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Assessing dugong distribution and overlapping threats along the northwestern Red Sea, Egypt

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ABSTRACT

An interview survey was conducted amongst (primarily) fishermen along the Egyptian Red Sea coasts to determine the distribution of vulnerable dugongs (*Dugong dugon*) and how human impacts overlap to help guide conservation actions. A total of 207 interviews were completed from August 2015 to May 2016 in seven regions along the Egyptian Red Sea coast. Dugongs were sighted at 95 locations, and the greatest number of dugong encounters happened during transit to fishing areas (>39%) and 27% during fishing activities. The majority of the fishermen (89%) believed that dugong captures in nets were decreasing, although it was we are unsure if this represents a decrease in the dugong population. Most of the captured dugongs were reportedly released alive (>72%), but 13% were reported as eaten, representing an ongoing threat to dugong survival in the Red Sea. Approximately 34% of the respondents thought that overall dugong numbers were in decline and >79% suggested that dugongs might become extinct in the future. Most fishermen understood it was illegal to catch a dugong on purpose (>89%) and 7% thought it was legal if the dugong was caught by accident. Dugong sightings from 1980 to 2016, seagrass distribution, and fishing areas were overlaid on Geographical Information System (GIS) maps to highlight the overlaps between dugong distribution, anthropogenic threats, and to identify potential conservation hotspots. The minimum population size was estimated between 73 and 97 individuals in the north-western Red Sea, Egypt.

INTRODUCTION

Conservation of dugongs is a complex process because of their patchy distribution over a large area and changes in their life history parameters associated with the availability of seagrass **Marsh (2002)**. Knowing where dugongs occur and what stressors they face are essential for conservation. For example, entanglement in fishing nets is the major hazard for dugongs and its impacts are under-estimated in many countries; **Read (2008)**, **Pusineri *et al*. (2013)**, **Wilcox *et al*. 2015**, and **Temple *et al.* (2019)**. A major challenge lies in documenting the effects from fisheries on the distribution and abundance of dugong populations in an economical and efficient way **(Lewison *et al*. 2004; Pauly 2006**; **Lewison *et al*. 2011)**.

Interview surveys are a low-cost solution for documenting the distribution and abundance of dugongs and fisheries' influences **(Pilcher *et al*. 2017)**. These surveys can provide data on dugong populations, habitat preference, and the reported number of individuals killed by hunting, boat strikes or found as by-catch in fishing gear. Information about dugongs and their traditional uses can be derived from the use of a standardized questionnaire that has a focus on conservation **(Ortega-Argueta *et al*. 2012)**. Interviews are also a way to identify the wider distribution of dugongs at present, in the past, and approximate population size **(Sivakumar and Nair, 2013)**. Many authors suggest that additional, more in-depth research can then be conducted following the acquisition of new information from interviews **(Silva and Araújo, 2001)**. Interview surveys have been used in several studies such as fishery by-catch studies **(Moore *et al*. 2010)**, key-informant stakeholders in marine turtle and dugong management **(Weiss *et al*. 2012)**, stock assessments **(Fairclough *et al*. 2014)** and status of dugong populations **(Hashim *et al*. 2017)**.

In the Egyptian Red Sea, dugong distribution and abundance has not been assessed in detail. **Gohar (1957)** reported specimens collected near Hurghada, on the Red Sea. Along the Gulf of Aqaba, two calves were sighted in Abu Galum Protected Area (AGPA) in 1997 **(Marsh ()**, and two dugongs were found in the mangrove zone of Nabq Protected Area (NPA) between 1999 and 2000 **(Jeudy de Grissac *pers comm*., 2001)**. Incidental sightings have occurred between the islands of Tiran and Sanafir, where widespread seagrass beds exist **(Marsh 2002)**. In June 2001, a herd of ten dugongs was recorded in this area; and one dugong was photographed south of Qosseir (**Jeudy de Grissac *pers comm*., 2001)**. Interview surveys were also used to determine the distribution and abundance of dugongs in the Egyptian Red Sea from Hurghada to Shalateen during 2001, 2002, and 2003 **(Hanafy *et al*., 2006)**.

This is the first detailed study that includes the use of specific and detailed questions for the determination of the dugong status in the Red Sea by means of a standardized questionnaire survey used across the dugong range and established by the CMS- UNEP Dugong MoU **(Pilcher *et al*., 2017)**. Data were collected on the status, fishing activities, trend, distribution, and abundance of dugongs on the north-western coast of the Egyptian Red Sea that was not obtained during earlier surveys. The

objectives of the survey were as follows: 1) determine the geographical distribution of dugongs; 2) assess dugong density and dominant group size; 3) estimate the minimum population size of dugongs; 4) assess local trends in dugong distribution and fishing activities; 5) identify threats and their impacts on dugong populations and 6) identify the role of protected areas in the conservation of dugongs' communities and their managements.

MATERIALS AND METHODS

1. Study sites

The interview surveys were conducted over a 10 month period from August 2015 to May 2016. A total of 207 interviews were conducted over 43 days of fieldwork at 20 sites within seven regions across the Egyptian Red Sea Coast **(Fig. 1)**. These regions were Elba Protected Area (EPA, n=8, one site); Ras Banaas (n=8, three sites); Wadi El Gemal National Park (WGNP, n=74, seven sites); Marsa Alam (n=88, five sites); Qosseir (n=3, two sites); Northern Islands Protected Area (NIPA, n=24, one site) and Southern Sinai (n=2, one site).

2. Questionnaire survey

The standardized dugong catch/bycatch questionnaire established by the CMS-UNEP Dugong MoU **(Pilcher *et al*., 2017)** was translated into Arabic by the first author. Interviewees were randomly selected including active fishers, a small number of women, and older retired fishermen who had been actively participating in fishing activities. The heads of villages were interviewed as critical informants, in addition to people whose role in the community exposed them to the type of information being required **Tremblay (1957)**. Information on dugong sightings, occurrence, habitat, threats, trends, the status of artisanal fisheries and the attitude of fishers towards dugongs, along with a suite of additional information (the questionnaire contained over 100 questions, see **(Pilcher *et al*., 2017)** for details which was collected and analysed. Detailed coastal area maps and dugong photo were provided during the interviews and were used to mark sightings, stranding, fishing areas, seagrass habitat and any other relevant spatial data on the map as the interview progressed **(Fig. 2)**.

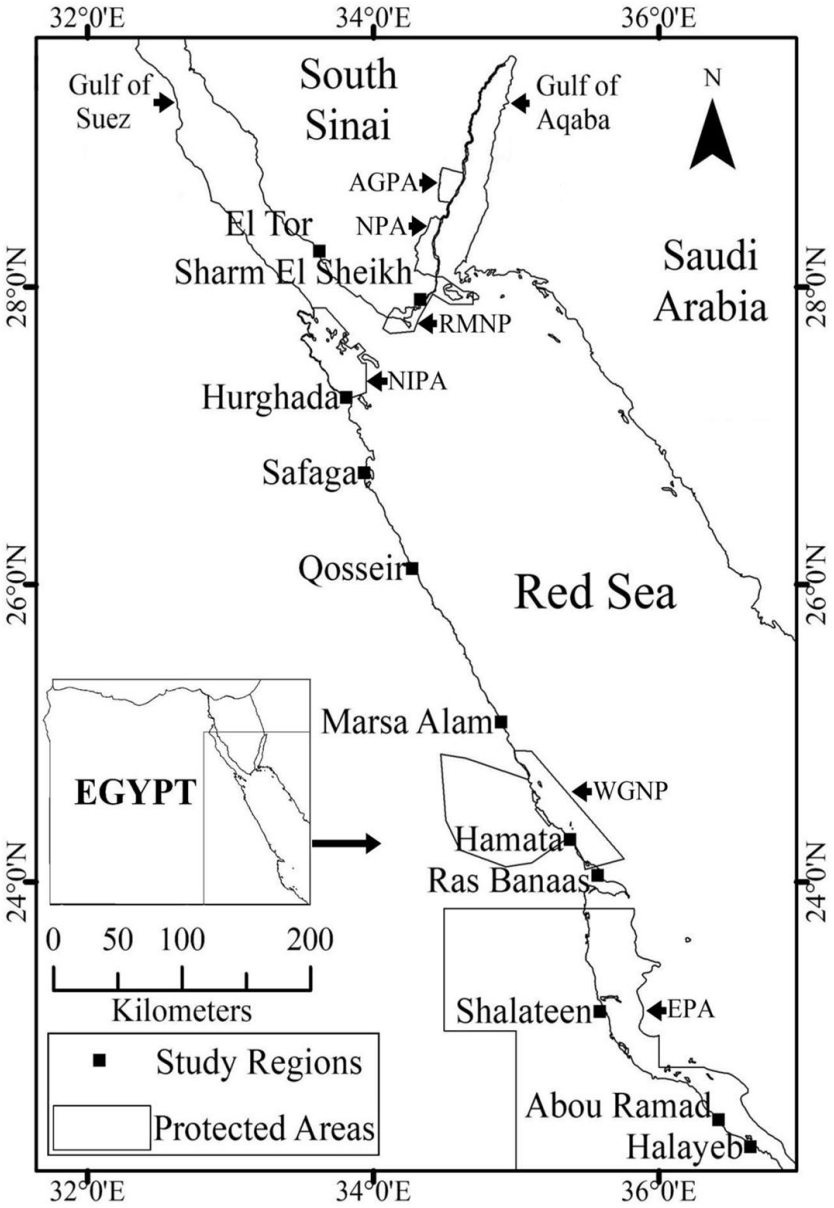

Fig. 1. Egyptian Red Sea map showing study regions of the dugong questionnaire survey and the boundaries of the protected area; AGPA (Abou Galum Protected Area), NPA (Napq Protected Area), NINP (Northern Islands National Park), WGNP (Wadi El Gemal National Park) and EPA (Elba Protected Area).

Fig. 2. Dugong photo show to the interviewers. © Ahmed M. Shawky.

Two types of questions were used in the interview. Closed-end questions such as "Yes, No" restricted response **(Ortega-Argueta *et al*., 2012)** and open-ended questions that encouraged interviewees to comment more freely **Hines (2002)**. The questionnaire contained 49 questions related to dugongs and was divided into different sections. These sections included interviewee background, dugong catch/ by-catch, sighting record, as well as perceptions and fishery information. The remainder of the questions were related to sea turtles/other species and were optional for respondents.

3. Dugong population size

During this study, two methods were applied to estimate the population size of dugongs in the Egyptian Red Sea waters. The first method used reviewing survey data for number of dugongs within each region that correlated with photo identification (Photo-ID) recorded by **Shawky *et al*., (2017, 2019)** and presence of feeding trails. Feeding trails can be used as indirect evidence for the presence of dugongs **Shawky (2019a, 2019b)** and by measuring the widths of the trails, provide an estimate of body size.

The second method used to estimate the maximum population size followed the methodology of **(Anand *et al*., 2015)** where the number of single, group, and mother-calf

dugong sightings by fishermen and number of villages is represented via the simple mathematical equation: $[(N_{vs})(D_s)]+[(N_{vdg})(D_{dg})]+[(N_{vmc})(D_{mc})]$ where,

N_{vs}= Number of villages with single dugong sightings

D_s= Number of dugongs sighted singly with a single dugong sighting =1

N_{vdg}= Number of villages with group sightings

D_{dg}= Number of dugong sighted in groups

N_{mc}= Number of villages with mother-calf dugong sighting

D_{mc}= Number of dugongs in mother-and-calf sighting per village =2.

RESULTS

1. Interviewee background

In this study, male respondents (93.7%) outnumbered females (6.3%). The majority of respondents (>77%) were linked to the 26-50 years age group with a mean age of approximately 35±6 years (**Fig. 3)**. A great number of respondents (n= 207), 70% (n=146) had a fishing background. Of the sampled population of fishers, 47% of their parents were fishermen, and 41% of their grandparents were also involved in fishery-related activities. On average, the respondents from all seven regions had been involved in fishing for about 19±15 years (**Fig. 4)**.

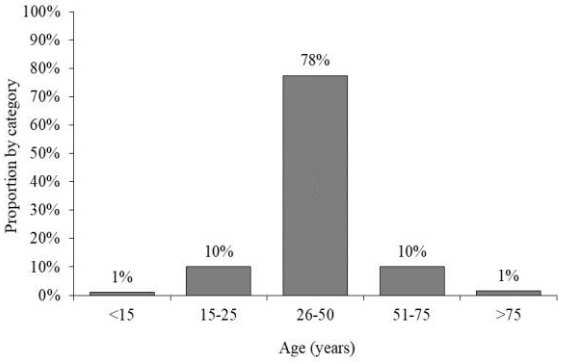

Fig. 3. Respondent age distribution.

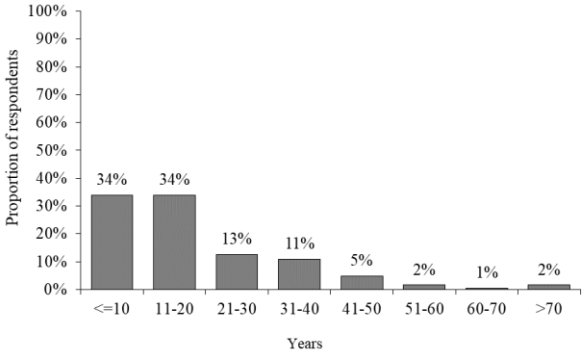

Fig. 4. Years of occupation.

Overall, fishing was the primary industry (48%), while other forms of livelihood such as tourism (10%), boatmen (30%) as well as another 40% were composed of Park Rangers, volunteers, diving and snorkeling guides. For 20% of the respondents, fishing was the sole way of earning a living; while the remainder, (80%) supplemented their income through other activities.

In this study, different local names for the dugong were recorded. The most common alternate name was "El-Geld" meaning "skin or leather" and "El-Egl" meaning "calf" which were common among southern Red Sea fishermen. This was followed "Gamal Al-Bahr" meaning "Sea-Camel". The name of "Arosset Al-Bahr" meaning "Mermaid" was more common among the fishermen of the northern Red Sea, around Hurghada.

2. Dugong catch/ bycatch

Dugongs were observed by >97% of respondents, and distinguish the difference between dugongs and dolphins, with approximately 97.5% positively identifying a dugong, suggesting high accuracy in species identification for this study.

The largest proportion of dugongs (39%) were sighted during transit to and from fishing areas; 28% were stranded; 27% were seen while fishing; and the remainder were observed trapped in nets (3.5%) or reported as hunted (2.5%). The frequency of dugong sightings and trends by region is presented in **Table 1** and **Fig. (5)**. When asked if the habitat of the dugong was changing 43, % answered "Yes", 36% answered "No", and 20% reported not knowing. Observations of calves were dominant in Marsa Alam and WGNP compared to other regions. Over 61% of respondents believed that the number of dugongs in key areas ranged between 2 and 10. Less (27%) thought that there were more than 10, but only 3% believed that only one dugong was present. According to regions, most respondents at EPA, Ras Banaas and Qosseir believed > 10 dugongs occurred in their key areas. Less than half of respondents in WGNP, Marsa Alam and NIPA believed that the number ranged between 2 and 10 dugongs **(Table 1)**. Confirmation of all dugongs in South Sinai was greater than 10 is based on an old stranding event south of Sanafir Islands, which is located within Saudi Arabia boundaries.

Table 1. Percentage of dugong sightings data and trends by region (A: Southern Sinai; B: NIPA; C: Qosseir; D: Marsa Alam; E: WGNP; F: Ras Banaas; G: EPA).

Region	% Sighting seen						% Last saw per years				Known areas	% No. of dugongs in key areas				% Seen calves In last years		
	Fishing	Transit	Netted	Hunted	Stranded	N/A	<1	1-3	3-10	>10		1	2-10	>10	N/A	1	1-2	>2
A	0	0	0	0	100	0	N/A	N/A	N/A	N/A	N/A	0	0	100	0	0	0	0
B	25	33	6	6	15	15	22	17	39	22	70.8	4	62	17	17	0	14	86
C	22	23	11	11	11	22	34	N/A	33	33	100	0	33	67	0	0	0	100
D	29	38	3	1	1	28	94	3	2	1	100	1	67	31	1	41	15	44
E	23	37	3	2	4	31	89	7	3	1	87.8	6	63	24	7	78	6	16
F	13	38	6	13	0	30	25	13	50	12	87.5	0	25	38	37	0	0	0
G	28	28	6	6	22	10	63	N/A	13	24	100	0	38	38	24	0	0	100

Legend: N/A= not asked.

Of the 49% of fishermen who responded to the questiton on whether the number of dugongs captured accidentally was increasing, declining or stable in fishing nets, 89% of this group noted the captured numbers had reduced. If the dugong was accidentally caught, most of the respondents stated that they would release the dugong back to the sea (72%), and 13% said they would eat it **(Fig. 6)**. When the catch was purposeful (n=24), more than 37% said they would eat the dugong while 29% said they would sell it. The response of selling the animal, occurred in multiple sites which included Ras Raya (100km south of El Tor, South Sinai), Hurghada, and the villages of Abou Ghossoon (WGNP) and Om Hashem (Ras Banaas).

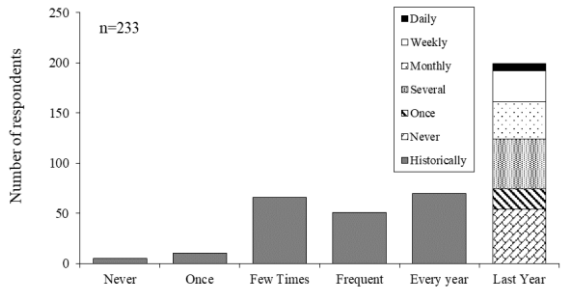

Fig. 5. Dugong sighting frequency.

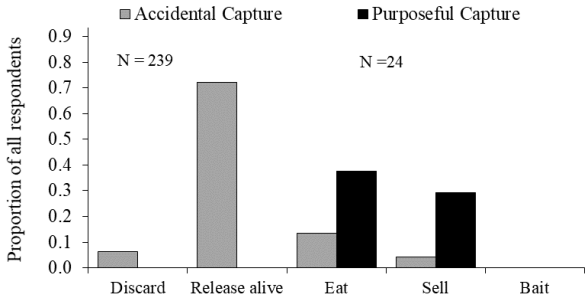

Fig. 6. Fate of caugh dugong

Dugongs were sighted at 95 sites; 17 in Elba Protected Area (EPA), five in Ras Banaas, 17 in WGNP, 31 in Marsa Alam, 11 in Qosseir, three in Safaga, nine in NIPA and two in South Sinai. A total of 1,322 dugong sightings were recorded for the period spanning 1980 to 2016. The sighting records were divided into four decades, 1980-1989 (n= 109); 1990-1999 (n= 100); 2000-2009 (n= 102) and 2010-2016 (n=1,011) to detect trends over time as well as seagrass and fishing areas **Fig. (7) and (8)**. Of the 1,322 sighting records, 1,968 dugong individuals were sighted between 1980 and 2016 (1,943 live and 25 dead) with approximate size ratio of 9 large: 1 small **Table 2**. A total of 1,127 (85%) of these records were recorded in seagrass habitats, followed by coral reefs (5%). Few respondents confirmed dugong sighting at night (1.5%) and these observations were mainly in the summer. Dugong sightings increased during Summer (45%, n= 596) and decreased in Winter (>15%, n= 201) which may be linked to fishing seasonality rather than dugong distribution.

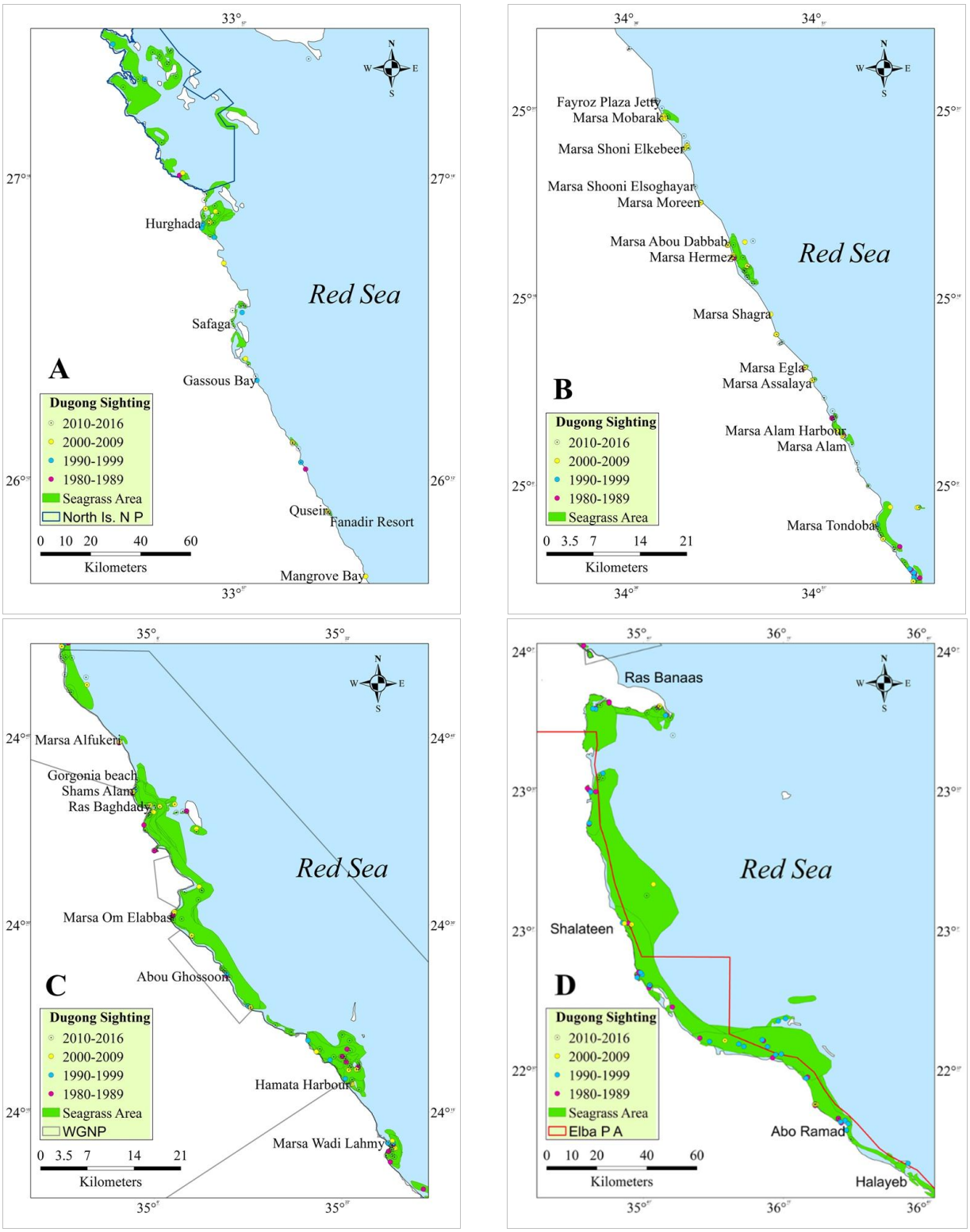

Fig. 7. Trend in dugong distribution and seagrass areas in last four decades along north-western Red Sea coasts, Egypt: A) Hurghada, Safaga and Qosseir; B) Marsa Alam; C) Wadi El Gemal National Paark; D) Ras Banaas and Elba Protected Area.

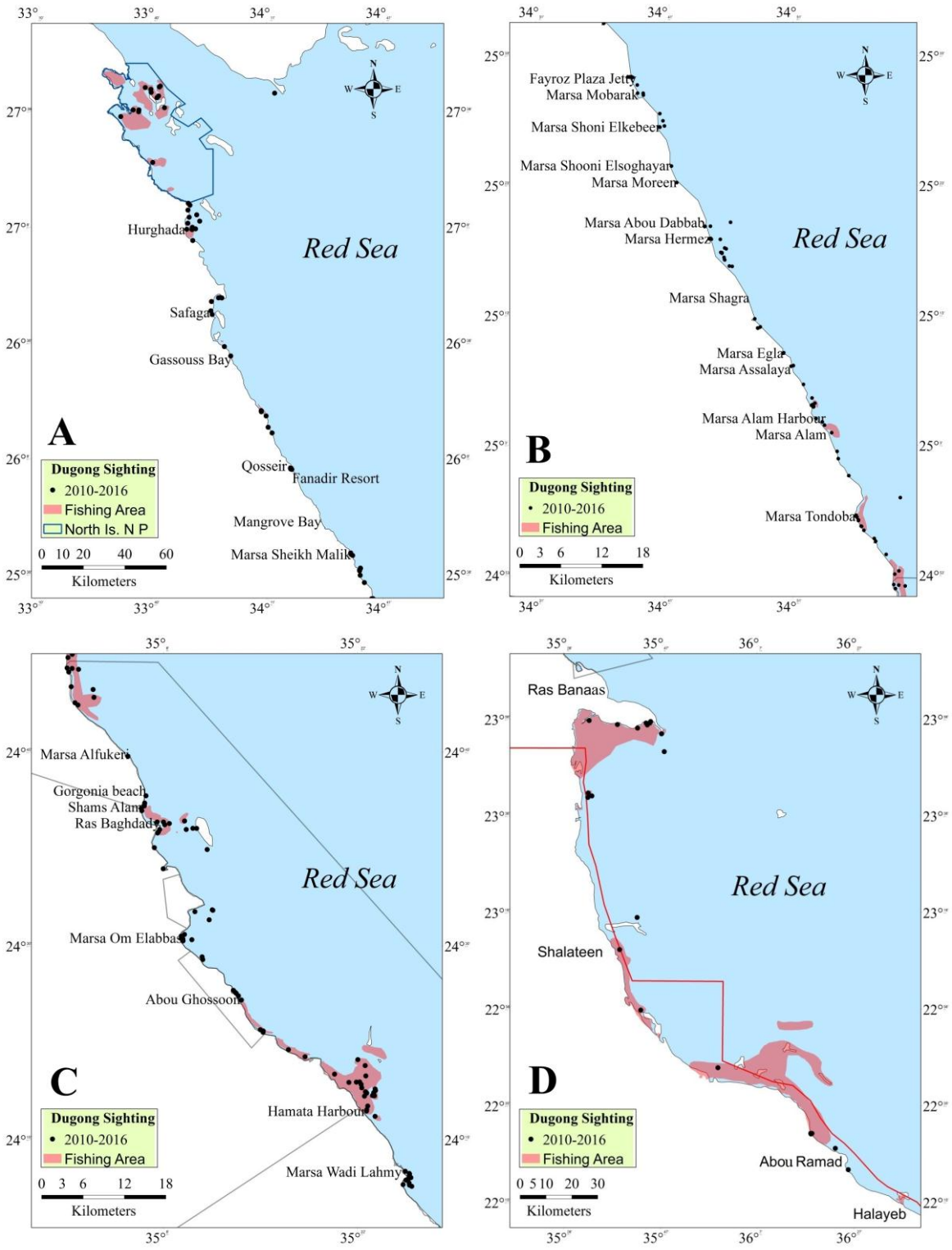

Fig. 8. Fishing areas with dugong distribution between 2010 and 2016 along north-western Red Sea coasts, Egypt: A) Hurghada to Qosseir, B) Marsa Alam, C) Wadi El Gemal National Park, and D) Ras Banaas and Elba Protected Areas.

Table 2. Sighting records of dugongs at the different decades in the study regions.

Sighting Records		Time Periods				No.
		1980-1989	1990-1999	2000-2009	2010-2016	
No. of responders		13	8	23	153	197
No. of sighting records		109	100	102	1011	1322
Dugong density category	1	62	48	83	849	1024
	2	26	16	16	110	168
	3-8	17	29	3	50	99
	12-20	4	7	0	2	13
Habitats	Deep water	9	1	5	40	55
	Coral reefs	1	1	5	63	70
	Seagrass	94	87	82	864	1127
	Fine sediment	4	9	9	39	61
	Mangroves	0	0	1	1	2
	Rock	1	2	0	4	7
Sizes	Large	226	327	110	1763	2426
	Small	19	16	14	200	249
Mother – Calf Pair	Yes	14	21	10	71	116
	No	95	79	92	940	1206
Time of Day	Day	102	95	100	1005	1302
	Night	7	5	2	6	20
Seasons	Winter	1	26	25	149	201
	Spring	0	4	13	296	313
	Summer	100	65	82	349	596
	Autumn	7	5	16	184	212
Status	Total	245	343	124	1256	1968
	Living	242	341	123	1237	1943
	Dead	3	2	1	19	25

Of the 205 respondents, 46% reported to have encountered a calf (n=95), and of those, 51% mentioned that the calf was seen during the previous year; 38% reported seeing calves during the previous two years. Only 29 respondents reported mother and calf pair sightings (n=116) **Fig. (9)**. The majority of sightings were recorded in NIPA and EPA, followed by WGNP **Fig. (10)**, and absent in Qosseir and Ras Banaas.

Dugong stranding were comprised of small and large animals with more dead carcasses reported than live releases **Fig. (11)**. Including the last five sightings between 2018 and March 2023, a total of 24 stranding (five live and 19 dead) were recorded between 1986 and 2023 **(Table 3)**. Of those, 16 cases were recorded during the last 10 years (13 dead and three live). The majority of dead stranded dugongs reported in EPA, while no dead dugongs were recorded in Qosseir. Over the last three decades, two large dugongs stranded in gill nets in the village of Abou Ghoson when the local fishers left their nets untended near the shore. Those dugongs were eaten and the skin used as armour. In the past, the skin of dugongs was used as armour because it is very hard to pierce by swords . For this reason, the dugong is named "El-Geld" meaning "skin or leather" and is common among southern Red Sea fishermen. More recently, it is used as tool for the local community during traditional dancing ceremonies.

Fig. 9. Dugong calf following the mother in WGNP. © Walid Abd Allah.

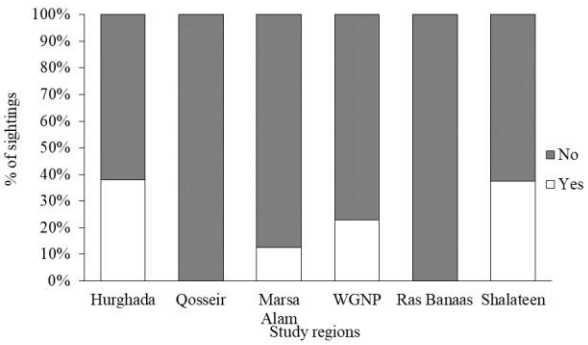

Fig. 10. Frequencies (%) of occurrence of mother with calf in regions.

Fig. 11. Stranded dugongs, A) Large female at Hurghada; B) Young female at Safaga; C) Large male at Hurghada; D) Male calf at WGNP'; E) Large dugong at Qolaan; F) Decomposed carcass at Adaldate and G) Skeleton at Adaldate. © Red Sea Rangers.

Table 3. Reporting of dugong stranding in the Egyptian Red Sea between 1986 and 2023.

Region	Site	Year	Size	Status	Observed by
WGNP	Om El Abass	1986	Small	Dead	Fisherman
Marsa Alam	Abou Dabbab	1990	Large	Live	Dive guide
EPA	Adaldate	1997	Large	Live	Fishermen
EPA	Adaldate	1997	Small	Dead	Park Rangers
NINP	Magaweesh Island	1998	Large	Dead	Fisherman
EPA	Adaldate	2010	Large	Dead	Park Rangers
NINP	El Gouna	2011	Large	Dead	Fisherman
NINP	Magaweesh Island	2012	Large	Dead	Park Rangers
Marsa Alam	Marsa Dorri	2013	Large	Live	Fisherman
NINP	Magaweesh Island	2014	Large	Dead	Park Rangers
Safaga	Safaga	2014	Small	Dead	Park Rangers
EPA	Adaldate	2016	Large	Dead	Park Rangers
Ras Bannas	Harbour	2014	Large	Dead	Fisherman
Ras Bannas	Harbour	2014	Large	Dead	Fisherman
Marsa Alam	Marsa Assalaya	2015	Small	Live	Fisherman
WGNP	Shams Alam	2015	Small	Live	First author
WGNP	Shams Alam	2015	Small	Dead	First author
WGNP	South of Qolaan	2016	Large	Dead	First author
Ras Banaas	Ras Banaas	2016	Small	Dead	Fisherman
South Sinai	Ras Raya	2018	Large	Dead	RMNP Skipper
EPA	Adaldate	2018	Large	Dead	Park Rangers
Marsa Alam	Check Point	2020	Large	Dead	Park Rangers
Safaga	Safaga	2022	Small	Dead	Park Rangers
EPA	N/A	2023	Large	Dead	Social Media

3. Dugong herd sizes

Herd size of dugongs was determined by a minimum number of three individuals, which sorted into four categories of dugong densities (i.e., 3, 4-8, 12-15 and 18-20) were recorded in EPA between 1980 and 1999 and between 2010 and 2016. Dugong pairs were sighted frequently at different sites of the Marsa Alam region; Marsa Seifein, Marsa Hermez, Marsa Abou Dabbaab, south of Marsa Alam harbour and between Marsa Mobarak and Marsa Shoni El Kebeer. Dugongs in a group of three individuals were recorded few times in Marsa Alam at Marsa Egla and Marsa Assalaya. Groups of two and three dugongs were primarily sighted in Wadi El Gemal Island, Hamata harbour, and Wadi Lahmi, while solitary ones were recorded at all locales. Herd sizes of 4-8 and 12-20 dugongs were recorded to be observed by only three interviewees in Marsa Halayeb. No herd sizes of 50 to 100 dugongs, such as are sighted in the Arabian Gulf **(Preen *et al*., 2004)**, were noted by any of the respondents.

4. Dugong population size

Two methods are used to estimate the population size of dugongs. First method is based on four references; number of dugongs in key habitats believed by fishers through questionnaire based survey, photo-ID **Shawky *et al*. (2017, 2019)**, widths of feeding trails **Shawky (2019a, 2019b)**, and personal observation by the primary author. Total estimated dugongs is 97, of which 3 in Hurghada (Shabroor Sheraton and Magaweesh Island), 3 in Safaga (Gassouss Bay), 11 in Qosseir (minimum of >10) , 19 in Marsa Alam (including trails of one calf and pair mother-calf), 21 in WGNP (including trails of three pairs mother-calf and one new identified dugong with code MWL32), 11 in Ras Bannas (minimum of >10), 11 in Shalateen (minimum >10), 16 in Halayeb (average of three herds), and 2 individuals where observed recently in South Sinai in Ras Raya on Gulf of Suze and Nabq Protected Area on Gulf of Aqaba **(Table 4)**. The second methods after **(Anand *et al*., 2015)**, estimated 73 dugongs, with the equation:

$$[(N_{vs})(D_s)]+[(N_{vdg})(D_{dg})]+[(N_{vmc})(D_{mc})]$$

Maximum population number = [(15x1)+(8x4.5)+(11x2)]

= (15+36+22) = 73 dugongs

Table 4. Dugongs' observations based on different references in the study regions.

Region	Reference of numbers				No.
	Questionnaire based survey	Photo-ID	Feeding trails	Personal observation	
Hurghada	2-10	3	-	-	3
Safaga	-	3	-	-	3
Qosseir	>10	-	-	-	11
Marsa Alam	2-10	16	3	-	19
WGNP	2-10	15	6	-	21
Ras Bannas	>10	-	-	-	11
Shalateen	>10	-	-	-	11
Halayeb	>10	-	-	-	16
South Sinai	-	-	-	2	2
Total population size					97

5. Threats

About 34% of respondents believed that dugongs could become extinct due to different threats. When respondents were asked about causes for dugong extinction and declines, 35% believed that fishing nets were the most prevalent reason. Other causes were tourism activities, boat strikes, human impacts (31%), and a lack of guidelines (17%). An inadequate balance of male and female dugongs were the main reasons for the reduction of dugong numbers thay may eventually drive them beyond recovery (10%), as well as seagrass deficiency (7%). More than 27% of respondents were thinking that the dugongs will always be in the sea and 34% were thinking less **Fig. (12)**. In March 2021, the popular dugong of Marsa Mobarak - 50km north of Marsa Alam City - was released by Red Sea Rangers and local community from a drifted gill net that entangeled the tail.

6. Importance of dugongs and seagrass areas

During this questionnaire, it was found that, 79% of respondents highlighted the role of dugongs in sustainable tourism and marine ecosystem equilibrium **Fig. (13).** Only

16% of the fishers did not recognise the importance of dugongs in the marine environment, while 5% believed that dugongs did not have any role in the sea. Most of the respondents (95%; n=206) knew about seagrass areas. Of them, 63 (47%) recognized that the seagrass areas were necessary food resources for turtles and dugongs, and 58 (43%) saw their significance as fishing areas. The balance of respondents (5%) considered that seagrass areas were essential for oxygen fixation and nutrient recycling (n=7) and as a nursery ground for fishes (4%, n=6). The obtained results also indicated that seagrass areas were widespread along the western coast of the Egyptian waters, where dugongs exist.

7. Illegal practices and enforcement

About 90% of the interviewees understood that intentional killing of dugongs was illegal and 68% believed that accidental entanglement was not illegal. Concerning law enforcement, 35% of respondents indicated that patrols were frequent, while 24% said their areas were never monitored **Fig. (14)**. As for whether any action was taken or penalties for violation of laws meant to protect dugongs, 35% of the respondents replied negatively, and 30% answered in the positive.

8. Fishery information

Among 186 respondents, the most commonly used fishing gear across regions were hook and lines (>61%) and gill nets (>31%). Other gear such as beach seines (3.2%), long lines (2.2%) and purse seines (1%) were also used **Fig. (15)**. It was found that, about 90% of gill net users (n=59) set the net on the bottom and 8.5% used mid-water gill nets, while only 1.5% used surface-set gill nets. About 54% of the gill nets were between 51 and 500m in length, 41% were 5 - 50m in length and the remainder were <5m length. For day and night periods, about 48% of the respondents left their fishing nets untended during the day and 12% at night. This ratio declined to about 38% of the fishermen (n=23) left their gill nets unattended for over 2–3 hours and 26% (n=16) left the nets for 4-6 hours. For the percentage of other times, leaving the gill nets 2 to 4 hours, 6 to 12 hours, 12 to 24 hours and >24 hours were represented by 13%, 18%, 3% and 2%, respectively.

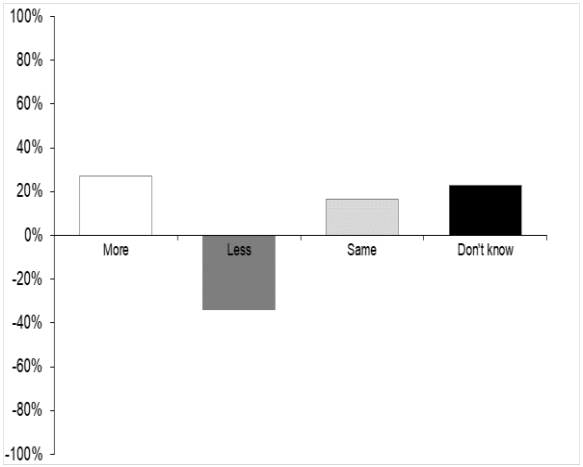

Fig. 12. Trend in dugong captures.

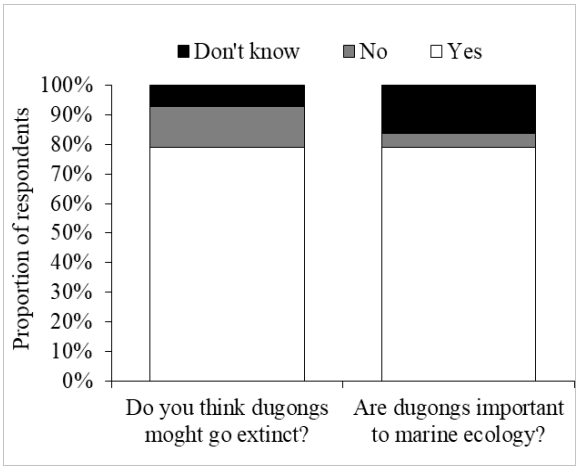

Fig. 13. Dugong perceptions.

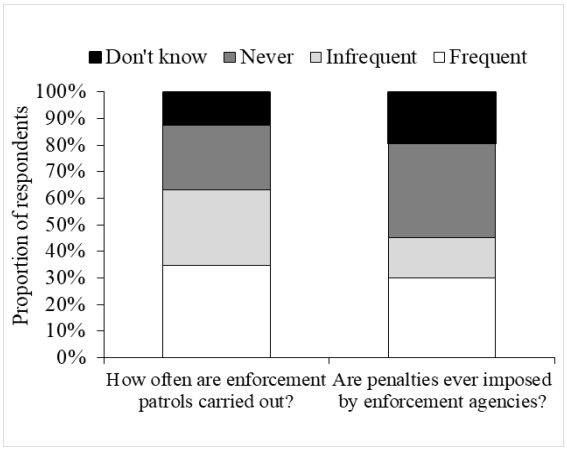

Fig. 14. Perception of enforcement.

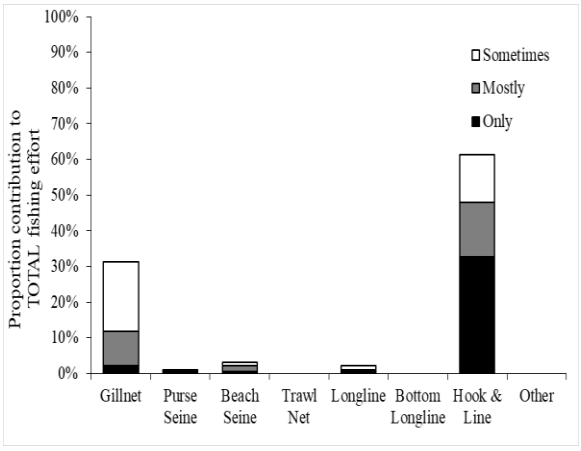

Fig. 15. Fishing gears characteristics.

Fishing areas were determined from physical markings made by respondents on maps **Fig. (7)**. All the artisanal fishers from the local communities informed that they fish by boat within their village only. Others transit to a specific close area, in addition to using the gill-net on the shore line and back reef facing these villages were carried out. At NINP (Northern Islands National Park), most of the fishing sites with very high to high intensity were Om Korash, Ashrafi light house, Towaal Island; while Gaysoom Island, and around El-Yasmeen Resort and Magaweesh Island reported between low and very

low fishing intensity. At Marsa Alam region, most fishing sites were around the harbour and north at Marsa Sefein had very low and low fishing intensity. These areas were the main location for sighting mother and calf pairs. Other sites like Marsa Tondoba and Marsa Dorri were used for fishing by the local community and reported between medium and very high fishing intensity. At WGNP, the most dominant sites for fishing in low and very low intensity were Ghadeer, south of Shams Alam, Ras Baghdady, Abou Ghosson, and Ranga; while medium to high fishing intensity were in Qolaan and surrounding Hamata Islands. South of Ras Banaas were fishing areas until El-Manazel north of EPA. Within Ras Bannas, low and medium fishing intensity were reported within all three villages , but high intensity usage was reported in the far village of Ras Bannas. The majority of fishing sites in EPA reported very low and low intensity in Marsa Shalateen, medium to high intensity in Shagaret El-Ameer, Adaldate and Sharm El- Madfaa. Other sites had low to very low fishing intensity in El-Soma, Shaab, Abou Fessi, Abou Heraab, Shoab Saleh, Seyal Island, Abou Naaam and Marsa Halayeb.

9. Conservation priority for dugong habitats

The distribution maps produced few spots of suitable dugong habitats scattered along the full length of the Egyptian coast of the Red Sea (Figure 5 and 6). There was a good concentration of conservation priority habitats in the north part of northern islands national parks. The suitable habitats for dugongs are located in the Marsa Alam region, WGNP from Ghadeer, Ras Baghdady, and around the south of Qolaan. On the other hand, there was a southern concentration of priority habitat around Ras Bannas region, especially the third village at the tip of the triangle. In the deep south, the coast of EPA is very important especially the south coast of shalateen and north of Abou Ramada with wide areas till Siyal Island.

DISCUSSION

This study introduced more details on dugong distribution in the Egyptian coast along the northwestern Red Sea, after a long time of data deficiency and poor knowledge on the dugong population **(Nasr *et al*., 2021)**. For the first time, the minimum size of the population is estimated in Egyptian waters to serve as a baseline

for further study on dugong status. For four decades extending from 1980 to 2016, dugong densities, mother-calf pairs, seagrass habitats, dugong captures, stranding events and threats affecting dugong populations are reported to understand temporal trends. This study shows modeling maps for seagrass areas, where fishing intensities overlap and the dugong hotspots that should be considered a conservation priority.

1. Distribution and population size of dugongs

A total of 95 sites reported sightings of dugongs, thus the interview-based survey indicated that the Egyptian Red Sea provides suitable key habitats for dugongs **(Gohar, 1957**; **Marsh, 2002; Hanafy *et al*., 2006; Rouphael *et al*. 2013; Nasr *et al*., 2019)**. Additional sites are expected by conducting more surveys to in villages like El Tor, Nabq and Abou Galum in South Sinai; El-Gouna, Hurghada, and Safaga in Northern Island National Park, and villages of Abou Ramada and Halayeb in deep south of Elba Protected Area. The provided modeling maps represent dugong densities areas' with occurrence in urban areas that were did not visit during our survey. **Gohar (1957)** recorded 16 individuals within 70 km north of Hurghada to Ras Gemsha using specially made fishing nets. Only five were reported from Hurghada to south in Safaga, which confirms the presence of higher numbers in remote areas than the urban areas **(Grech and Marsh, 2007)**.

The population size of dugong was estimated between 73 and 97 individuals. In Hurghada, most of the respondents believed that dugongs in the area are between two and less than 10. Only three individuals were identified using photo-ID, and three other dugongs in Safaga. In Qosseir and Ras Bannas, most of the respondents believed that dugong numbers are more than 10, so the minimum number was reported as 11 individuals per region.

For Marsa Alam and WGNP, although most of the respondents believed that dugong numbers ranged between two and less than 10, however, it was more than 10. In 2016, a total of 16 dugongs in Marsa Alam and 14 in WGNP were identified using photo-ID **(Shawky *et al*., 2017)**. In Marsa Alam, one mother/calf pair travelling was photo- identified between Marsa Egla and Marsa Asalaya and one more pair in Marsa Hermez. Using data of feeding trail widths in Marsa Asalaya (7km north of Marsa

Alam city), two small trails (11cm & 12cm in width) which confirms the presence of one more calf was reported **Shawky (2019b)**. Later in 2019, a feeding trail of 30cm width on a seagrass bed beside a small one (6cm wide) were reported for the first time in Marsa Hermez **Shawky (2019a)**. Further, one trail width of 10cm is documented in Marsa Mobarak, 55km north of Marsa Alam city **Shawky (2019b)**. Thus, 16 dugongs identified by Photo-ID plus three that were documented through feeding trails, which up to 19 individuals were reported for the Marsa Alam region.

In WGNP, after measurements of feeding trail widths, evidence of four mother/ calf pairs was recorded. Two pairs were in Wadi El-Gemal Island (25cm, 24cm, 13cm and 10cm), one pair in Ras Baghdady (26cm and 12cm), and one pair in Shams Alam (24cm and 10cm). Because the photo-ID catalog of WGNP includes one mother/calf pair, only three pairs were recorded. Later in March 2023, one new large male dugong was identified via photo-ID in Marsa Wadi Lahmi. Thus, 14 photo-identified dugongs plus six individuals through evidence of feeding trails, and the new individual MWL32, gives a total of 21 dugongs in WGNP.

In Shalateen, most of the respondents believed that more than 10 dugongs utilize the area. Therefore, a minimum estimate of 11 individuals was reported. But in Halayeb, the average of reported herd sizes and obtained a maximum of 16 individuals was calculated. In South Sinai, only two observations of single individuals in Ras Raya and Nabq Protected Area were received. In contrast, no specific number of dugongs was obtained for the Abou Ramada region. However, it had many sighting records. Using photo identification techniques is an ideal tool to confirm the obtained findings in this study as well as to identify numerous free-ranging marine mammal species which agree well with previous record **(Hammond *et al*., 1990; Hines *et al*., 2012; Shawky *et al*., 2019)**. In this study, mothers with a calf were more often observed in NINP in Hurghada **Gohar (1957)** and EPA, while absent in Qosseir and Ras Banass This could due to fishing activities in dugong key habitats, or indicate a low reproductive output **(Pilcher *et al*., 2017)**.

Another method to estimate the population size of dugongs using interview surveys only is applied in this study using the number of single dugongs (=1), mother-calf (=2), and group (=3 and more) sightings as well as the number of villages where

interviews were conducted **(Anand *et al*., 2015)**. The use of mathematical equation depends on presumed unique single dugong, groups and mother/ calf at each village was carried out. The results included 73 dugongs correspond to the estimated maximum population size of dugongs. When compared to the maximum estimate of 73 dugongs using the interview based survey only, the minimum number of 79 dugongs using underwater data, can support the results. Otherwise, the authors didn't visit most of the villages on the western Red Sea, Egypt. In the future, more accurate estimates for the dugong population by repeating the standardized questionnaire could be got. Supplementary data using widths of feeding trails at dugong feeding sites, photo-ID for notches were observed underwater **(Shawky *et al*., 2019)** and scars observed from the surface on the dugong's back **Anderson (1995)** is highly recommended, particularly in remote areas, to get accurate estimates of population size of dugongs.

2. Dugong bycatch

By-catch was the main reason for dugong mortality **(Nanayakkara *et al*., 2016)**. Dugong bycatch occurred mostly accidentally and reportedly resulted in the release of live dugongs. In Elba National Park, 9% of fishermen reportedly caught dugongs as bycatch in the nets **(Rouphael *et al.*, 2006)**. Fishermen don't like to catch dugongs as it can damage the net. Therefore, in Marsa Halayed, some fishermen informed that they survey for dugongs before casting their nets. This information is important in awareness for dugong conservation program with the fishermen. Otherwise, when dugongs are caught accidently, it is usually used for meat and skin **(Bertram and Bertram 1968; Daley *et al*., 2008; Adulyanukosl *et al*., 2010; Brookes *et al*., 2018)**, as was informed recently during this study in Umm Hashem Village at Ras Bannas, and Ras Raya in El Tor at South Sinai on the Gulf of Suez. Others were informed in the last few decades in Abou Ghoson, Tondoba, Qosseir, and Hurghada. In the Egyptian watres, the dugong skin was used in the manufacturing of armour by the local community **(Nasr *et al*., 2019)**.

By-catch is the major threat that influences dugong populations and has been identified as a global conservation concern **(Mangel *et al*., 2010)**. Incidental captures in fish and shark nets, seagrass habitat degradation due to coastal development, hunting and water quality impacts are primary causes of dugong mortality **(Rajamani *et al*., 2006b;**

Jaaman *et al*., 2009; Cullen-Unsworth and Unsworth, 2013; Rajamani, 2013; Briscoe *et al*., 2014; Ponnampalam *et al*., 2015; Cullen-Unsworth *et al*., 2018; Temple *et al*., 2019). In the Red Sea, the dugong population has reportedly decreased due to fishing activities and coastal development **(Nasr *et al*., 2019)**. During this study, in the south region of Shalateen, all the locals that were met confirmed that the commercial fishers, who come from northern Egypt to fish in the south, are the main problem due to using large nets that can exceed a few kilometers. Unfortunately, the authors don't have the ability to interview these fishers, so information is lacking regarding the fishing areas and dugong sighting in the remote southern areas. This information demonstrated a decreasing trend in the dugong population after 1980-1989. Moreover, there has been, a more alarming decline in the last decade between 2000 to 2016. Successful strategies for reducing the by-catch of marine mega-fauna like dugongs are needed to address different drivers of small-scale fishing behaviour as well as ecological considerations **(Teh *et al*., 2015)**.

3. Dugong stranding

Dugongs were the most regular marine mammal to strand **(Jaaman *et al*., 2009)**. In the last decade, 16 dugongs stranded (13 dead and 3 live), seven recorded inside the National Parks and mainly due to natural causes. One respondent reported an encounter where tiger shark (*Galeocerdo cuvier*) attacked a dugong while diving at 30 m depth around Seyal Island in front of Abou Ramada (Shoab Saleh site). Another study recorded the presence of dugong in the same seagrass habitat at 30 m when travelling between different habitats **(Chilvers *et al*., 2004)**. The other dugong was not sighted for one month, which suggested that the tiger shark had a direct effect on the distribution of dugong **(O'Connell and de Jonge, 2014)**. Dugongs may adapt to this predation by changing their behavioural activities in spatial and temporal ranges **(Wirsing and Heithaus, 2012)**. Discussions with interviewees during the present study revealed that dugong strandings could be due to either boat accidents or gastrointestinal blockage. Accidents take place when the dugongs get trapped between boats and coral reefs which results in their inability to escape. Choking happens during grazing due to the accidental ingestion of the toxic rabbitfish *Siganus rivulatus* that is commonly found between the

seagrass beds. Therefore, the fishers can hear the sound of dugong splash on the surface before death. Then, the animal was caught for consumption and the presence of rabbit fish was discovered by the fishermen while eating the dugong.

Sightings of stranded dugongs were high in protected areas and this could be attributed to frequent patrolling by Red Sea Rangers and continuous communication with the local communities. It is possible that mortality is much higher than reported. In this study, several stranded female dugongs were reported in Hurghada, Safaga, and Marsa Alam, where they are the popular areas for tourism and fishing in the western Red Sea, Egypt. Anthropogenic disturbance can cause stranding due to coastal development, entanglement in fishing gear and boat propellers **(Hashim *et al*., 2017)**. Most of the dugongs die because they get trapped in drifting nets and can't surface to breathe **(Wongsuryrat *et al*., 2011)**. In WGNP, a calf stranded in 2015 because of entrapment in a net within the coral reefs **(Shawky *et al*., 2016)**. On the other side of the Red Sea, a total of 21 carcasses were recorded at the Gulf of Salwah on the eastern southern coasts of Saudi Arabia **(Abdulqader *et al*., 2017)**.

4. Seagrass area and threats

Coastal seagrass habitats were determined in this study, which correlated with dugong presence in seagrass areas commonly used for feeding **(Preen, 1995**; **Marsh *et al*., 2002)**. In the present study, the illustrated maps show wide extensions of seagrass areas in seaward which overlap with high. dugong densities and extend out to the boundaries of the Protected Areas of NIPA and EPA. Other seagrass areas not protected in south of Hurghada, Safaga, Qosseir, Marsa Alam and south round of Ras Bannas regions, and should include inside the boundaries of the nearest National Park. This action is required by management plan for more protection and conservation of dugongs in the Red Sea **(Khamis *et al*., 2022)**.

Identification of threats is essential in order to decrease the high risk to marine mammals and establish key habitats for conservation **(Avila *et al*., 2018)**. Dugongs, like other marine mammals, are affected by human activities that need to be examined within key habitat to avoid negative impact **(Avila *et al*., 2018)**. Oil exploration in the northern part of the NINP and any further activities may take place in the deep southof the

Egyptian Red Sea, may have harmful effects on dugongs and seagrass beds. Dugongs can be affected by the accumulation of polychlorinated biphenyls in the liver **(Vijayasarathy *et al*., 2019)**. Oil spill events have been reported along the Egyptian Red Sea coastline and might have destructive consequences on the sensitive marine ecosystem and economy **(Kostianaia *et al*., 2020)**. Acoustic pollution by seismic surveys causes physical stress, impacts behavioural activities, injuries **(Erbe *et al*., 2018)** and stranding of marine mammals **(Dubhat *et al*., 2022)**. None of respondents mentioned oil pollution, although it is one of the main threats to marine ecosystems in the northern part of the Northern Islands National Park **(Kostianaia *et al*., 2020)**. All these activities may increase the stranding events of dugongs especially in the deep south of Ras Bannas and north of Hurghada regions. So, the law is an essential tool that urgently needs application to conserve and protect the seagrass beds **(Ramesh *et al*., 2018)**. It can be applied through the creation of a mitigation plan to protect the zones around seagrass areas, and monitoring the project areas using visual observers to low-power or shut-down operations if dugongs are encountered inside these areas.

5. Fishing activities

In this study, the local communities who fish along the shore line, left their nets for several hours during the day in shallow areas. A total of five areas were determined with high fishing activities comprising: far north of NINP (i.e. Ashrafi Light House, Om Koraash , Gaysoom Island, and Towaal Island), Qolaan in WGNP, south east of Ras Bannas shore line, and two areas within EPA south of Shalateen and Abou Ramada). Except Qolaan, all other areas are to far to reach for law enforcement. So, illegal fishing is expected in these remote areas, and the chance of dugong catch/ bycatch increased. This was evident during the interview surveys as dugongs were released in the sea and found dead on shorelines to be used by other artisanal fishers as baits for fishing. This result in the death of dugongs comes from the coastal fisheries because seagrass beds are zones where fishery resources are abundant **(Hines *et al*., 2005; Adulyanukosol and Poovachiranon, 2006; Rajamani *et al*., 2006a; Pilcher *et al*., 2008; Wongsuryrat *et al*., 2011).** The use of drifting nets to catch fish along the coastline in addition to the nearby seagrass beds tend to block the paths which dugongs use to enter the feeding

grounds. Elimination of the pathway that dugongs can access prevents them from following their typical route. This is, currently occurring in Qolaan and south of Ras Bannas. Many fishermen were unaware that dugongs were protected by law **Anonymous (2015)**.

6. Implications for dugong conservation

The main outputs of this study for conservation are in three main topics: policy for action, research by monitoring survey, and public awareness of the stakeholders (Jontila et al. 2018).

Policy action for dugong priority conservation **Fig. (8)** is highly recommended, including seagrass areas which extend outside the boundaries of protected areas. This should include the following areas: south of Hurghada to Qosseir can be included within the boundary of NIPA and the coastal habitat of Marsa Alam to seagrass areas of WGNP. Marsa Alam has many bays with different individual dugongs, and these areas are considered popular dive and snorkel sites for dugong watching. Four of these sites include Marsa Mobarak, Marsa Shoni El Kebeer, Marsa Abou Dabbab, and Marsa Hermez, were visited daily by dive boats and speed boat. The last site has a Marina for speed boats that park within the shallow area of high densities of dugong feeding trails. Areas around Ras Banaas can include to the boundary of EPA after updating the extent of seagrass areas in front of Shalateen and Abou Ramada. Based on the current study, it is highly recommended and suggesting the boundary should be detected beyond the end of seagrass areas and dugong sighting location with a minimum 1km buffer zone. Determining the dugong protected area (DPA) within the marine protected areas boundaries is an essential action to protect the dugong in their habitats **Marsh (2002)**. The management of dugongs as one of a charismatic species is recommended for conservation **(Jin *et al*., 2018; Koshy *et al*., 2018)**.

Survey and monitoring is highly recommended to assess the status of dugong since 2020 after the COVID19 pandemic, where all activities stopped except for artisanal fishing in local communities. It was speculated that dugong recovery occurred, but at the same time, dugong catch/ bycatch may have also taken place. Thus, the results for these

three years will update dugong status with the current study. The interview-based survey should include South Sinai at different cities/ villages on along the southern portions of the Suez Gulf mainly around El Tour and along Gulf of Aqaba in Nabq and Abou Galoum Protected Areas. Dugongs have not been recorded along the Gulf of Aqaba for two decades. In contrast, the commercial fishers in EPA were using long gill nets that extended to several kilometers. Others liked ghost nets that can have a hazardous effect on the dugong **(Wilcox *et al*., 2015)**. Therefore, it suggests to conduct 500 interview surveys distributed along 10 regions of South Sinai, Hurghada, Safaga, Qosseir, Marsa Alam, Wadi El Gemal, Ras Bannas, Shalateen, Abou Ramada, and Halayeb. Visiting the remote areas shown in the given modeling maps is important to detect new dugongs especially mother-calf pair and herds, and document by photo-ID from the surface for different scars **Anderson (1995)**. Identifying new habitats in the south will avoid destruction by further activities for oil exploration and coastal development. At the same time, this enable continue to study the dugong population using photo-ID **(Shawky *et al*., 2017, 2019)** and monitoring the feeding trail widths in seagrass beds **(Shawky, 2019a, b; Nasr *et al*., 2019; Khamis *et al*., 2022)**.

Raising public awareness via conducting PADI dugong conservation specialty courses, will allow more volunteers to enroll in a dugong monitoring program. This program will include using the sighting record as a citizen science program in the form of reporting form via QR code, link on the website and mobile application. Photographing dugongs underwater for photo-ID, and how to measure the feeding trail widths will add to the monitoring program. The Egyptian Dugong Team (EDT), founded by the first author **(Nasr *et al*., 2019)** will participate and train more volunteers to be part of the team to improve the continuity of the monitoring program. An awareness program provided to the fishermen will recommend using the outputs of this study.

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