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Characteristics and spatial identification of Antillean manatee (*Trichechus manatus manatus* Sirenia: Trichechidae) strandings in Guatemala

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ABSTRACT

Introduction: Marine mammal strandings can be used to determine the impacts of anthropogenic activity on the species survival, population health, and levels of environmental pollution in ecosystems. In addition, these data can help design conservation and management strategies as well as identify priority areas for the species. The West Indian manatee (*Trichechus manatus*) is listed as endangered throughout its range. In Guatemala, it is distributed along the Caribbean coast. Anthropogenic activities appear to be having a direct pressure on the species, affecting the status of the population.

Objective: The general purpose of this study was to analyze the 30 years of documented manatee stranding reports available for Guatemala. Two specific objectives were defined to: 1) conduct a spatial analysis of manatee strandings to identify the areas of high stranding concentration, and 2) determine whether there were sex differences in the number of strandings.

Methods: Characteristics and areas of concentration of manatee strandings were described along the Caribbean coast between 1992 to 2022. Sites with the highest probable density of strandings were identified using a Kernel density analysis. We compared the number of stranding events that occurred in each protected area that included manatees in their management plans and each municipality of Izabal. We determined whether there were sex differences in the number of stranded manatees. We use the potential biological removal to estimate the maximum number of manatees that can be removed from the population due to anthropogenic causes without negatively impacting species survival.

Results: Forty-three manatee stranding events were recorded throughout the species' range in Guatemala (48 total individuals). The sites with the highest predicted density of strandings were Santo Tomás de Castilla bay, followed by Lake Izabal (including the limits of the Refugio de Vida Silvestre Bocas del Polochic) and Parque Nacional Río Dulce. The majority of the cases were registered in protected areas (60 %). Estimates of potential

biological removal were equivalent to less than one manatee per year, which was exceeded by the annual average of stranded manatees recorded (three manatees).
Conclusions: Anthropogenic activities cause mortality of manatees in this region, despite the implementation of protected areas. Poaching was identified as the main cause of manatee mortality in Guatemala. The implementation of management strategies focused on minimizing threats to the species, based on the application of environmental legislation and environmental awareness, is essential. The creation and implementation of a protocol for the stranding of marine mammals on the Caribbean coast of Guatemala is necessary, in order to obtain standardized records of these events and conduct rescue efforts and releases when possible.

Key words: marine mammals; mortality; conservation; poaching; protected areas.

RESUMEN

Características e identificación espacial de los varamientos del manatí antillano (*Trichechus manatus* Sirenia: Trichechidae) en Guatemala

Introducción. Los registros sobre varamientos de mamíferos marinos pueden utilizarse para determinar los impactos de la actividad antropogénica en la sobrevivencia de la especie, la salud de las poblaciones y los niveles de contaminación ambiental en los ecosistemas. Además, estos datos pueden utilizarse para diseñar nuevas estrategias de conservación y manejo en las áreas prioritarias para la especie. El manatí antillano (*Trichechus manatus manatus*) está catalogado en peligro de extinción en todo su rango de distribución. En Guatemala, se distribuye a lo largo de toda la costa caribeña. Las actividades antropogénicas están ejerciendo una presión directa sobre la especie, afectando el estado de las poblaciones.
Objetivos. El objetivo general de este estudio fue analizar 30 años de información sobre los eventos de varamiento de manatíes en Guatemala. Dos objetivos específicos fueron definidos: 1) realizar un análisis espacial sobre las áreas con mayor concentración y densidad de varamientos de manatíes, y 2) determinar diferencias en el número de manatíes varados con base en datos sobre el sexo.
Métodos. Se describieron las características y áreas de concentración de varamientos de manatíes registrados de 1992 a 2022, en la costa caribeña. Se identificaron los sitios con mayor densidad probable de varamientos utilizando el análisis sobre densidad de Kernel. Se comparó el número de eventos de varamientos ocurridos en cada área protegida y municipio de Izabal donde se distribuye la especie. Se determinaron diferencias en la edad, sexo, y causa de muerte en los varamientos. Además, se utilizó la eliminación biológica potencial para estimar el número máximo de manatíes que pueden ser removidos de la población debido a causas antropogénicas, sin afectar negativamente la supervivencia de la especie.
Resultados. Se registraron 43 eventos de varamiento de manatíes en todo el rango de distribución de la especie en Guatemala (48 individuos en total). Los sitios con mayor densidad prevista de varamientos fueron en la Bahía Santo Tomás de Castilla, seguido del Lago de Izabal (incluyendo los límites del Refugio de Vida Silvestre Bocas del Polochic) y el Parque Nacional Río Dulce. La mayoría de los eventos se registraron en áreas protegidas (60 %). Las estimaciones sobre la eliminación biológica potencial fueron equivalentes a menos de un manatí por año, sobrepasando la media anual de manatíes varados (tres manatíes).
Conclusiones. Las actividades antropogénicas causan mortalidad en los manatíes distribuidos en la región, a pesar de la creación de áreas protegidas. La cacería ilegal fue identificada como la principal causa de muerte de los manatíes en Guatemala. Es fundamental la implementación de estrategias de manejo enfocadas en minimizar las amenazas hacia la especie, teniendo como base la aplicación de la legislación y conciencia ambiental. Es necesario crear e implementar un protocolo de varamiento de mamíferos marinos en la costa caribeña de Guatemala, para obtener registros estandarizados sobre este tipo de eventos y realizar rescates y liberaciones cuando sea posible.

Palabras clave: mamíferos marinos; mortalidad; conservación; cacería ilegal; áreas protegidas.

INTRODUCTION

Understanding animal strandings helps attain information about endangered aquatic species that are hard to see on the surface. Stranding data provides critical information on the species' life history, population health, environmental contamination levels, and general impacts of anthropogenic activities on marine ecosystems (National Oceanographic and Atmospheric Administration [NOAA], 2019). It is one of the primary sources of evidence

regarding the effect of human activities such as vessel strikes and fishery interactions on aquatic mammals (Van der Hoop et al., 2013). The data is also extremely valuable for informing management and policy decisions (Geraci et al, 2005).

Spatial analysis of stranding data can be helpful for recognizing patterns. For example, identifying areas with a high concentration of strandings can depict the interaction between a species and human activities if strandings occur in areas of high vessel traffic (Bedriñana-Romano et al., 2021). Spatial patterns can also help enhance surveillance and monitoring programs and predict carcass deposition during mortality events (Norman, 2008). This is extremely important in the case of endangered species, where the death of one individual could significantly impact the population's health (Onens et al., 2022).

The Antillean manatee (*Trichechus manatus manatus*) is one of the subspecies of the West Indian manatee, and it is classified as endangered throughout its range (Diario de Centro América [DCA], 2021; Quintana-Rizzo & Reynolds, 2010; Self-Sullivan & Mignucci-Giannoni, 2008). Manatee hunting is prohibited by the Presidential Agreement of 1981 (DCA, 1981), which is still in effect. Further, Article 80 of the General Law on Fisheries and Aquaculture prohibits the intentional capture or hunting of threatened or endangered marine mammals (Ministerio de Agricultura, Ganadería y Alimentación, 2002).

Poaching has significantly reduced different manatee populations throughout their distribution, including those in Central America (Machuca-Coronado & Corona-Figueroa, 2019; Ruiz Valladares et al., 2008). Interestingly, in this region, Belize has the largest population of Antillean manatees, estimated to be around 1 000 individuals (O'Shea & Salisbury, 1991; Quintana-Rizzo & Reynolds, 2010), while the neighboring country of Guatemala has only approximately 150 manatees (Quintana-Rizzo & Reynolds, 2010). Although Guatemala has a small coastline, an average of 50 manatees were sighted per survey of the entire Atlantic coast during aerial surveys conducted between 1992 and 2014 (Quintana-Rizzo, 1993, Quintana-Rizzo, 2005; Quintana-Rizzo & Machuca-Coronado, 2008; Quintana-Rizzo et al., 2023).

There are anthropogenic activities that have put direct pressure on manatees. In Guatemala, the recognized threats are poaching for meat consumption, bycatch, entrapment and hooking in fishing gear, vessel collisions, and habitat deterioration and contamination (Herrera et al., 2004; Machuca-Coronado & Corona-Figueroa, 2019). Despite efforts to address cases of local manatee strandings, quantified information and an analysis of how each threat affects the manatee population are scarce or nonexistent. Thus, the general purpose of this study was to analyze the 30 years of documented manatee stranding reports available for Guatemala. The specific objectives were to: 1) conduct a spatial analysis of manatee strandings to identify the areas of high stranding concentration and 2) determine whether there were sex differences in the number of strandings. The information was used to evaluate the role of protected areas in conserving the species. We also used the potential biological removal (PBR) approach to determine if the level of human-caused mortality in the manatee population could be sustained while allowing the population to recover. The PBR approach is suited to data-poor situations (Punt et al., 2020). The study results are expected to strengthen the management of protected areas and bring attention to cases of stranded manatees. The evidence can be used to promote the creation of an aquatic mammal stranding network and to help regulate anthropogenic activities in the Caribbean of Guatemala.

MATERIALS AND METHODS

Study area: The study area included the state of Izabal, which encompasses the distribution area of the Antillean manatee in Guatemala. The state is bordered on the north by the Caribbean Sea, and on the east by the Gulf of Honduras (Arrivillaga & Baltz, 1999; Ixquiac et al., 2008). It includes five municipalities: El

Estor, Livingston, Morales, Los Amates, and Puerto Barrios (Fig. 1). Izabal has remnants of warm subtropical and very humid tropical forest, wetland areas, mangrove forests, estuaries with patches of submerged vegetation, secondary forests, areas of intensive agricultural cultivation (e.g., oil palm, cattle pastures, banana, pineapple, cardamom, etc.), urban centers, beaches, and port areas (Suárez, 2011; Yáñez-Arancibia et al., 1999).

There are four designated protected areas within the study area, which include manatees as a conservation element of their management plans (Machuca-Coronado & Corona-Figueroa, 2019). Those protected areas are: (1) Refugio de Vida Silvestre Bocas del Polochic (RVSBP; total area 207.60 km^2: 143.60 km^2 terrestrial and 64.00 km^2 aquatic zones; Fundación Defensores de la Naturaleza [FDN], 2003), (2) Parque Nacional Río Dulce (PNRD; total area 165.90 km^2: 93.92 km^2 terrestrial and 71.98 km^2 aquatic zones; Consejo Nacional de Áreas Protegidas [CONAP], 2019), (3) Área de Uso Múltiple Río Sarstún (AUMRS; total area 475.82 km^2: 437.93 km^2 terrestrial and 37.89 km^2 aquatic zones; Fundación para el Ecodesarrollo y la Conservación [FUNDAECO], 2009), and (4) Refugio de Vida Silvestre Punta de Manabique (RVSPM; total area 1,519 km^2: 492.89 km^2 terrestrial and 1,025.89 km^2 marine zones; Fundación Mario Dary Rivera [FUNDARY] et al., 2006) (Fig. 1).

Manatee stranding records: Information on live and dead manatee stranding events was compiled in two ways. First, we obtained records documented by the government (CONAP) and non-government (FDN and FUNDAECO) organizations in Izabal. Second, we obtained data on manatee strandings in national museum collections, and grey literature (e.g., unpublished reports, newspaper articles, theses, and social media). Stranding records were stored in a database that included the following data points: year of the stranding, stranding location, geographical coordinates (when available), name of the organization or person who made the report, manatee sex, manatee age class, cause of death if known (poaching, bycatch, boat impact), and whether the stranding occurred within a protected area. In some cases, it was impossible to record all of these data points, due to the degree of decomposition of the carcasses or due to lack of record by the stranding response personnel. Data compiled in technical reports generated by CONAP and non-government organizations were considered "verified." The data was classified as "unverifiable" when obtained from unofficial sources or non-technical reports (e.g., communication with fishermen or tour operators). Boundaries of the protected areas were extracted from the World Database of Protected Areas (United Nations Environment Programme World Conservation Monitoring Centre & International Union for Conservation of Nature [UNEP-WCMC & IUCN], 2021).

Data analysis: Descriptive statistics (average and standard deviation) were used for stranding events that occurred over the years inside protected areas and municipalities. Percentages of manatee strandings based on sex, age class, and cause of death were calculated. To determine whether there were sex differences in the number of stranded manatees, we used a chi-square test in R statistical software (R Core Team, 2021). The spatial analysis included two components. First, to assess whether there are concentrated areas where strandings occur, a Kernel density plot was created, which estimated the probability density function of a stranding along the coast. The Kernel density analysis was performed using a raster with cells of 1 km^2 size on the minimum convex polygon (MCP) using ArcGIS Pro 3.0.0. The MCP is the smallest possible convex polygon encompassing all the known locations of manatee strandings (Hayne, 1949). Spatial Kernel density is a non-parametric method that measures the local spatial clustering of a point pattern, visualized by a continuous estimated surface density layer distributed through and between all points (Worton, 1989). Second, we compared the concentration of stranded manatees and the number of stranding events between

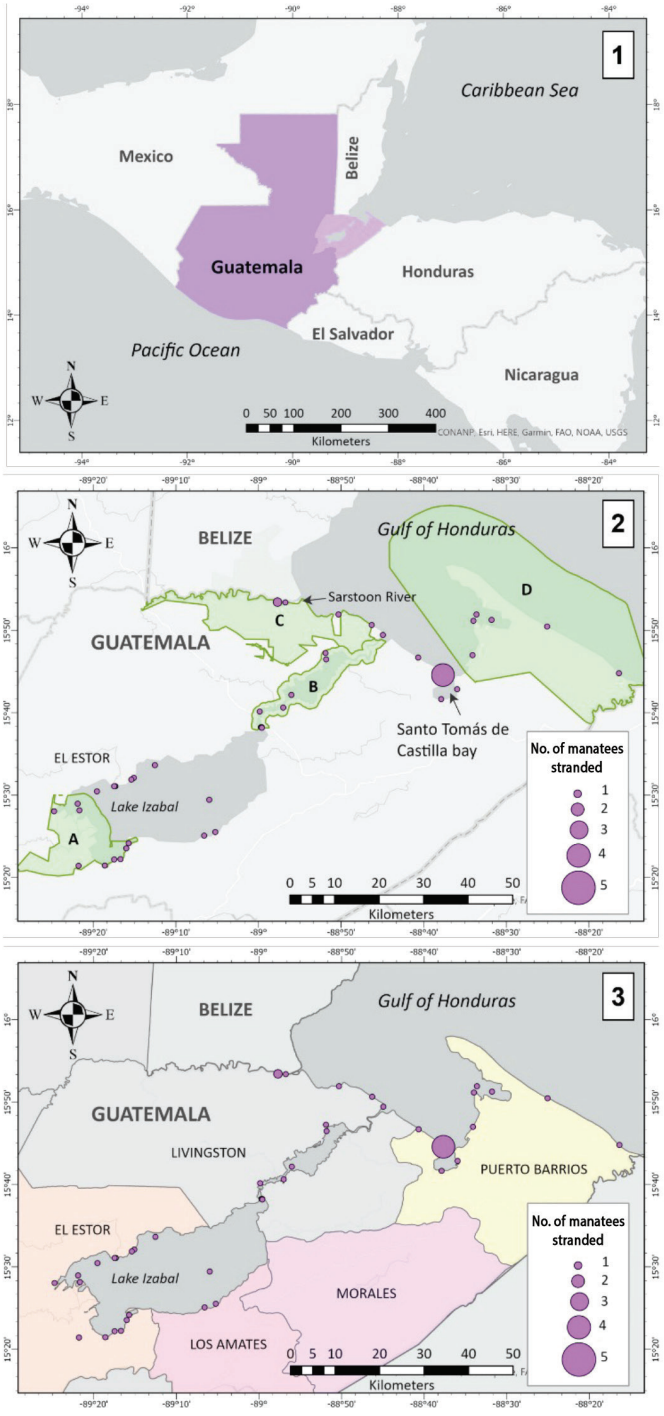

Fig. 1. (1) Study area and general overview of the region. Location of *Trichechus manatus manatus* stranding events between 1992 and 2022 along the Caribbean coast of Guatemala, including (2) protected areas and (3) municipalities. Protected areas are A) Refugio de Vida Silvestre Bocas del Polochic (RVSBP), B) Parque Nacional Río Dulce (PNRD), C) Área de Uso Múltiple Río Sarstún (AUMRS); and D) Refugio de Vida Silvestre Punta de Manabique (RVSPM).

protected areas and between municipalities, by using a chi-square test in R statistical software (R Core Team, 2021).

We used the potential biological removal (PBR) to estimate the maximum number of animals that could be removed from the Guatemalan manatee population (due to anthropogenic mortality) without affecting the optimal population size (Wade, 1998). The U.S. Marine Mammal Protection Act developed the PBR statistic for managing the impacts of fishing on marine mammal populations. PBR is calculated as:

$$Nmin \times 1/2Rmax \times Fr$$

Where Nmin is the estimate of the minimum population size of the stock, 1/2Rmax is one-half the maximum theoretical or estimated rate of population growth, and Fr is the recovery factor which is selected depending on the species conservation status (lower values for poorer conservation status) and varies from 0.1 to 1 (Wade, 1998). To calculate the PBR for the Guatemalan population, we used the most recent population estimate of 150 manatees (Quintana-Rizzo & Reynolds, 2010). Additionally, a PBR for 70 % and 40 % of this population were calculated since those percentages are within the range of older population estimates (Quintana-Rizzo, 1993). We used the minimum (0.04) and maximum (0.08) growth rates previously described or suggested for West Indian manatees (Marsh et al., 2011; National Marine Fisheries Service [NMFS], 2016; Runge et al., 2004) after Galves et al. (2022). A Fr equal to 0.1 was used because this is the value expected for endangered species or stocks that are declining (Taylor et al., 2000; Wade, 1998).

RESULTS

A total of 48 manatee individuals were recorded in 43 stranding events from 1992 to July 2022 (Table 1; $\bar{x}$ = 1.07, SD = 0.33). Of the 48 manatees, 96 % (N = 46) were dead animals and only two were live animals (4 %, all female orphan calves). The age group was determined for 46 manatees; 61 % were adult manatees (n = 28), 26 % calves (N = 12), and 13 % juveniles (N = 6). Sex was determined for 24 manatees (50 %). No significant difference was found in the percentage of male and female manatee strandings (χ^2 = 0.050, d.f. = 1, p = 0.818). Cause of death was determined in 65 % of the stranded manatees (N = 30), due to the degree of decomposition of the carcasses or lack of record in some cases. Poaching was the main cause of mortality (70 %, N = 21), followed by entanglement in fishing gear (hereafter referred to as bycatch) (17 %, N = 5) and boat collisions (13 %, N = 4; Fig. 2). Entanglement in fishing nets was recorded in six separate events. Of these events, three were recorded in the RVSBP (two dead adult manatees and one live calf), two in the PNRD (two dead manatee calves), and one in Lake Izabal (one dead adult manatee). The highest number of stranding events were reported in 2015 and 2020, with a total of 6 stranded manatees each year (Fig. 3). Since Guatemala has not implemented a protocol for marine mammal stranding, there were no standardized records of stranding. Consequently, there were no recorded reports of manatee stranding events during the following years; 1993-2002, 2006, 2010, 2012, and 2017 (Fig. 3).

Stranding events were recorded throughout the distribution range of manatees in Guatemala (Fig. 1). The Kernel analysis showed that the highest predicted density of strandings occurred in the Santo Tomás de Castilla bay and surrounding waters. The second highest predicted stranding density was the southern corner of Lake Izabal including the limits of the protected area RVSBP, and a third, less dense area, was in the southern section of the protected area PNRD (Fig. 4).

Of the 43 stranding events, 65 % (N = 28) occurred inside protected areas (AUMRS: $\bar{x}$ = 1.33, SD = 0.58; PNRD: $\bar{x}$ = 1.00; SD = 0.00; RVSBP: $\bar{x}$ = 1.00; SD = 0.00; RVSPM: $\bar{x}$ = 1.00; SD = 0.00) involving 29 individual manatees. In protected areas, no statistically significant differences were found among the number of stranding events (χ^2 = 3.43, d.f. = 3, p = 0.330) and the number of manatees stranded

Table 1

Chronological records of *Trichechus manatus manatus* strandings in Guatemala from 1992 to 2022. Date is reported as year, month, and day when available.

Date	No. manatees	Age class /sex	Municipality	Protected area*	Cause of stranding
1992/03/01	1	NA/NA	Livingston	PNRD	Boat impact
2003	1	Adult/NA	Livingston	PNRD	Unverifiable
2004	1	Adult/NA	El Estor		Bycatch
2004	1	Juvenile/NA	El Estor		Poaching
2005/05/25	1	Adult/NA	Puerto Barrios	RVSPM	Poaching
2005/06/18	1	Juvenile/male	Livingston	PNRD	Unverifiable
2005/09/20	1	Adult/NA	El Estor		Poaching
2005/10/20	1	Juvenile/NA	El Estor	RVSBP	Poaching
2007/05/10	1	Adult/female	El Estor	RVSBP	Bycatch
2007/12/05	1	Calf /male	El Estor	RVSBP	Unverifiable
2008	2	Adults/NA	Livingston	AUMRS	Poaching
2008/07/12	1	Calf/female	El Estor	RVSBP	Orphan
2008/08/11	1	Adult/NA	Livingston		Poaching
2009/06/08	1	Calf/NA	El Estor	RVSBP	Poaching
2009/06/10	1	Adult/female	El Estor	RVSBP	Poaching
2009/07/20	1	Adult/NA	El Estor		Poaching
2009/10/01	1	Adult/NA	El Estor	RVSBP	Unverifiable
2011/07/01	1	Calf /male	Livingston	PNRD	Boat impact
2013	1	NA/NA	El Estor		Poaching
2013/01/23	1	Adult/NA	El Estor	RVSBP	Bycatch
2013/08/09	1	Juvenile/female	Puerto Barrios	RVSPM	Unverifiable
2014/05/05	1	Calf/NA	Los Amates		Unverifiable
2015/04/06	1	Adult/female	Livingston	AUMRS	Poaching
2015/07/01	5	1 adult/female 3 adults/NA 1 calf/NA	Puerto Barrios		Poaching
2016/06/01	1	Adult/NA	El Estor		Unverifiable
2016/07/24	1	Adult/NA	Puerto Barrios	RVSPM	Poaching
2018/07/19	1	Adult/female	Livingston	AUMRS	Poaching
2018/07/31	1	Adult/female	Puerto Barrios	RVSPM	Poaching
2019/10/13	1	Adult/male	El Estor		Unverifiable
2020	1	Calf/NA	Puerto Barrios	RVSPM	Unverifiable
2020/02/15	1	Adult/male	Livingston	PNRD	Boat impact
2020/02/27	1	Juvenile/male	El Estor		Unverifiable
2020/05/06	1	Adult/male	Puerto Barrios		Unverifiable
2020/05/13	1	Juvenile/male	El Estor	RVSBP	Unverifiable
2020/06/14	1	Calf/NA	Livingston	PNRD	Bycatch
2021/07/21	1	Calf/female	Livingston		Orphan
2021/11/13	1	Calf/male	Puerto Barrios	RVSPM	Unverifiable
2021/12/09	1	Adult/NA	Livingston	PNRD	Poaching
2022/02/04	1	Adult/male	Los Amates		Unverifiable
2022/04/29	1	Calf/male	Livingston	PNRD	Unverifiable
2022/05/05	1	Calf/male	Livingston	PNRD	Bycatch
2022/07/12	1	Adult/male	Puerto Barrios		Boat impact
2022/07/14	1	Adult/male	Puerto Barrios	RVSPM	Unverifiable

NA = Not available. * PNRD (Parque Nacional Río Dulce); RVSPM (Refugio de Vida Silvestre Punta de Manabique); RVSBP (Refugio de Vida Silvestre Bocas del Polochic); AUMRS (Área de Uso Múltiple Río Sarstún).

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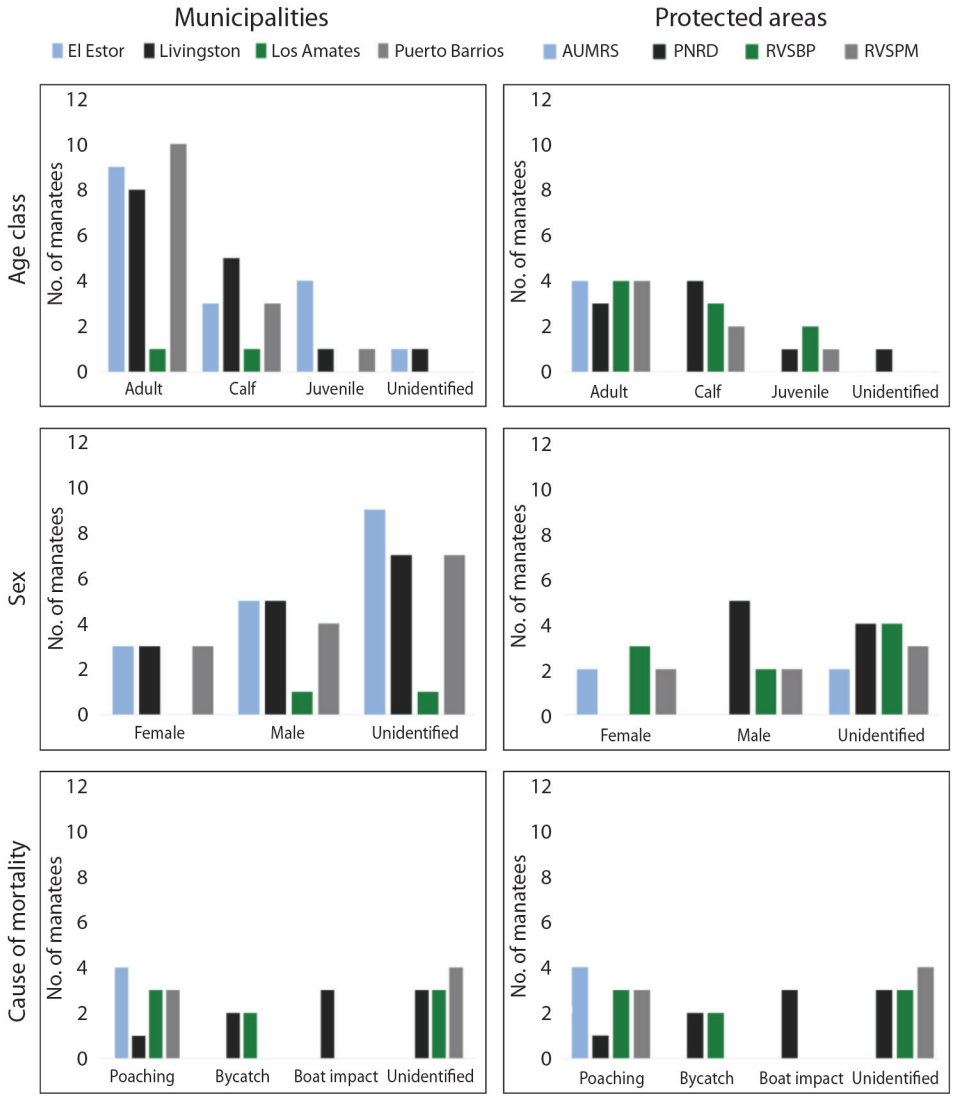

Fig. 2. *Trichechus manatus manatus* strandings based on age class, sex, and cause of mortality for each municipality and protected area on the Caribbean coast of Guatemala.

(χ^2 = 0.231, d.f. = 3, p = 0.510). Regardless of location, the stranding events of two protected areas combined included the highest proportion of the strandings in the study area (42 %). Those protected areas were RVSBP and PNRD (stranding events in each: 21 %, N = 9; stranded manatees N = 9).

In municipalities, significant differences were found in the number of stranding events (X^2 = 11.7910, d.f. = 3, p = 0.0081) and the number of manatees stranded (χ^2 = 11.50, d.f. = 3, p = 0.009) among them. The highest number of stranding events were recorded in El Estor (39 %, N = 17; $\bar{x}$ = 1.00; SD = 0.00), followed by Livingston (33 %, N = 14; $\bar{x}$ = 1.07; SD = 0.27), Puerto Barrios (23 %, N = 10; $\bar{x}$ = 1.17, SD = 0.58), and Los Amates (5 %, N = 2; $\bar{x}$ = 1.00, SD = 0.00). The percentage of stranded manatees in each municipality was 35 % (N = 17) in El Estor, 31 % (N = 15) in Livingston, 29 %

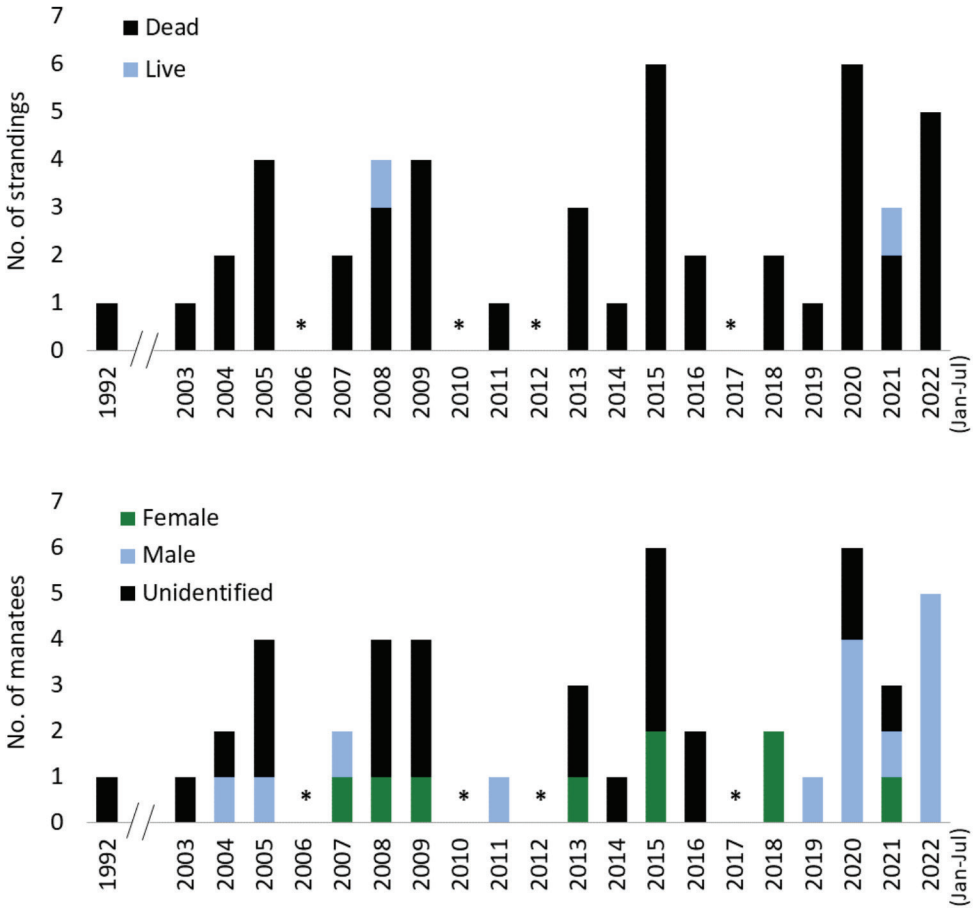

Fig. 3. Number of *Trichechus manatus manatus* strandings (live and dead) and number of individuals per sex identified from 1992 to July 2022. * = years with no stranding reports.

(N = 14) in Puerto Barrios and 4 % (N = 2) in Los Amates (Fig. 2).

The mean annual verified mortality for years with reported sightings was three manatees, with three yearly events directly resulting from anthropogenic causes. The estimated PBR for a population of 150 manatees is 0.6 if the growth rate is 0.08 and 0.3 if the growth rate is 0.04. The PBR decreases for smaller populations of manatees (Table 2). Therefore, in all cases, the PBR was equivalent to one manatee. This PBR was exceeded in each reported year.

DISCUSSION

This study compiles data on manatee strandings over 30 years throughout the species distribution range in Guatemala. It represents the country's most extensive and complete summary of manatee strandings. The results show that a significant number of strandings occurred in particular areas of the coast, including protected areas, and that a large percentage of the strandings involved the poaching of adult males.

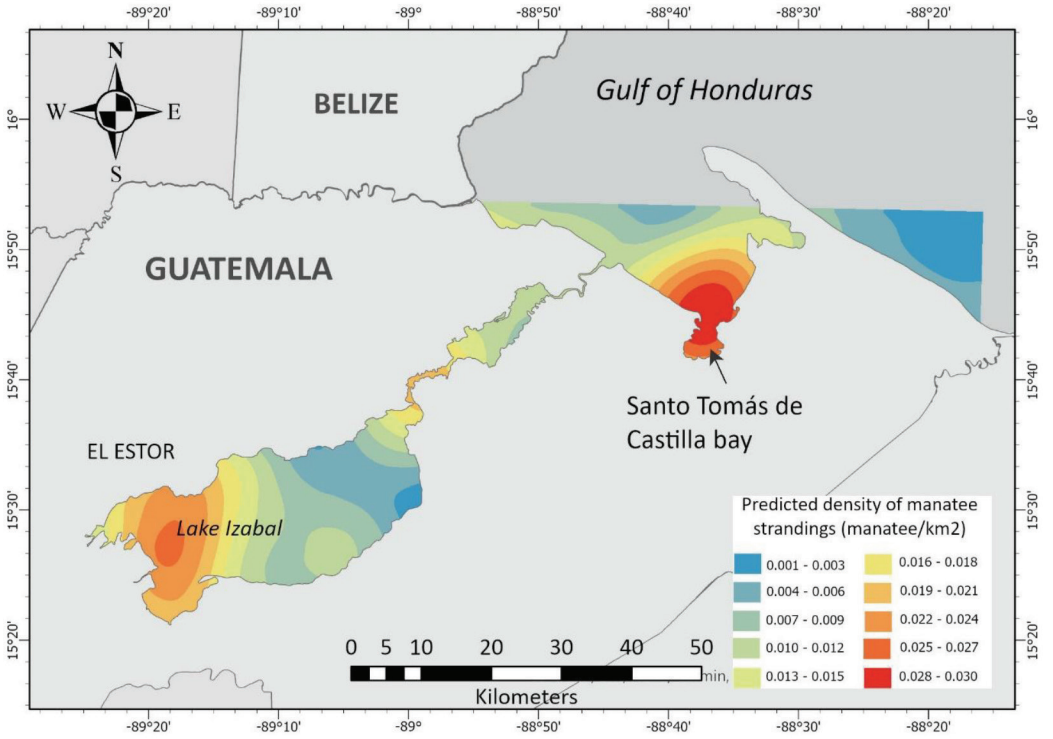

Fig. 4. Predicted Kernel density of stranded *Trichechus manatus manatus* along the Caribbean coast of Guatemala.

Table 2

Potential biological removal for the population of *Trichechus manatus manatus* in Guatemala using both maximum (0.08) and minimum (0.04) estimated growth rates based on Marsh et al. (2011), NMFS (2016), and Runge et al. (2004).

Population size estimates*	Potential Biological Removal	
	Growth rate = 0.08	Growth rate = 0.04
60	0.24	0.12
105	0.40	0.21
150	0.60	0.42

* Based on (Quintana-Rizzo, 1993; Quintana-Rizzo & Reynolds, 2010).

Predicted density of stranded manatees. The predicted density of stranded manatees was highest in Santo Tomás de Castilla bay and surrounding waters, as well as in the southern corner of Lake Izabal. In both locations, manatee carcasses with harpoons or wounds on the body consistent with hunting processes were recorded. Poaching was the leading cause of death in these places (> 55 % of stranded manatees). These areas are in close proximity to municipal markets where there is evidence of an illegal market for manatee meat (Ruiz Valladares et al., 2008). In Santo Tomás de Castilla bay, the Kernel density area of high concentration of stranded manatees (0.019 to 0.030 manatees/km^2) included the clustering of nine manatees that were part of five stranding events. Two events involved the poaching of six manatees, including a calf. The other causes of mortality were unverifiable. In this bay, groups of manatees are commonly observed (T. Sandoval, pers. obs.), possibly due to the presence of aquatic vegetation and seagrass patches (Arrivillaga & Baltz, 1999; Ixquiac et al., 2008; MacDonald, 2011; Yáñez-Arancibia et al., 1999). However, Santo Tomás de Castilla bay is a vulnerable area for manatees due to the commercial vessel traffic of port Santo Tomás de Castilla. This medium-sized commercial port is located in the southwestern part of the

bay. The vessel traffic in this area includes oil/chemical tankers, container ships, bulk carriers, general cargo, and crude oil tankers. Vessels as large as 244 m have entered the bay and port (Marine Traffic, 2022).

The other area with a high predicted stranding density of manatees was the southern corner of Lake Izabal, including the area within the limits of a protected area (RVSBP). Kernel density analysis projected strandings in the center of Lake Izabal. However, only one stranding was recorded at approximately 6.5 km from the coast, and it could be a case of a carcass transported by currents to the deep waters of the lake. All other stranding events were within 1.5 km from shore. In the southern corner of Lake Izabal, 37% (N = 16) of the total stranding events were recorded, representing the highest concentration of strandings in the entire country. This is worrisome as RVSBP has been identified as a priority area for the manatees in Guatemala (Quintana-Rizzo, 1993, Quintana-Rizzo, 2005; Quintana-Rizzo & Machuca-Coronado, 2008; Quintana-Rizzo et al., 2023), and poaching was the leading cause of death within this protected area (60 %, N = 3), followed by bycatch (40 %, N = 5). Since the sex of most of the manatees poached is unknown (N = 11, 52 %), there is no clear evidence of a sex-bias in manatee poaching. However, in another study, some hunters recognized that female manatee meat is softer and has a better flavor (Del Valle, 2002).

The highest mortality cases involved adults (eight out of 15 identified by age-class) and males (five out of eight identified by sex). Similar sex- and age-biased poaching mortality has been observed in other wildlife populations (Archie & Chiyo, 2012; Ginsberg & Milner-Gulland, 1994; Jones et al., 2018). From a demographic standpoint, age- and sex-biased poaching mortality is expected to bear fitness consequences in a population (Ginsberg & Milner-Gulland, 1994). The PBR suggests that this mortality is indeed having an effect on the Guatemalan manatee population. Furthermore, removing adult individuals from a population could lead to a more significant reproductive investment by young adults, with potentially detrimental consequences on their overall survival (Ginsberg & Milner-Gulland, 1994). In Guatemala, poaching continues to be a significant challenge in spite of the fact that manatees are protected by the Fisheries and Aquaculture law, Decreto 80-2002, which declares that it is illegal to hunt any endangered marine mammal and that the fine for breaking this law is high for the socio-economic status of the average person living in Izabal (approximately USD $1 055.00 – USD $10 555.00). However, effective law enforcement is problematic and generates conflict between the authorities and residents as there are no alternatives for the sustainable use of natural resources.

Protected areas, management, and conservation.

Although protected areas have management plans and the legal basis to protect manatees and natural resources, more than half of the cases of strandings were reported within those areas (N = 28; 65 %). All types of mortality were identified, but poaching was again the leading cause of mortality. Eleven cases of poaching were registered in all four protected areas combined. Further, bycatch was identified in RVSBP and PNRD, but mortality due to motorboat collisions was only reported in PNRD. This protected area is one of the sites with the highest tourism records in the country (Instituto Guatemalteco de Turismo [INGUAT], 2015). Watercraft collisions are among the leading causes of anthropogenic mortality for manatees in other habitats in Florida (Lightsey et al., 2006), Puerto Rico (Mignucci-Giannoni et al., 2000), and Belize (Galves et al., 2022). In Guatemala, studies have shown that manatee sightings are (weakly) positively correlated with the presence of motorboats (Quintana et al., 2023) in PNRD, suggesting the probability of vessel collisions exists.

The variety and number of stranding cases inside different protected areas demonstrate that management strategies and actions have not been sufficient for species protection. There

is no surveillance within the protected areas to prevent poaching. Protected areas managers have not proven effective at preventing poaching or other threats to biological diversity. In addition, it is necessary to regulate the speed of boats within protected areas to avoid collisions with manatees. Although there is no national legislation that supports the implementation of navigational regulations, in each municipality, the authorities must disclose to motorboat users the current navigation guidelines. For example, the PNRD Management Plan stipulates navigation at speeds between 9 and 18 km/h (CONAP, 2019). This aspect is important, because in this protected area, mortality related to boats was recorded. Indeed, the shallow, narrow waters and interconnected channels of PNRD require high regulation (Corona-Figueroa, 2012). Evidence shows that speed restrictions reduce manatee deaths (Calleson & Frohlich, 2007; Laist & Shaw, 2006).

Municipalities, management, and conservation.

Poaching was the leading cause of manatee death in the municipalities of Puerto Barrios, El Estor, and Livingston. In these municipalities, it is known that manatee poaching has occurred for at least 20 years (Del Valle, 2001; Machuca-Coronado & Corona-Figueroa, 2019). Groups of hunters have been identified moving along the coast to areas with manatee presence (including inside protected areas). Hunters from Livingston and Puerto Barrios have even been reported to travel to Belizean territory, where hunting is also illegal. In the 1990s, there were reports of manatee poaching in Belize that appeared to be the result of poaching from Guatemala and possibly Honduras (E. Quintana-Rizzo pers. obs.). In August-September 1995, at least 35 manatee carcasses were found in the Port Honduras area, Belize, in what appeared to be a butchering site. Manatee skulls had deep cut marks, and evidence suggests they were shot, harpooned, or chased until exhausted (Bonde & Potter, 1995). A year later, a second report of poaching was documented south of Port Honduras, where another nine manatees were found dead (Morales-Vela et al., 2000). In Guatemala, manatee meat is illegally sold in the main municipal markets at a lower price than other types of meat (Quintana-Rizzo & Reynolds, 2010; Ruiz Valladares et al., 2008).

In this study, reports of manatee entanglement in fishing gear occurred inside and outside protected areas. The use of trawl nets in large-scale commercial fishing (nets > 4 km in length) is common in the municipalities of El Estor and Livingston, even though this type of fishing is prohibited in inner or continental waters (Ministerio de Agricultura, Ganadería y Alimentación, 2002). Large fishing nets interrupt the movement of manatees, mainly at the mouth of rivers; they also reduce the available habitat for the species (Machuca-Coronado & Corona-Figueroa, 2019; Ruiz Valladares et al., 2008).

Differences in the number of reported stranding events in each municipality are likely related to the presence of government (CONAP) and non-governmental organizations co-managing protected areas in the different municipalities. Those organizations have taken the lead in reporting and documenting manatee strandings. In the case of El Estor, since 2007, FDN established a protocol to record manatee stranding data in collaboration with community members, fishers, and boat captains. This collaboration was fundamental in implementing the procedures, mainly in the notification of cases and location of manatee carcasses (Quintana-Rizzo & Machuca-Coronado, 2008), some of which are part of this study. These actions represent the first efforts toward the establishment and implementation of a stranding protocol for marine mammals in Izabal (Quintana-Rizzo & Machuca-Coronado, 2008); however, implementation has slowed down in recent years. In Livingston and Puerto Barrios, the presence of CONAP is fundamental to registering and confirming manatee stranding cases. Since 2010, systematic reports of each manatee stranding have been produced. In Los Amates, the number of stranding records is lower than in other municipalities;

this could be because the government authorities of this municipality have not implemented a stranding protocol in their work plans.

Sex and age class.

Most stranding records include dead manatees, and only two cases of live manatees were recorded, both corresponding to female orphan calves (Machuca-Coronado & Quintana-Rizzo, 2014; Quintana-Rizzo et al., 2008; T. Sandoval personal communication July 21, 2021). Calf strandings could be related to the poaching of the corresponding mothers. Manatee hunters are known to focus on adults (Ruiz Valladares et al., 2008); however, they take the opportunity to hunt calves when they are in the company of their mother (Ruiz Valladares et al., 2008). Poaching targeted to this demographic group can directly affect the population's stability. Females have low reproductive rates since they do not reach sexual maturity until 3-years of age and produce an average of one calf every two to four years, which means that the growth of manatee populations is significantly slow (Hartman, 1979; Powell, 2002; Quintana-Rizzo & Reynolds, 2010).

Stranding records were biased towards adult males; 63 % of the stranding events corresponded to this demographic group. Male manatees are vulnerable because they spend more time moving around than females and calves (Quintana-Rizzo & Reynolds, 2010). This behavior pattern may increase their exposure to different threats. In fact, 75 % (N = 3) of the registered cases of boat collisions correspond to male manatees. However, the relationship between strandings and demographics is likely underestimated because sex and cause of death determination were only possible in 50 % (N = 24) and 36 % (N = 16) of events, respectively.

Potential biological removal.

PBR has been used to calculate the species-specific level below which human-induced mortality must be reduced for species survival (Marsh et al., 2004). If the anthropogenic mortalities are less than the PBR, then a depleted population should recover given sufficient time (Williams et al., 2016). Our PBR estimates were equivalent to less than one manatee per year, which is lower than the annual average number of stranded manatees recorded in Guatemala over the past thirty years. As such, anthropogenic activities affect the local manatee population, although long-term studies on population dynamics are needed to understand the gravity of their impact.

Conservation and future recommendations.

The success of conservation relies on key factors, including the collection of scientific data to understand species threats, the development of stakeholder partnerships to address potential threats, consistent enforcement of regulations to protect the species, and equally on public adherence to protection programs. The lack of any one of these factors makes conservation efforts more challenging and less efficient. In Guatemala, there is a great need to increase awareness of the threats facing manatees and their habitat at all levels, and the enforcement of laws is critical. Poaching was identified as one of the main threats affecting the local manatee population more than 30 years ago (Lefebvre et al., 1989; Quintana-Rizzo, 1993), and this study shows that the threat continues to be significant. If manatees are to survive in Guatemala, developing a strategic plan to significantly reduce human-related mortalities is crucial to their conservation and proper management.

There is also a great need to develop and implement a protocol for manatee strandings. This includes performing necropsies and taking samples of biological material. The existing marine mammal stranding protocol for the Guatemalan Pacific coast (WWF, 2018) could serve as a starting point, but a protocol specifically focused on manatees must be included. In addition, a marine mammal stranding network needs to be established in the Caribbean area, together with training sessions for technicians,

park rangers, and key local people. Finally, a reduction in anthropogenic mortality of manatees can be accomplished through education and proactive management and training of the park rangers and other stakeholders, together with a conservation plan that includes law enforcement, mortality assessment, scientific research, and stakeholder involvement and cooperation.

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