

Echinoderm research perspectives: A Central American bibliometric review

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ABSTRACT. Introduction: Central America, a narrow strip of land dividing the Atlantic and Pacific oceans, has a high diversity of marine and terrestrial species. Echinoderms are one of the most diverse marine groups with 420 reported species. **Objective:** To summarize echinoderm research in Central America. **Methods:** We compiled the literature from SCOPUS, Web of Science, SciELO, Google Scholar, Biodiversity Heritage Library, the Internet Archive and the Smithsonian Library. **Results:** We found 324 publications dating from 1840 to 2020; the early studies had a strong taxonomic focus, but after the 1970s, ecology, evolution and reproduction gained prominence. Echinoidea is the most studied class (38% of publications) due to its use in evolutionary studies as well as the importance of the genus *Diadema* in reef ecology and dynamics. **Conclusion:** We recommend more research on fisheries management, conservation and environmental education; and greater integration of local and international research.

Keywords: Ecology, Echinoidea, evolution, *Diadema*, collaboration networks.

RESUMEN. “Perspectivas en investigación de equinodermos: una revisión bibliométrica en Centroamérica”. **Introducción:** Centroamérica, una estrecha franja de tierra que divide los océanos Atlántico y Pacífico, tiene una gran diversidad de especies marinas y terrestres. Los equinodermos son uno de los grupos marinos más diversos con 420 especies reportadas. **Objetivo:** Resumir la investigación sobre equinodermos en Centroamérica. **Métodos:** Recopilamos la literatura de SCOPUS, Web of Science, SciELO, Google Scholar, Biodiversity Heritage Library, Internet Archive y Smithsonian Library. **Resultados:** Identificamos 324 publicaciones que datan de 1840 a 2020; los primeros estudios tenían un fuerte enfoque taxonómico, pero después de la década de 1970, la ecología, la evolución y la reproducción ganaron importancia. Echinoidea es la clase más estudiada (38% de las publicaciones) debido a su uso en estudios evolutivos, así como a la importancia del género *Diadema* en la ecología y dinámica de arrecifes. **Conclusión:** Recomendamos más investigación sobre manejo pesquero, conservación y educación ambiental; y una mayor integración de la investigación local e internacional.

Palabras clave: Ecología, Echinoidea, evolución, *Diadema*, redes de colaboración.

Central America is a narrow strip of land dividing the world’s two largest oceans: Atlantic and the Pacific (Cortés, 2007). It includes seven countries: Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama; and has an Exclusive Economic Zone of 1 518 705km², 156 251km² of continental platform and 6 603km of coastline (Alvarado et al., 2013; Coppard & Alvarado, 2013; Coppard & Lessios, 2017). The region is highly rich in coastal ecosystems, which include carbonate platforms, soft and rocky bottoms, coral environments, seamounts, coastal and oceanic islands, gulfs and coastal upwelling areas, among other geomorphologic and oceanographic features, all of which translate to a high diversity of organisms (Cortés, 2007).



One of these highly diverse groups is the phylum Echinodermata. Echinoderms are deuterostome invertebrates that are only found in marine environments (including mangroves, coastal lagoons and anchialine caves). The phylum is characterized by pentamerous radial symmetry, a carbonate skeleton, a water vascular system used for feeding and movement, and a great ability to regenerate their tissues (Pawson, 2007). These organisms have colonized every marine environment, from the depths of abyssal plains to shallow coastal areas, fulfilling a wide range of key ecological roles, as herbivores, predators and filter feeders (O'Hara & Byrne, 2017). More than 7,000 echinoderm species have been identified worldwide, and they belong to five extant classes (Crinoidea, Asteroidea, Ophiuroidea, Echinoidea and Holothuroidea) (Pawson, 2007). In over 180 years of research, 420 species have been named (Alvarado et al., 2013; Coppard & Alvarado, 2013; Coppard & Lessios, 2017; Cambrono-Solano et al., 2019).

Echinoderm research in the region began in the mid-19th and early 20th centuries with scientific expeditions from the United States that produced a great variety of monographs containing multiple species descriptions. Most of these documents are available through the Biodiversity Heritage Library (Biodiversity Heritage Library, 2021). In the second half of the 20th century, the increasing development of universities and research centers enabled scientific publications to proliferate. Some of these papers, however, remained buried in grey literature or were only published in minor local journals, making them difficult to trace.

Bibliometric tools and literature search engines, such as SCOPUS and ISI Web of Science, have provided a more extensive analysis of scientific products, and have helped to draw attention to publications that otherwise might have remained unnoticed. The goal of this study is to quantify scientific literature regarding echinoderms in Central America to identify research needs, as well as to detect and strengthen lines of research that already exist in the region.

MATERIALS AND METHODS

We used: SCOPUS, ISI Web of Science, SciELO, and Google Scholar. Combinations of the names of Central American countries and echinoderm class names or the derivatives of phylum name "Echinodermata" were used as keywords. Example search terms could be constructed as follows: Ophiuroidea AND Panama, Crinoidea AND Honduras, Holothuroidea AND Central America. Searches considered the title and abstract as well the whole text of the document. Literature was subsequently examined to check if it included a real reference to the region and echinoderms. Likewise, a literature search was made in the Biodiversity Heritage Library (<https://www.biodiversitylibrary.org/>), the internet archive (<https://archive.org/>) and the Smithsonian Library (<https://library.si.edu/>) to cover monographs published in the 19th and early 20th centuries. Only those works that explicitly indicate the collection and analysis of material from Central America were considered.

The publications were classified in a database in which different variables were considered: 1) coast (Pacific, Caribbean or both); 2) country (Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panama or all Central America); 3) source (journal, thesis, report, book chapter or book); 4) taxonomic class (Crinoidea, Asteroidea, Ophiuroidea, Echinoidea, Holothuroidea, or more than two); 5) research topic (taxonomy, parasitism, reproduction, physiology, ecology, fisheries, diversity, evolution, and environmental education); 6) name of first author; 7) nationality of authors (Central American, Foreign, or collaboration between Central Americans and authors of other nationalities); 8) number of authors (1, 2, 3, 4, 5, >5); and 9) gender of authors (male or female). For research topics, a study could be classified into more than one topic if it applied. For the authors' nationalities, we use their affiliation.

RESULTS

In accordance with the search criteria, 324 documents were identified (supplementary materials), dating from 1840 to 2020. These publications were primarily found in scientific journals, book chapters, books, conference proceedings, and reports. Six scientific journals contained 33% of these publications. The rest of publications are distributed in 116 journals. Of these six, the journal containing the most publications that fit the search criteria was the *Revista de Biología Tropical* (9,3%), followed by the *Bulletin of Marine Sciences* (6,2%), *Marine Biology* (4,9%), *Evolution, Coral Reefs, the Journal of Experimental Marine Biology and Ecology* (with 3,1% each). 87% of these studies were published since the 1970s (Fig. 1A). From 1840 to 1969, one to seven scientific works on the subject were published per decade. Most of the publications were monographs or expedition memoirs. From a geographic standpoint, most publications were carried out in the Caribbean (154) while 116 publications cover the Pacific coast. There are 53 studies that encompass both coasts. The Pacific coast was the most researched region until the 1960's (31 publications). In the last four decades, focus has shifted to both coasts with a total of 44 scientific publications.

The first 100 years of scientific research were mainly focused on works throughout the region (Fig. 1B) and studies focusing on specific countries were isolated efforts. It was not until after the 1960s when Belize, Panama and Costa Rica started to become more relevant, and continue to do so. The countries with the most scientific publications are Panama (134 studies), Belize (62) and Costa Rica (60), and the countries with the least contributions are Honduras (12), Nicaragua (9) and Guatemala (5).

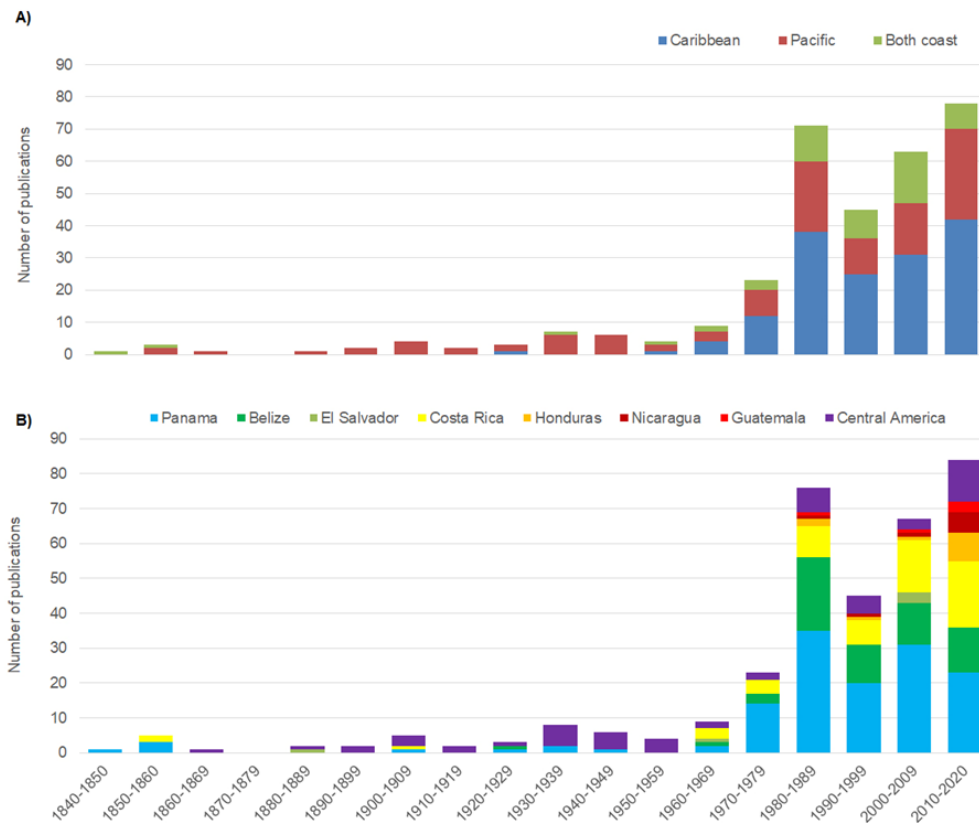


Fig. 1. Number of publications on echinoderms in Central America from 1840 to 2020, split into decades according to A) the coast on which these studies took place; and B) the countries in which these studies developed.

The first echinoderm publication was written by J. E. Gray (1840) and focused on the Asterozoa class. Echinozoa has been the most researched class, with 122 studies overall and an average of 23 studies per decade between 1970 and 2020 (Fig. 2A). The other classes, Ophiurozoa, Holothurozoa and Asterozoa possess 47, 29 and 27 scientific studies, respectively. There are 82 studies focused on two or more classes. Crinozoa is the least studied class throughout the period analysed and is the subject of only 15 studies.

Before the 1970's, the focus of most published studies was taxonomy (38 publications). These were monographs and expedition reports that described species without further investigation of their ecology. Beginning in the 70's, the diversity of study organisms (Fig. 2A) and research topics (Fig. 2B) increased and shifted towards a focus on ecological topics. The research topic with the most publications since the 70's is ecology (141 publications), followed by evolution (45), diversity (37) and reproduction (27). The least studied topics are physiology (15 published studies), fisheries and management (9), parasitism (7) and environmental education (2).

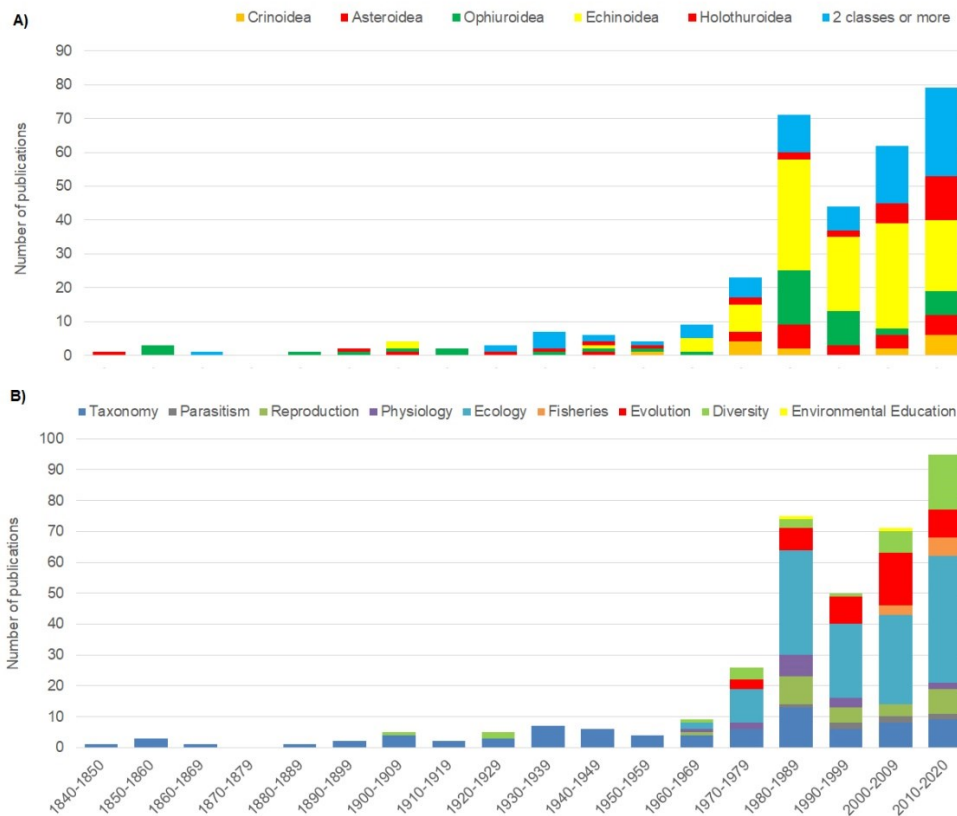


Fig. 2. Number of publications on echinoderms in Central America from 1840 to 2020, split into decades according to A) taxonomic class; and B) research topic.

Most published studies (80%) were performed by foreign authors and Central American authors produced 12%. Publications regarding echinoderms by local authors first appeared in the 1970's and have increased in number in the last two decades (2000-2020). There are few collaborative publications with foreign authors (8%), though they have become more numerous in the last decade (Fig. 3A).

Publications were normally written under the name of a single author from the 1840 until the 1990's (Fig. 3B). The number of authors on each publication increased from the 1990's until the

present. Of all studies considered, 46% were published under the name of a single author, 26% were published by two, 10% by three, 9% by four, 4% by five and 6% by six or more authors. If only the first or lead author is considered, a single author (Harilaos A. Lessios) composed more than 30 published works (0,7% of all studies considered) (Fig. 4). Most first authors (66,2%) appear in only one publication and 28,2% appear in two to four publications. Overall, a total of 708 authors contributed to publications that met the search criteria and only 24,3% were female. Female authorship first appeared in 1938 (Deichmann, 1938) (Fig. 3C). In the 1980's the ratio of male to female authorship shrinks and female authors appear more frequently.

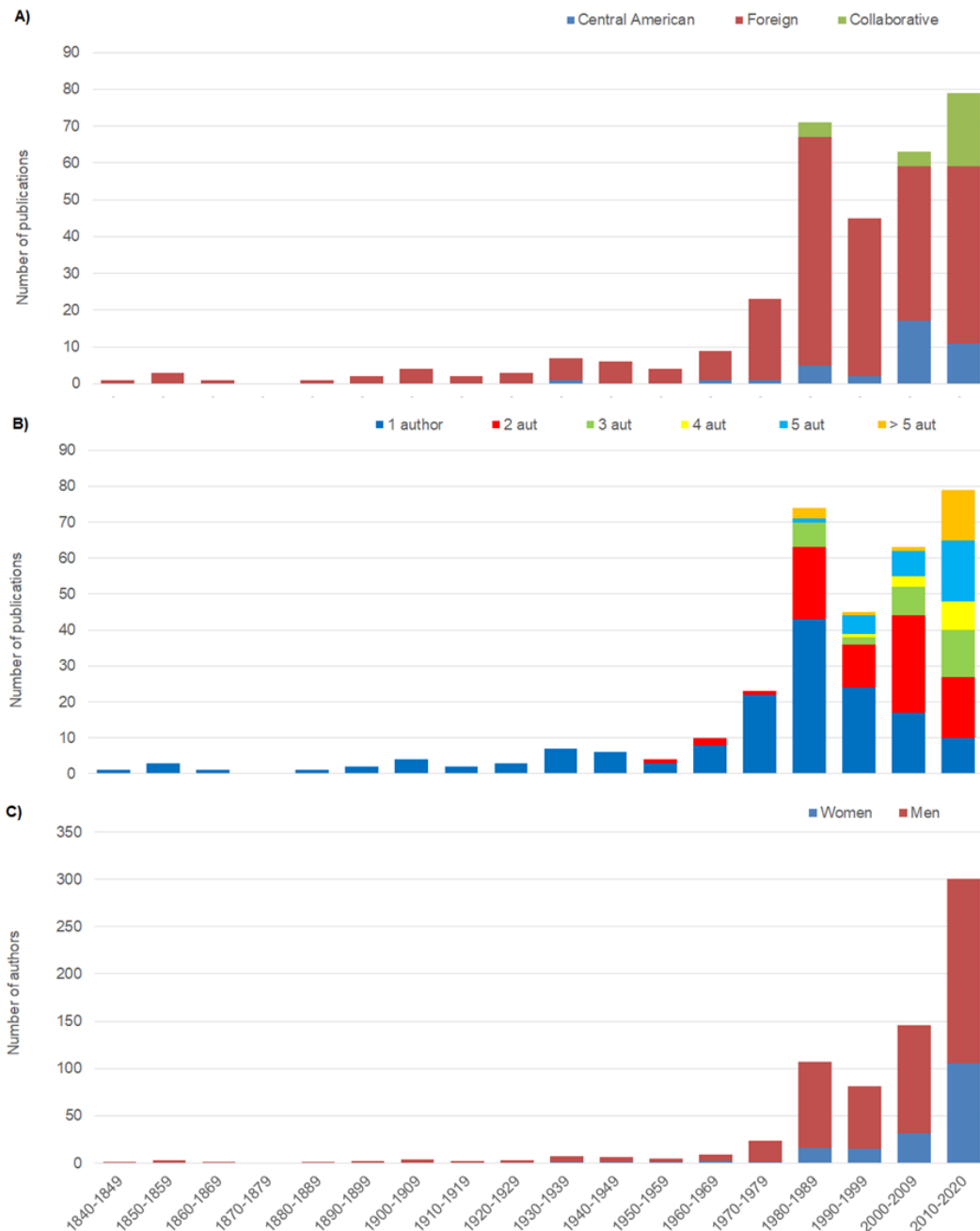


Fig. 3. Number of publications on echinoderms in Central America from 1860 to 2020, split into decades according to A) nationality of authors; B) number of authors per publication; and C) gender of authors in publications.

DISCUSSION

From 1840 until 1980, echinoderm research was monopolized by foreign male researchers, mainly from Europe and the United States. This time period was focused mainly on the description of species collected during of scientific expeditions including the *USS Albatross*, *Allan Hancock Foundation Velero III*, *SY Zaca*, *SY Arcturus*, *RV Stranger*, *RV Te Vega* and the Rosaura Expedition (Alvarado et al., 2013; Coppard & Lessios, 2017). Female participation in echinoderm studies has been lower than male, with a ratio of five male authors for each publication by a woman. These differences were even more pronounced during the first decades of echinoderm investigation. The presence of the renowned Danish scientist Elizabeth Deichmann stands out as the first woman to publish on echinoderm research in the region. She described, among other groups, several new echinoderm species and, thanks to her dedication, was one of the first women to be appointed Knight of Order of the Dannebrog by the King of Denmark (Levi, 1976; Ogilvie & Harvey, 2000). Between the studies of Deichmann (Deichmann, 1938, 1941, 1958) and those of Susan Foster (Foster, 1987a, b), 29 years passed without a woman as the lead author of a published study. Female authors were always foreign to the region until Marta Valdez from Costa Rica, published a collaborative study as a first author (Valdez & Villalobos, 1978). To date, no Central American woman has published as a sole author on a publication regarding echinoderms. Although female participation in publications in the region has been steadily increasing for the last decade, female authors are predominantly foreigners. This highlights the need for more integration of local women in these research projects.

Marine laboratories such as the Smithsonian Tropical Research Institute in Panama and Belize (Smithsonian Tropical Research Institute, 2021) were established during the 1970's and 1980's. This contributed to publications dealing with a wider variety of research topics such as physiology, evolution, fisheries, among others. Additionally, the development of SCUBA diving technologies as a research tool not only catapulted the number of publications but also opened the new fields of research, such as ecology and physiology, which would have otherwise been challenging to carry out (Lang et al., 2013).

The class Echinoidea could be the topic of the most publications concerning echinoderms for several reasons. The relatively large sizes and the high abundance of sea urchins coupled with their easy observation and collection and the presence of marine laboratories were big factors. The presence of marine laboratories was a key factor in moving from only ecological or taxonomic work to more applied and specialized research, which only this type of facility can provide. On the other hand, since the isthmus is relatively young geologically (approximately 3,5 million years) (O'Dea et al., 2016), sea urchins have been used in numerous evolutionary studies (Lessios, 1979, 1981a, 1990; Lessios & Cunningham, 1990; Bermingham & Lessios, 1993; Lessios et al., 1998, 1999; 2003, Coppard & Lessios, 2017, among others). The genus *Diadema* is responsible for many Echinoidea studies in both coasts. The mass mortality of *D. antillarum* that occurred in the Caribbean during the 1980's (Lessios et al., 1984) gave rise to a great number of studies focusing on understanding the causes and ecological impact of the genus on coral reefs (Valdez & Villalobos, 1978; Lessios, 1981b, 1985, 1988, 2016; Murillo & Cortés, 1984; Foster, 1987a, Alvarado et al., 2004; Myhre & Acevedo-Gutiérrez, 2007; Bodmer et al., 2015; Cramer et al., 2017). On the Pacific coast, the genus *Diadema* also contributes to a high number of publications that mainly focus on the impact of *D. mexicanum* population outbreaks on coral reefs and carbonate budgets linked to El Niño events (Glynn, 1985, 1988; Eakin, 1992, 1996, 2001; Alvarado et al., 2012, 2016).

The few publications on Crinoidea, the least studied class, are focused on shallow reef species in the Caribbean coast of Honduras and Belize (Meyer et al., 1978; Marcuda, 1982; Syverson et al., 2015). On the Pacific side, crinoid species are primarily found in deep waters (Alvarado et al.,

2013) which has made their study a difficult feat since it requires the use of remotely operated underwater vehicles (ROV's) and submarines. Recent studies have been carried out on the Pacific coast of Costa Rica that aim to investigate deep sea environments and contribute to a deeper understanding of this class (Levin et al., 2012, 2015).

The relative political stability in the last 20 years has favoured the development of universities and local research centres and a corresponding greater presence of local researchers. Nonetheless, much more remains to be done to promote the strength and collaboration of marine sciences. Scientific collaboration between researchers, institutions and countries has been proven to be a valuable tool that contributes to scientific progress (Newman, 2001; Nieto & Santamaría, 2007; García-Hernández, 2013). Collaboration facilitates the sharing of knowledge, economic and material resources, which otherwise not be available. Concrete results of scientific collaboration networks are co-authorships of scientific papers and may also include participation in thesis committees, courses, seminars, and internships. In the last two decades, these networks are flourishing with technological progress in communication and scientific advancement in developing countries (Radicchi et al., 2004; Gazni et al., 2012). The Iberoamerican Echinoderm Network (Red Iberoamericana de Equinodermos, 2021), founded in 2006, has facilitated collaboration between researchers and peers in Mexico, Spain, Colombia, Brazil, Uruguay, Ecuador and Argentina (Alvarado & Cortés, 2005, 2008; Alvarado & Solís-Marín, 2013, 2015; Rubilar et al., 2017). Although there has been notable progress, much remains to be done to improve gender equality and local participation among the Central American scientific community.

The region is classified as an intense illegal fishing site for sea cucumbers (Holothuroidea). There are few protection measures and many signs of overexploitation (Purcell et al., 2013) that indicate the urgency to assume management and conservation measures for the resource. This apparent and pressing need contrasts with the small number of published studies focusing on fisheries and their management (only 2,8% of studies found). Because only 9,1% of considered studies focus on sea cucumbers, more knowledge is needed to preserve the echinoderms as a resource. It is vital to conduct baseline studies of the population dynamics, genetic connectivity, and physiology and reproduction of these organisms. Additionally, these studies must go hand in hand with research that educates, creates and raises awareness, and provides innovative, sustainable alternatives and collaboration with the private sector. It is crucial to start developing new fields of research that focus on aquaculture, fisheries, environmental education, conservation, and management of shallow-water echinoderms, and to continue expanding our current knowledge of deep-sea groups in order to make the most of the valuable trajectory that has been developing over the 180 years of scientific research in the region.

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ETHICAL, CONFLICT OF INTEREST AND FINANCIAL STATEMENTS

The authors declare that they have fully complied with all pertinent ethical and legal requirements, both during the study and in the production of the manuscript; that there are no conflicts of interest of any kind; that all financial sources are fully and clearly stated in the acknowledgements section; and that they fully agree with the final edited version of the article. A signed document has been filed in the journal archives.

J.J.A.: Study design, data collection and analysis. S.F.M.: Data collection. All co-authors: preparation and final approval of the manuscript.

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SUPPLEMENTARY MATERIAL

TABLE S1

Chronological list of contributions of echinoderms in Central America.

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