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Increasing mortality of Endangered Antillean manatees *Trichechus manatus manatus* due to watercraft collisions in Belize

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ABSTRACT: Belize maintains the largest proportion of the Endangered Antillean manatee *Trichechus manatus manatus* population in its range, but tourism and boat traffic have increased substantially over the past 3 decades. We utilized 25 yr of Belize Antillean manatee stranding data (1995–2019), 6 aerial surveys (1997, 1999, 2000, 2001, 2002, 2014), and 2 decades of boat registration data to examine: (1) spatial patterns in stranding incidence and risk of watercraft collision; (2) temporal patterns in strandings and registered watercraft; and (3) the relationship between manatee strandings attributed to watercraft collision and watercraft numbers. The number of watercraft collision strandings increased significantly over time, from 1–4 yr^{-1} in the late 1990s and early 2000s to 10–17 yr^{-1} in the late 2010s. The per manatee risk of watercraft collision stranding increased across space and time with the number of registered boats. Strandings were greater in areas of high boat traffic, high human population density, and mangrove habitats, particularly in Belize City and Placencia. These results highlight the need to reduce the threat of watercraft collisions to conserve this Endangered subspecies in Belize. Conservation efforts should focus on reducing the number of boats and their speed within zones of high manatee use to reduce mortality due to boat collisions, including establishing additional non-motorized vessel areas, restricted access, and reduced speed zones.

KEY WORDS: Antillean manatee · Belize · Stranding · Watercraft collision · Mortality · Aerial survey

1. INTRODUCTION

Globally, there are 4 extant species of Sirenia (Marsh et al. 2011), with all species listed as Endangered or Vulnerable by the International Union for Conservation of Nature (IUCN) (Marsh et al. 2011). The Antillean manatee *Trichechus manatus manatus*, a subspecies of the West Indian manatee, is declining and listed as Endangered on the IUCN Red List of Threatened Species (Self-Sullivan & Mignucci-Giannoni 2008), and as an Appendix 1 species by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2021). In Belize, the Antillean manatee is considered nationally endangered, protected under Section 88 of the Belize Fisheries Resources Act No. 7 of 2020, and managed by the Belize Fisheries Department (Fisheries Resource Act 2020). With a population estimated at around 1000 individuals (UNEP 2010), Belize possibly maintains the largest population of the Antillean manatee, and is considered to be a stronghold of this sub-

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species throughout its range (O'Shea & Charles 1991).

Though protected, Antillean manatees face many anthropogenic threats that have resulted in reduced and isolated populations in the Caribbean, including poaching, habitat degradation and loss, watercraft collision, entanglement in fishing gear, and pollution (Mignucci-Giannoni et al. 2000, Hunter et al. 2010, Balensiefer et al. 2017, Alvarez-Alemán et al. 2021). In Belize, there have been increasing numbers of manatee strandings resulting from collisions with the hulls or propellers of watercraft (Galves et al. 2013, 2023), likely exacerbating documented population declines for this subspecies; however, very little is known about the nature of this emerging threat and its direct repercussions for the manatee population in Belize (Castelblanco-Martínez et al. 2012).

Our goal was to examine the relationship between intensity of boat use and manatee strandings as a first step in understanding the threats to the Belize Antillean manatee population. We tested the hypothesis that Antillean manatee strandings increase with the number of registered boats across space in 12 analysis zones in Belize and over time. We examined spatial correlations using historical stranding and aerial survey data from 1995 to 2019 to quantify the per capita risk of watercraft collision within each zone. We also examined temporal correlations using boat registration data from 1994 to 1998 and 2005 to 2019 in each zone and correlated Antillean manatee watercraft collision strandings with temporal changes in the number of registered boats.

2. MATERIALS AND METHODS

The study area encompassed the entire coastal zone of Belize, from a northern boundary at the Hondo River to a southern boundary at the Sarstoon River (Fig. 1). Belize's coastline is 386 km (240 miles) in length and comprises coastal, estuarine, and deeper waters (CZMAI 2016). Coral reef, seagrass, and mangrove habitats are the primary habitat types along this coastal zone, and they support many species of fauna including the Antillean manatee (CZMAI 2016).

2.1. Aerial surveys

Aerial surveys (Table 1) were conducted in 1997, 1999, 2000, 2001, 2002, and 2014 by the Belize Coastal Zone Management Authority and Institute to examine the spatial distribution of Antillean manatees and minimum population size encountered across the surveyed area (O'Shea & Charles 1991, Belize Manatee Recovery Plan 1998, Auil 2004). In most years (all but 2001 and 2014), surveys occurred twice per year, during the wet (August–November) and dry (March–April) seasons (Auil 2004). We used a linear model to determine if there was a significant difference between the number of manatees sighted during the wet versus dry season. Manatee aerial surveys were conducted using a Cessna 206 aircraft which was flown at an average altitude of 168 m, and an average speed of 161 km h^{-1} (Auil 2004). The aircraft was flown approximately 0.5 km from the coastline, except at river mouths where the aircraft was flown upriver starting at the river mouth for a maximum distance of 11 km (Auil 2004). The country was divided into 3 regions, i.e. northern, central, and southern, which were surveyed in that order over 3 consecutive days for each survey (Auil 2004). All survey flights departed from Belize City, and the survey effort was similar for each region, with an average flight time of approximately 3.5 h $region^{-1}$. For each manatee sighting, time, location, number of individuals, whether a group of 2 or more included adults and calves (based on size differences), activity, and environmental conditions were recorded.

2.2. Strandings

We collated 25 yr (1995–2019) of existing Antillean manatee stranding data from the Belize Marine Mammal Stranding Network (BMMSN) program (Table 1). A stranding included any dead or incapacitated (generally injured, trapped, or entangled) live adult manatee or dependent calf encountered onshore or in shallow water (Geraci & Lounsbury 2005). Reported manatee strandings were investigated by the BMMSN, who responded to each stranding to verify the status (alive or dead), location, and cause of stranding. For stranded manatees encountered dead, carcasses were recovered, external examinations were conducted, and morphometric data and genetic samples were collected. Whenever possible, a field necropsy was also conducted to determine the cause of mortality. For live strandings, the animal's situation (i.e. what caused the animal to be stranded, body condition) was assessed, and it was recovered for rehabilitation when necessary and feasible. Here we include both dead and live strandings, as well as verified (confirmed by a member of the BMMSN) and unverified strandings (strandings reported by a

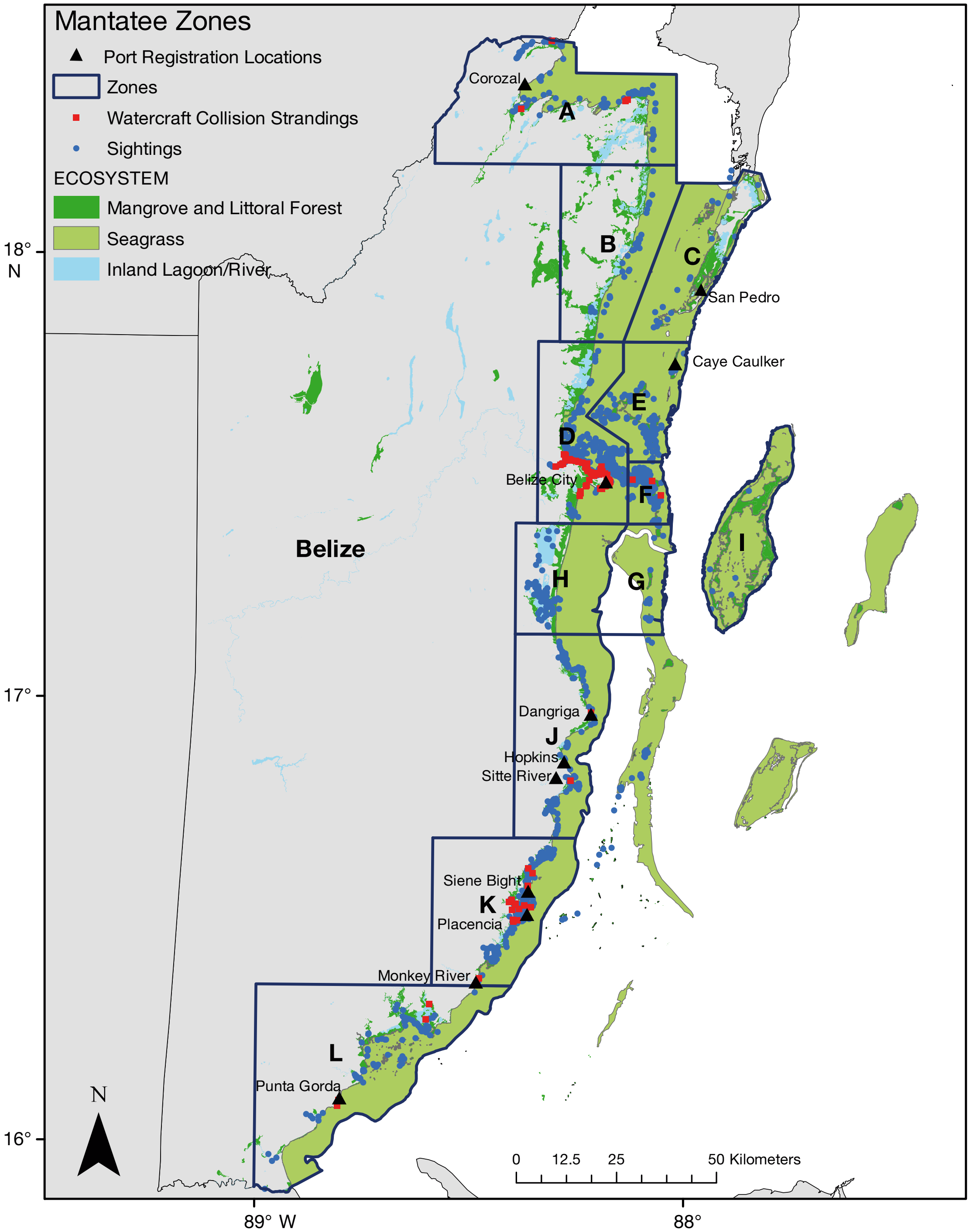

Fig. 1. Twelve manatee zones (A–L) with watercraft collision strandings (red squares) and manatee sightings from aerial surveys (blue circles) within mangrove and littoral forest habitat (dark green), seagrass habitat (light green), and lagoons (light blue)

member of the public but BMMSN was unable to confirm the stranding) in our analysis; 85.4% of strandings were verified. Live and dead strandings were classified by the cause of mortality: watercraft collision, poached, drowned, entangled, lone dependent calf (<150 cm), undetermined, and other. In this paper, 'stranding' refers to all of the above causes including watercraft collision. 'Watercraft collision stranding' refers to manatee strandings that were the result of watercraft collision, determined by whether the animal exhibited signs of sharp- or blunt-force trauma. Sharp-force trauma was identified by a

Table 1. Belize aerial survey data and manatee stranding data, 1995–2019

Year	Aerial surveys: Individuals dry season (n)	Aerial surveys: Individuals wet season (n)	Manatee strandings: Total (n)	Dead (n)	Watercraft collisions (n)	Dead, watercraft collisions (n)	% of strandings due to watercraft collisions
1995			35	35	0	0	0
1996			3	3	0	0	0
1997	310	300	8	8	2	2	25
1998			16	15	2	2	12.5
1999	219	211	16	14	4	4	25
2000	290	257	16	16	2	2	12.5
2001	136		12	12	1	1	8.3
2002	73	480	13	10	3	2	23.1
2003			16	14	4	3	25
2004			8	7	1	0	12.5
2005			16	16	3	3	18.8
2006			13	11	2	2	15.4
2007			11	10	3	2	27.3
2008			7	6	0	0	0
2009			12	10	4	3	33.3
2010			20	17	5	4	25
2011			20	19	5	5	25
2012			17	13	4	2	23.5
2013			28	25	10	9	35.7
2014	297		29	26	13	12	44.8
2015			42	35	15	9	35.7
2016			23	19	8	7	34.7
2017			36	36	17	17	47.2
2018			44	38	13	10	29.5
2019			40	36	13	12	32.5
TOTAL			**501**	**451**	**134**	**113**	**26.7**
Mean ± SE			**20.0 ± 2.3**	**18.0 ± 2.1**	**5.4 ± 1.0**	**4.52 ± 0.9**	**22.9 ± 2.6**

series of pink, equally spaced, superficial or deep cut wounds to the body of a live or dead stranding, generally attributed to boat propeller injuries. Blunt-force trauma was identified in live strandings by buoyancy issues and evidence of external scars or injuries, or in dead strandings after an internal examination or necropsy was conducted to look for broken, fractured, or dislocated bones (usually ribs), internal bleeding, or punctured organs. We assessed pre- vs. post-mortem collisions based on the state of decomposition of the manatee and the wounds and the location of the injury/scar (injuries on manatees' stomachs suggest post-mortem strikes because dead manatees often float belly-up).

2.3. Boat registration

We obtained coastal boat registration data for 1994–1998 (partial data in 1998) and 2005–2019 from the Belize Port Authority as a proxy for boat traffic in Belize. Boat registration became mandatory in 2005 leading to a large number of registrations in 2005–2006. Because boats are not required to re-register each year, a cumulative count of boats registered over time can serve as an index of the magnitude of boat traffic. However, boats have a finite lifespan, and it is likely that some boats registered in 1994 were no longer operating in 2019. We did not include vessels registered with no address, or under temporary registration, or vessels registered at the inland ports of Orange Walk or Cayo.

2.4. Analyses

2.4.1. Temporal analysis

We examined temporal correlations between both total manatee strandings and watercraft strandings and the cumulative number of boats registered. We performed correlations both for Belize as a whole and separately for the 2 zones where the vast majority of strandings occurred (Zones D and K with 104 and 16 total strandings; all other zones had 0–4 strandings over the 25 yr). We performed 2 analyses with different assumptions about the lifespan of boats: one using cumulative boat registration data from the period 2005–2019 (which assumes boats are used for 15 yr), and one that includes data from 1994 onward (which assumes a longer lifespan of 26 yr). We regressed yearly strandings and watercraft collision strandings against the number of registered boats using a generalized linear model with a Poisson distribution and a log link.

2.4.2. Spatial analysis

To examine patterns in boat traffic, strandings, and sightings, we divided the coastline and offshore waters of Belize into 12 zones (A–L) (Fig. 1). Zone boundaries were determined to divide the coastline into zones with internally consistent features that differentiated that area from adjacent areas (e.g. distribution of habitat types, human density, manatee presence, ability to report strandings). The northern limit of the zones was the offshore limit of Belizean waters (Zones A, B, C), and the eastern edge of most zones was the eastern limit of seagrass distribution as mapped by Ecosystem Belize 2017, since seagrass is an important habitat for manatees (Meerman & Clabaugh 2017). We excluded areas where it was not possible to report manatee strandings (e.g. remote regions lacking communication infrastructure).

We assigned each stranding and aerial survey sighting to 1 of the 12 analysis zones using ArcMap 10.7 (ESRI 2018). We assumed that the probability of detection of a manatee stranding or a manatee sighting were approximately the same in each zone. Six strandings that occurred outside of the 12 zones were excluded from analyses. Registered boats were also assigned to 1 of the 12 analysis zones based on the location of their port of registration. Boats from ports with multiple adjacent zones (e.g. Belize City) were allocated based upon relative proportions of boat traffic between zones (Table S1 in the Supplement at www.int-res.com/articles/suppl/n051p103_supp.pdf).

We calculated a spatial stranding risk index by dividing the average yearly number of watercraft collision strandings by the average number of manatees observed during aerial surveys across years within each zone:

$$\text{Stranding risk incidence} = \frac{\text{Total number of manatee watercraft collision strandings}}{\text{Average manatees per aerial survey} \times 25 \text{ yr}} \quad (1)$$

To test the hypothesis that spatial variation in stranding risk was correlated with boat traffic, we conducted a logistic regression (a generalized linear model with a binomial distribution and a logit link) of watercraft collision strandings in each zone against the number of registered boats. For each zone, we used the manatee-years at risk of stranding as the number of trials, by multiplying the average aerial survey count by the number of years in the stranding data set. We used the number of watercraft collision strandings in each zone as the number of events. Because there was little to no potential for manatee strandings to be reported in Zone B (few people live along or visit this area), this zone was excluded from the spatial stranding incidence analysis. All analyses were performed in R v4.1.3 (R Development Core Team 2023).

3. RESULTS

Antillean manatee strandings and aerial survey sightings occurred along much of the coastline of Belize, including freshwater, estuarine, and marine habitats (Fig. 1).

3.1. Aerial surveys

In the 6 years of manatee aerial sightings over a 17 yr period, we recorded a total of 2573 manatee sightings (Fig. 1), with an average of 257.3 ± 34.8 (mean ± SE) individual manatees survey^{-1} (Table 1). Manatee group sizes in aerial surveys ranged from 1 individual to 22 manatees (mean 1.65 ± 1.61). We found no significant difference among seasons in the number of manatees seen in wet and dry years (season effect in the linear model with year: coeff. −89.0, SE = 106.2, $t = -0.838$, p = 0.460). Manatees were sighted along the entire Belize coast, and of the 2573 manatee sightings in aerial surveys, all but 39 occurred within the 12 analysis zones. The greatest number of manatee sightings occurred in Zones D and K, while the offshore Zones C, G, and I had the fewest (Fig. 1, Table 2).

3.2. Strandings

A total of 501 strandings were recorded during the 25 yr period (1995–2019) with a mean of 20.0 ± 2.3 (mean ± SE) strandings yr^{-1} (Table 1), with 451 (90%) strandings of dead manatees. Of these 501 strand-

Table 2. Mean ± SE aerial counts survey^{-1}, mean ± SE watercraft collision strandings yr^{-1}, calculated strandings per incidence zone (stranding incidence = average stranding / average aerial survey count), total number of watercraft collision strandings, and total number of registered boats per zone in 12 zones in Belize (see Fig. 1 for zones)

Zone	Aerial count survey^{-1}	Watercraft collision strandings yr^{-1}	Stranding incidence yr^{-1}	Total watercraft collision strandings (n)	Total registered boats (n)
A	14 ± 2.9	0.18 ± 0.08	0.013	4	294.4
B	12.7 ± 4.5	0	0	0	73.6
C	2.8 ± 1.1	0	0	0	2224
D	72.5 ± 8.6	4.73 ± 0.83	0.065	104	1634.04
E	20.7 ± 3.5	0	0	0	1140.6
F	22.0 ± 3.4	0.14 ± 0.07	0.006	3	240.3
G	4.5 ± 0.9	0	0	0	43.9
H	18.2 ± 6.0	0	0	0	21.95
I	0.8 ± 0.8	0	0	0	48.06
J	21.8 ± 4.4	0.14 ± 0.07	0.006	3	520.15
K	51.7 ± 14.8	0.73 ± 0.19	0.014	16	853
L	13.5 ± 1.9	0.18 ± 0.11	0.013	4	550

ings, 134 involved watercraft, with 113 being fatal, for an average of 5.4 watercraft collision strandings yr^{-1}, and 4.5 (82.4%) fatal watercraft collision strandings yr^{-1}. (Table 1). Watercraft collision strandings were first documented in 1997 and increased during the subsequent 23 yr, with a peak of 17 in 2017 (Table 1, Fig. 2).

3.3. Temporal analyses

A total of 7644 boats were registered in Belize between 1994 and 2019, 30% of which were registered in the port of Belize City (Table 3). The number of manatee strandings yr^{-1} and the number of watercraft collision strandings yr^{-1} both increased significantly with the number of registered boats for a given year (generalized linear models with a Poisson distribution and a log link: total strandings = $e^{2.28 + 0.000154 \times \text{Boats registered}}$), $Z = 6.21$, $p < 0.001$; watercraft collision strandings = $e^{-0.99 + 0.000484 \times \text{Boats registered}}$, $Z = 6.66$, $p < 0.001$; Fig. 3). Relationships were similar using watercraft collision strandings and boat registration data between 2005 and 2019 (generalized linear model with a Poisson distribution and a log link: watercraft collision strandings = $e^{-0.43 + 0.00054 \times \text{Boats registered}}$, $Z = 5.58$, $p < 0.001$).

Manatee watercraft collision strandings were only observed in Zones A, D, F, J, K, and L (Table 2; Table S2), and the greatest average annual strandings (4.73 strandings yr^{-1}, 78%) and majority of manatee watercraft collision strandings (104, 78%) occurred in Zone D. Zone D also had the second greatest number of registered boats (1634; 21.4% of all registered boats), followed by Zone K (853; 11.2%; Table 2). Because of the large number of manatee sightings, total strandings, watercraft collision strandings, and registered boats in Zones D and K each year (Table 2; Table S2), we examined the relationship between the number of registered boats yr^{-1} and the number of manatee watercraft collision strandings in these zones and found a significant relationship in both Zone D (generalized linear model with a Poisson distribution and a log link; Watercraft collision strandings = $e^{-0.615 + 0.00184 \times \text{Boats registered}}$; $Z = 6.03$, $p < 0.001$; results were similar using data from 2005–2019; watercraft collision strandings = $e^{-0.380 + 0.00181 \times \text{Boats registered}}$; $Z = 4.32$,

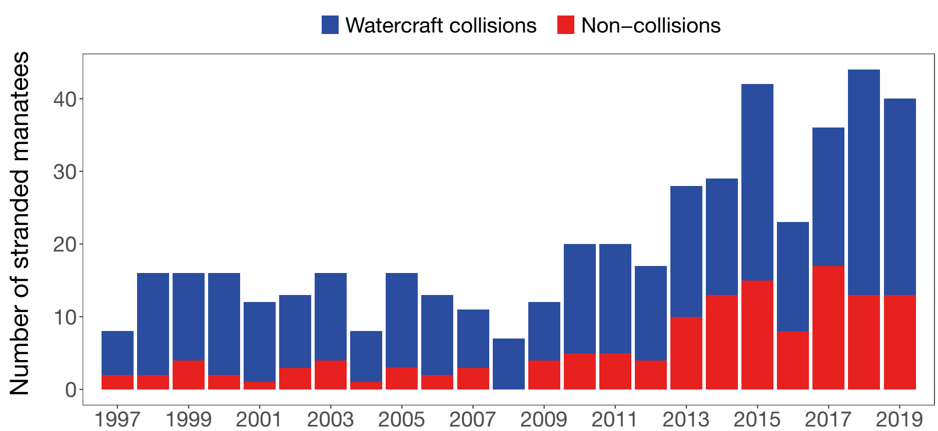

Fig. 2. Watercraft collision strandings (red) and non-collision strandings (blue) of manatees from 1997 to 2019 in Belize

Table 3. Total number of newly registered boats by zone by year for 1994–1998 and 2005–2019. Note that boats are not required to re-register each year, thus the total number of boats in use is proportional to the cumulative/running total in the rightmost column. For the analysis using data from 2005–2019, we did not include the boats registered in 1994–1998 in the cumulative total

Year	Zone												Newly registered boats (n)	Total registered boats (n)
	A	B	C	D	E	F	G	H	I	J	K	L		
1994	0	0	164	23.8	60	3.5	0.7	0.35	0.7	5.95	0	2	261	261
1995	0	0	132	24.48	61.2	3.6	0	0	0.72	0	48	7	277	538
1996	0	0	159	13.6	75	2	0.2	0.1	0.4	1.7	40	23	315	853
1997	1.6	0.4	178	27.2	96	4	2	1	0.8	29	73	25	438	1291
1998[a]	0	0	200	17	80	2.5	5	2.5	0.5	42.5	70	40	460	1751
2005	38.4	9.6	253	166.6	121	24.5	6.9	3.45	4.9	80.65	132	29	870	2621
2006	103.2	25.8	303	459	217	67.5	7.6	3.8	13.5	92.6	112	108	1513	4134
2007	50.4	12.6	89	152.32	58.8	22.4	1.7	0.85	4.48	22.45	56	38	509	4643
2008	14.4	3.6	124	98.6	44	14.5	2.5	1.25	2.9	29.25	48	27	410	5053
2009	12	3	71	94.52	47.8	13.9	2.4	1.2	2.78	29.4	33	35	346	5399
2010	5.6	1.4	57	74.8	25	11	0.6	0.3	2.2	11.1	21	17	227	5626
2011	5.6	1.4	56	93.16	44.4	13.7	0.3	0.15	2.74	3.55	5	11	237	5863
2012	11.2	2.8	71	62.56	31.4	9.2	2.4	1.2	1.84	28.4	20	53	295	6158
2013	4.8	1.2	66	44.2	24	6.5	1.6	0.8	1.3	16.6	18	33	218	6376
2014	7.2	1.8	60	44.88	21.2	6.6	1.6	0.8	1.32	21.6	24	12	203	6579
2015	8.8	2.2	43	66.64	41.6	9.8	2.2	1.1	1.96	28.7	15	27	248	6827
2016	8.8	2.2	46	44.88	26.2	6.6	2.2	1.1	1.32	23.7	20	18	201	7028
2017	6.4	1.6	56	50.32	25.8	7.4	1.3	0.65	1.48	17.05	56	15	239	7267
2018	10.4	2.6	66	46.24	24.6	6.8	2.2	1.1	1.36	24.7	39	20	245	7512
2019	5.6	1.4	30	29.24	15.6	4.3	0.5	0.25	0.86	11.25	23	10	132	7644
Total	294.4	73.6	2224	1634.04	1140.6	240.3	43.9	21.95	48.06	520.15	853	550	7644	7644

[a]Registration data were incomplete in 1998

$p < 0.001$) and Zone K (watercraft collision strandings = $e^{-6.36 + 0.00875 \times \text{Boats registered}}$; $Z = 2.91$, $p = 0.004$; results were similar using data from 2005–2019 (watercraft collision strandings = $e^{-4.17 + 0.00856 \times \text{Boats registered}}$; $Z = 2.98$, $p = 0.003$). Too few strandings (0–4) occurred in other zones to analyze temporal correlations with registered boats.

3.4. Spatial analyses

The risk of watercraft collision per manatee, per year, as measured by stranding incidence, increased significantly with the number of registered boats across the 11 zones included in the analysis (generalized linear model with a binomial distribution: logit(stranding incidence) = −5.66 + 0.00171 × registered boats, $Z = 9.79$, $p < 0.001$; Fig. 4). Watercraft stranding incidence was greatest in Zones D (0.064 strandings sighting^{-1}) and K (0.019 strandings sighting^{-1}; Table 2).

4. DISCUSSION

Antillean manatees are listed as Endangered by the IUCN (Self-Sullivan & Mignucci-Giannoni 2008), and watercraft collisions represent a key threat and source of mortality for some populations (Mignucci-Giannoni et al. 2000, Lightsey et al. 2006, De Meirelles 2008). In Belize, consistent with previous work (Auil 2004), we found that manatees were concentrated in areas near river mouths and lagoon systems and were sparser in open ocean areas with high wave action, deeper waters, and limited freshwater sources (Fig. 1). We also found the greatest number of registered boats in some of these same areas, associated with intensive tourism activities and cargo and cruise shipping ports (Belize Tourism Board

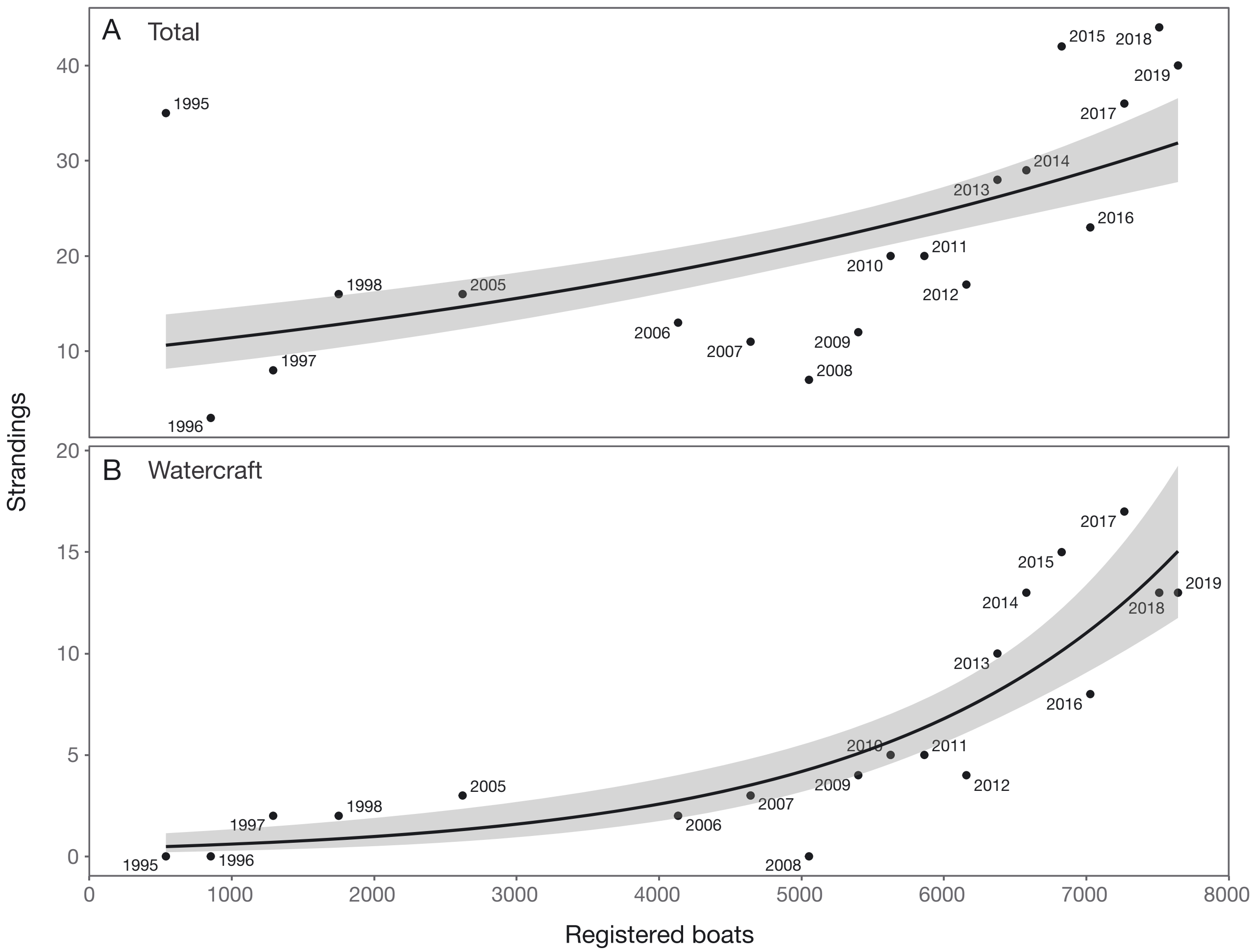

Fig. 3. Temporal correlation between (A) total and (B) watercraft collision manatee strandings and the cumulative number of boats registered from 1994 to the year labeled near the point. Lines show fitted generalized linear models with a Poisson distribution and a log link. In 1995, all 35 strandings came from a poaching slaughter site

2018). Since the consistent collection of manatee stranding data in 1995, the highest annual stranding count was recorded in 2018, which coincided with a 17% increase in tourism compared to the previous year (Galves et al. 2023). Although increased tourism could increase the probability of observing a stranded manatee, increased detectability is unlikely to explain the 30-fold increase in watercraft strandings between 1995 and 2019. The probability of detecting a manatee on an aerial survey also may have varied among zones or among surveys, but this variation is unlikely to explain the very strong correlations with registered boats over space and time.

Prior to 1997, poaching was believed to be the main cause of manatee mortality in Belize (Galves et al. 2023). Since 2010, watercraft collision has been recorded as the main cause of manatee strandings, accounting for 131 of the 376 strandings (Galves et al. 2023). In 1998, a 27 km radius around Belize City, Zone D, was first identified as a high-vulnerability area for manatee watercraft collision strandings (Belize Manatee Recovery Plan 1998). We found that the number of manatees stranded due to watercraft collisions was greater in areas where manatees were concentrated (Zones D and K), and the per capita risk of watercraft collision strandings was greater in areas with more registered boats. In a recent study that examined all causes of manatee strandings in Belize, the Belize District, Zone D, accounted for 76.1% of the total strandings, of which 36.5% were a result of watercraft collision, while the Stann Creek District, Zone K, which includes Placencia, accounted for 13.3% of the total strandings, of which 36% were a result of watercraft collision (Galves et al. 2023). While this recent study examined spatial and temporal patterns of manatee strandings, our study analyzed the relationship between the number of registered boats and the stranding risk incidence, taking into consid-

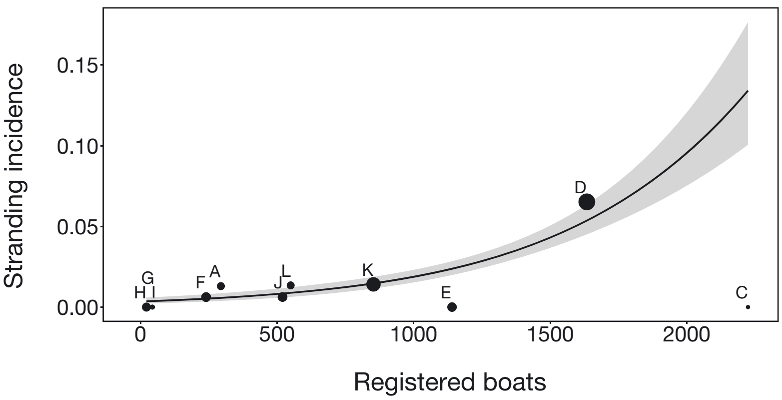

Fig. 4. Spatial correlation between manatee strandings and the number of registered boats. Stranding incidence (stranded manatees per manatee sighted) plotted against the total number of boats registered in 11 zones along the Belize coast (labels near points correspond to zones in Fig. 1). The size of each point is scaled to the average number of manatees seen in that zone across surveys (Table 2). The line shows a fitted binomial regression model. Zone C, where no strandings were observed, is an outlier; the lack of strandings observed in this zone may be due to very low manatee abundance (Table 2) or a very low likelihood of a stranding being reported

eration aerial survey sightings and manatee watercraft collision strandings, within specific zones in Belize. We found that the number of watercraft collision strandings increased with boat registrations through time. Taken together, these relationships indicate that increasing the number of boats in an area or over time will likely result in more manatee watercraft collisions. Our estimate of watercraft collision being the cause of 27% of reported strandings is slightly higher than the 20–25% of reported mortalities in Florida manatees *Trichechus manatus latirostris*, where boat collision has been determined as a significant threat (Wright et al. 1995, Lightsey et al. 2006, Florida Fish and Wildlife Conservation Commission 2007, Runge et al. 2015, Bassett et al. 2020). Reducing watercraft collisions in key areas should be an important focus for Antillean manatee conservation. While some areas with high manatee concentrations and number of boats have speed zones and restrictions, enforcement is limited. Importantly, many key areas of manatee habitat with high manatee sightings did not contain any spatial protected status.

There are multiple feasible conservation interventions to protect and recover the Belize Antillean manatee population. It is important to consider expanding the status designation of wildlife sanctuaries, special management areas, or other protected areas, particularly in zones with large numbers of manatees and strandings. The designation of 'non-motorized boating' areas or 'restricted access' at manatee resting areas within high manatee density zones should also be a high priority. In areas where this is infeasible, boat speeds and boating activities should be regulated through an inter-agency approach in shallow seagrass habitats commonly used by manatees (Calleson & Frohlich 2007). Specific interventions should include: (1) creation of a Species & Habitat Management Plan to provide protected status at the national level; (2) evaluation of the efficacy of existing manatee wildlife sanctuaries and addressing gaps as appropriate; (3) creation of a spatially detailed Manatee Management Plan across important manatee use zones that addresses the expansion and establishment of manatee sanctuaries, non-motorized boating/restricted access zones/speed restrictions, and the implementation of boating navigation regulations proven to mitigate manatee collision (e.g. restricting boating activities to specific routes/channels/lanes); (4) establishment of limits for watercraft in zones of high manatee use; (5) a socioeconomic analysis of the potential impact of manatee conservation actions on local fishermen and boat operators (Calleson & Frohlich 2007); and (6) increased education and outreach to boat operators particularly in zones where the risk of manatee watercraft collision is high and to encourage the reporting of manatee stranding incidents to facilitate rescue of live strandings and additional data on causes of mortality. Similar interventions have been successfully implemented in other important sirenian regions (e.g. Florida and Australia; US Fish and Wildlife Service 2001, Dobbs et al. 2008, Runge et al. 2015), and can lead to the long-term recovery of the Endangered manatee population in Belize.

5. CONCLUSION

Identifying and understanding the dominant threat to the Antillean manatees in Belize is an important first step in conserving this imperiled species and its habitat. We found strong links between registered boats and watercraft collision strandings in both space and time. Watercraft collisions are an important source of mortality for manatee populations in Belize, and an increase in boat traffic within manatee hotspots raises concern about the survival of the Antillean manatees in Belize. Protection for these priority areas is recommended to provide safer habitat for this subspecies. Our hope is that conservation interventions and regulations will be implemented to directly address this threat.

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