatomus dorsalis*) and cladocerans (*Ceriodaphnia* sp.) at site “Este Centro” indicates a relatively healthy zooplankton community and represents a focal point for managing the conservation of this lake.

**Keywords:** conservation; eutrophication; exotic species; tropical lakes; zooplankton

## 1. Introduction

The knowledge of zooplankton in the Neotropical region is growing with fragmented studies. Therefore, it is likely that the species richness of zooplanktonic taxa is underestimated because of the presumably high diversity and scarcity of zooplankton taxonomists [1–3]. In addition, the progressive destruction of aquatic habitat and the progressive spread of exotic species threaten native biodiversity, ecosystem health, and environmental services.

The zooplankton community and abundance are closely linked to the trophic state of the water system; for this reason, its diversity has been deemed as an indicator of water quality [4]. In eutrophicated systems (at tropical and temperate latitudes), the dominance of microzooplankton is common, compared with larger organisms, owing to the increased availability of food and water conditions [5,6].

Article

# Phenetic and Genetic Variability of Continental and Island Populations of the Freshwater Copepod *Mastigodiatomus ha* Cervantes, 2020 (Copepoda): A Case of Dispersal?

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**Abstract:** The diversity of freshwater zooplankton is still little known in Mexico, particularly in reference to insular zooplankton communities. Diaptomid copepods (Crustacea: Copepoda: Calanoida) are a widespread group worldwide, and Mexico harbours high diaptomid diversity. Based on a recent sampling of freshwater zooplankton on a Caribbean Island of Mexico, we present the first record of a diaptomid copepod from an island freshwater ecosystem. It shows the well-known tendency of Neotropical diaptomids to have restricted distributional patterns and high levels of endemism. The species recorded, *Mastigodiatomus ha* (Cervantes-Martínez, 2020) appears to have a restricted distribution in the Yucatan Peninsula (YP), and the island as well. In order to explore potential differences between the island and continental populations of this species, its phenetic and genetic diversity was analysed by performing morphological comparisons and also by exploring differences of the habitat conditions and genetic sequences (CO1 gene). Our analysis revealed a low (average = 0.33%) genetic divergence between both populations; likewise, both the morphology and habitat conditions closely resemble each other in these two populations. The low genetic divergence between the continental and island populations of *M. ha* suggests an early common origin of the species in the geological history of the YP.

**Keywords:** barcoding; Calanoida; diaptomids; freshwater; insular water bodies; new record

## 1. Introduction

The diverse zooplankton community inhabiting the epicontinental and underground freshwater ecosystems of the Yucatan Peninsula (YP) can be largely constituted by calanoid copepods belonging to the most successful freshwater group; the family Diaptomidae. Diaptomids tend to have restricted distributional patterns, with many endemic species in the Neotropical region [1].

*Mastigodiatomus* is one of the most diverse genera in Mexico, currently including 13 species. The genus is widely distributed in the Neotropical region, including the Caribbean islands, Central America, and areas of the Southern United States [2,3].

Recently, Gutiérrez-Aguirre et al. [3] described three new species of the genus from Mexico; *Mastigodiatomus cihuatlan* (Gutiérrez-Aguirre, 2020), *M. alexei* (Elías Gutiérrez, 2020), and *M. ha* (Cervantes-Martínez, 2020). The latter was found in sinkholes (locally known as cenotes) in the northeastern continental zone region of the YP.

After 15 years of basic studies on the freshwater and anchialine zooplankton in Cozumel Island [4–6], this is the first report of a diaptomid copepod on a Mexican island. Previously, *M. ha* has been recorded in continental freshwater systems in the north-northeastern region of the YP [3]. In this study we analysed the phenetic and genetic distances between the island and continental populations, and specimens from the type

**NOTE**

# Lords of the Rings: Mud ring feeding by bottlenose dolphins in a Caribbean estuary revealed from sea, air, and space

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Bottlenose dolphins (*Tursiops* spp.) display a remarkably diverse array of individual and cooperative foraging tactics across their global distribution that typically reflect local adaptations to habitat conditions and prey types (Finn et al., 2009; Mann & Sargeant, 2003; Torres & Read, 2009). Specialized foraging methods documented to date include strand feeding (Hoese, 1971; Sargeant et al., 2005), kerplunking (Connor et al., 2000; Nowacek, 2002), cooperative foraging with fishermen (Pryor & Lindbergh, 1990), driver-barrier feeding (Gazda et al., 2005), foraging in or around trawl nets (Kovacs & Cox, 2014), and using tools, particularly sponges (Krützen et al., 2014; Smolker et al., 1997) and shells (Allen et al., 2011; Wild et al., 2020).

Mud ring feeding is a tactic used by common bottlenose dolphins (*T. truncatus*) inhabiting the interior of Florida Bay (Engleby & Powell, 2019; Torres & Read, 2009). This tactic involves a single “ring-maker” dolphin (typically in a group) that swims rapidly in a circle near the seafloor along shallow inner-basin mud banks. Strong fluke kicks against the muddy substrate create a large circular mud plume or mud ring barrier used to encircle a fish school, commonly mullet (*Mugil* spp.). Once the prey are encircled, individual dolphins wait with open mouths and lunge to catch airborne fish as they attempt to flee at the water’s surface (Engleby & Powell, 2019; Torres & Read, 2009). In the lower Florida Keys, bottlenose dolphins display mud plume feeding behavior where they individually create a semi-circular-shaped mud plume over seagrass beds and lunge into the plumes to capture prey (Lewis & Schroeder, 2003).

Novel remote-sensing techniques such as small unmanned aerial vehicles (UAVs or, commonly, drones) and the analysis of very high-resolution (VHR) satellite imagery (<1 m spatial resolution), have become increasingly affordable



# Spatial patterns of shark-inflicted injuries on coastal bottlenose dolphins in the Mesoamerican Reef System

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## ABSTRACT

Understanding predator–prey relationships is critical in ecology, but relatively challenging when investigating elusive marine megafauna. In this study, we document the presence of shark-inflicted injuries on coastal bottlenose dolphins (*Tursiops truncatus*) in the Mesoamerican Reef System using photo-identification methods. We analyzed data from a total of 533 photo-identified bottlenose dolphins in Mexico (Ascención Bay, Espíritu Santo Bay, and Chetumal Bay), Belize (Turneffe Atoll, Drowned Cayes, Barrier Reef, and Placencia), and Honduras (Utila). We identified 16 individuals with shark-inflicted injury scars consistent with attacks by large sharks of the Family Carcharhinidae. Additionally, two bottlenose dolphins were encountered with round-shaped crater wounds, likely inflicted by a cookiecutter shark (*Isistius* spp.). The prevalence of shark-inflicted wounds in bottlenose dolphins varied markedly between sites, with the highest prevalence in Placencia and Ascención Bay (Mexico), and lowest in Turneffe Atoll and Drowned Cayes (Belize). Further research is required to evaluate how predation risk shapes the ecology of bottlenose dolphins in the Mesoamerican Reef region.

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Shark bites; *Tursiops truncatus*; cetaceans; carcharhinids; cookiecutter sharks; Caribbean

## Introduction

Understanding predation pressure on animal populations is critical in community and behavioral ecology. Predation risk can have a major role in shaping the population dynamics and behavior of animal species (Lima & Dill 1990; Magnhagen 1991; Lima & Bednekoff 1999; Creel et al. 2007). Although considered as high trophic level consumers, most small cetacean species are mesopredators and can experience varying levels of predation pressure from large apex marine predators, particularly killer whales (*Orcinus orca*) and sharks (Heithaus 2001a; Kiszka et al. 2015). Very little is known on the exposure of small cetaceans to predation risk for most coastal cetacean populations, and how predation risk can affect behavior, habitat use patterns, and fitness (Heithaus & Dill 2006; MacLeod et al. 2007; Kiszka et al. 2011). However, various studies have shown that small cetaceans exposed to predators and predation risk (particularly from large sharks and killer whales) include short to long-term responses. Short-term responses include fleeing or changes in group behavior (Connor & Heithaus 1996;

Ford & Ellis 1999), and longer-term responses can include changes in habitat use and grouping tactics (Heithaus & Dill 2002, Kiszka et al. 2011). Assessing relative predation risk is challenging since predation events on small cetaceans can be rare or difficult to observe. Several studies have suggested that predation attempts (e.g. scars and other injuries) could be used to gain insights into predation risk or pressure to a wide range of taxa, including coastal dolphins (Heithaus 2001b; Smith et al. 2018).

The Mesoamerican Reef System (MARS) is the largest continuous reef in the Western Hemisphere (16.48–21.5° N, 85.77–86.8° W). It stretches over 1,000 km from the Bay Islands (Utila, Cayos Cochinos, Roatan, and Guajana) north of Honduras through Guatemala and Belize to the tip of Mexico's Yucatan peninsula (Paris & Chérubin 2008). Many productive ecosystems are part of the MARS including coral reefs, seagrass beds, and mangrove areas, which provide critical habitats for many species and coastal fisheries. At least 19 species of marine mammals have been reported in the Exclusive Economic Zones (EEZ) of the Mexican Caribbean and Belize (Niño-Torres



# Historical analysis of a karst aquifer: recharge, water extraction, and consumption dynamics on a tourist island (Cozumel, Mexico)

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**Abstract** – On Cozumel Island, access to freshwater depends on the extraction of the resource from the aquifer located north of the island (catchment area). Water resource management on the island must be based on updated knowledge of the indicator dynamics related to the recharge of the aquifer, groundwater extraction and the distribution of the resource. In this study, trends, variations and time series of 30 years of monthly data for precipitation, temperature, evapotranspiration, and estimated aquifer recharge were calculated for the catchment area. Additionally, groundwater extraction, water consumption for the main uses over a 13-year period (monthly data), and the 5-year status of wells were considered. The results show decreasing trends in precipitation and estimated recharge volumes in the catchment area, in addition to increasing trends in mean air temperature, evapotranspiration, water extraction volumes and consumption by the commercial sector for the considered time periods. Additionally, an increase in dejected (77%) and reposed (38%) wells within the catchment area was observed. Evidence from this study suggests a dynamic behaviour of the analysed indicators over time that increases pressure on karstic, Caribbean aquifers for which monthly monitoring and data analysis are encouraged as the basis for adequate management.

**Keywords:** Aquifer sustainability / groundwater management / Mann Kendall trend test / time series / water consumption

## 1 Introduction

Coastal aquifers (CAs) are a valuable source of freshwater for the coastal environment well-being of over 60% of the global population that is concentrated around the shoreline (Zepeda *et al.*, 2018) and 11% that lives on islands (Mendoza-Vizcaino *et al.*, 2016). Aquifers near coastal areas are susceptible and sometimes unable to cope with the adverse effects of overextraction (Jaleel *et al.*, 2020; Zepeda *et al.*, 2018), sea water intrusion (Deng *et al.*, 2017), pollution (Hernández-Terrones *et al.*, 2011; Kammoun *et al.*, 2021), and climate change effects, such as rainfall pattern modification and sea level rise (Cashman, 2014; GWP, 2014; Hall *et al.*, 2013; Pulido-Velazquez *et al.*, 2018). Because of their nearness to the sea, CAs and island aquifers (IAs) share similarities, although IAs are unique in that they are confined to a geographical area. Also, IA territory may typically

correspond only to one country, and rainwater infiltration is the main source of recharge (Falkland, 1993), with most systems being just as complex as continental counterparts that require particular assessment for management (Gamble, 2004). These characteristics allow an IA to be an ideal model and scenario for research on aquifer recharge, groundwater withdrawals and water demand, which will contribute to further understanding IA dynamics as the basis for sustainable water management.

Cozumel is the third largest island in Mexico and the most populated island, located in the southeastern State of Quintana Roo, where the drinking water supply depends on the aquifer recharged only by rain (Gutiérrez-Aguirre *et al.*, 2008). Like in many other karstic nature islands, rainwater rapidly infiltrates into the aquifer, although they are highly vulnerable to pollution infiltration and water scarcity (Medici *et al.*, 2019, 2020). Vulnerability is an intrinsic property of karstic island aquifers, which depends on characteristics of the area and the sensitivity of the system to human and natural impacts (Ducci and Sellerino, 2013; Kačaroğlu, 1999; Medici *et al.*, 2021), such as wastewater infiltration, hurricanes and saltwater

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## *Paracyclops chiltoni* inhabiting water highly contaminated with arsenic: Water chemistry, population structure, and arsenic distribution within the organism<sup>☆</sup>

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### ABSTRACT

We investigated population structure and arsenic bioaccumulation and distribution in zooplankton inhabiting highly contaminated freshwater with arsenic. We collected water and zooplankton samples over a 4 year period, determined environmental temperature as well as water temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), dissolved oxygen (DO), major cations and anions and total arsenic concentration. We identified zooplankton species and determined their abundance, length, sex ratios, and arsenic bioaccumulation and distribution in exposed organisms. At the study site, an extremophile, *Paracyclops chiltoni*, was found to survive in an environment with high concentration of arsenic, sulfate and fluoride in freshwater as a well-adapted organism. Results showed that the average arsenic concentration in freshwater was  $53.64 \pm 10.58$  mg/L. Exposed organisms of *Paracyclops chiltoni* showed arsenic accumulation (up to  $9.6 \pm 5.4$  mgAs/kg) in its body, likely in the digestive tract as well as typical abundance and length, which showed a relationship to environmental temperature and oxic conditions in freshwater. Metallotolerant copepods might help to better understand if arsenic methylation processes occur in freshwater aquatic organisms.

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### 1. Introduction

Due to natural and anthropogenic processes and activities, arsenic (As) can be found in freshwater at concentrations that can cause stress to zooplankton, impacting their population ecology and morphology as well as their abundance, size, sex, and sex ratio (female:male), among other parameters (Conde-Porcuna et al., 2004; De la Lanza-Espino et al., 2011; Dinh et al., 2020; Karlsson

and Winder, 2020; Zhao et al., 2018; Zhu et al., 2020). Concentrations of As as high as 3 mg/L have been reported to be lethal to zooplankton experimentally (Chen et al., 1999). However, it is fairly well known that all main groups of freshwater zooplankton, cladocerans, rotifers and copepods, bioaccumulate As (Alvarado-Flores et al., 2019; Byeon et al., 2020; Caldwell et al., 2011; Caumette et al., 2012; 2014 Rubio Franchini et al., 2015). This is likely due to the biotransformation of more toxic inorganic As species to less toxic arsenobetaine and arsenosugars species, as it has been demonstrated for marine and freshwater organisms, respectively (Caumette et al., 2012, 2014).

X-ray Fluorescence (XRF) studies on cladocerans, *Daphnia pulex* inhabiting in lakes with 0.25 mg/L of As and *Daphnia magna* exposed to As in laboratory cultures, indicate arsenic accumulation

<sup>☆</sup> This paper has been recommended for acceptance by Philip N. Smith.

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# Detecting, counting and following the giants of the sea: a review of monitoring methods for aquatic megavertebrates in the Caribbean

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## Abstract

The Caribbean is a mega-diverse and bio-geographically important region that consists of the Caribbean Sea, its islands, and surrounding coastlines. Among the billions of aquatic species inhabiting this region, the mega-vertebrates stand out for their social, economic and ecologic relevance. However, the Caribbean has been threatened by climate change, poverty, pollution, environmental degradation and intense growth of the tourism industry, affecting megafauna species directly and indirectly. Population monitoring plays a critical role in an informed conservation process and helps guide management decisions at several scales. The aim of the present review was to critically examine the methods employed for monitoring marine megafauna in the Caribbean, so as to create a framework for future monitoring efforts. In total, 235 documents describing protocols for the monitoring of sirenians, cetaceans, elasmobranchs, sea turtles and crocodylians in the Caribbean region, were reviewed. The methods included community-based monitoring (interviews, citizen science and fisheries monitoring), aerial surveys (by manned and unmanned aerial vehicles), boat-based surveys (including manta tow, and side-scan sonars), land-based surveys, acoustic monitoring, underwater surveys, baited remote underwater video, mark–recapture, photo-identification and telemetry. Monitoring efforts invested on aquatic megafauna in the Caribbean have been highly different, with some species and/or groups being prioritised over others. The present critical review provides a country-based overview of the current and emerging methods for monitoring marine megafauna and a critical evaluation of their known advantages, disadvantages and biases.

**Additional keywords:** Atlantic sea, crocodylians, elasmobranch, marine mammals, megafauna, sea turtles.

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## Introduction

The Caribbean region stands out for its beauty and biodiversity. It also encompasses several low-income countries; poverty is widespread throughout both the mainland and islands countries, where an average of 38% of the population is impoverished (Barker 2002). In consequence, the economic investment in natural-resource management, enforcement and monitoring is still low, despite the regional intergovernmental cooperation for marine conservation (Barker 2002). As all aquatic systems on the Earth, the Caribbean is threatened by climate change, pollution and environmental degradation (Lewsey *et al.* 2004).

A constantly growing tourism industry adds additional impacts on these ecosystems and species (Holder 1988).

Overall, large-bodied species play an important role in the trophic dynamic of aquatic ecosystems, consuming large amounts of food necessary to maintain their large biomass, and control prey populations (Morissette *et al.* 2006; Castelblanco-Martínez *et al.* 2012; Heupel *et al.* 2014). Some megavertebrates (marine mammals and elasmobranchs) have *K*-selected life-history features (i.e. longevity, late maturation, large size, and small number of progeny) that make these species particularly prone to hunting and/or fishing, boat collisions,

# EL MANEJO INTEGRADO DE LOS RECURSOS HÍDRICOS EN EL ACUÍFERO INSULAR DE COZUMEL, QUINTANA ROO, MÉXICO

## *Integrated Water Resource Management in the island aquifer of Cozumel, Quintana Roo, Mexico*

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## Resumen

El Manejo Integrado de los Recursos Hídricos (MIRH) es de vital importancia para ambientes insulares donde el volumen del acuífero es limitado y el incremento en la demanda, junto con el deterioro en su calidad, amenazan su disponibilidad para el futuro. En el siguiente ensayo se analiza el MIRH en la isla Cozumel (México) a partir de la definición de la Asociación Mundial para el Agua (AMA), con lo cual se caracteriza la situación actual de las políticas, instituciones e instrumentos (PIEs) en el contexto local y federal. El análisis bajo la definición de la AMA permite homologar criterios para abordar el MIRH y así aportar al enriquecimiento del concepto a través del estudio del caso particular en la isla Cozumel; además de contribuir a identificar los retos para la implementación del MIRH en la zona de estudio. Mediante este ensayo fue posible identificar las bases de las PIEs y su sincronización local con la federal, así como el manejo actual del acuífero, y

## Abstract

The Integrated Water Resource Management (IWRM) is vital for island environments where the volume of the aquifer is finite. The following essay analyzes IWRM in Cozumel Island (Mexico) based on the definition of the Global Water Partnership (GWP), which allows to characterize the current situation of policies, institutions and instruments for management in the local and federal context. The analysis under the definition of the GWP allows to standardize criteria to address the IWRM and thereby contribute to the enrichment of the concept through the study of specific cases such as Cozumel Island; it also contributes to identify current challenges for the implementation of the IWRM in the study area. Throughout this essay, the bases and concordance between local and federal level of policies, institutions and instruments, along with the current aquifer management used in the island, were identified. Furthermore, a lack of instruments

