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Monitoring hawksbill turtle nesting sites in some protected areas from the Persian Gulf

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Abstract

Iranian nesting populations of the critically endangered hawksbill turtle (*Eretmochelys imbricate*) are some of the most important in the Indian Ocean. In this study, four of the most important hawksbill nesting grounds in the Persian Gulf, situated within three Iranian marine protected areas, were surveyed during nesting season, including Nakhiloo, Ommolgorm and Kharko Islands and the mainland beaches of the Naiband Marine-Coastal National Park (NMCNP). We present GIS maps of these key nesting grounds and describe sand texture of key nesting zones, along with conservation recommendations. About 9.2 (28.3%) out of 32.5 km of all shores surveyed in this study were used by nesting hawksbill turtles follows: Nakhiloo: 1.4 km (52% of potential nesting area); Ommolgorm: 1.94 km (40%); Kharko: 3.4 km (28%), and NMCNP: 2.46 km (18.9%). The average nesting density was calculated as 131 nests/km at Nakhiloo, 76 nests/km at Ommolgorm, 7 nests/km at Kharko, and 15 nests per km at NMCNP. Highest nesting density was observed in Nakhiloo and Ommolgorm. It is thought that high hawksbill nesting density in these islands seems likely a result of limiting adequate nesting shores rather than the size of population, and also low density in Kharko and NMCNP more related to past and current pressures and low population density. With the exception of Ommolgorm Island, sands at the nesting grounds were well sorted. Grain size indicated that female hawksbill turtles in the Iranian Persian Gulf nest in sands that are generally mixed, with mean grain size ranging from coarse sands (0.4Φ; ~0.5–1 mm) to fine sands (2Φ; ~0.25 mm). We provide and discuss conservation recommendations and suggestions for future.

Key words: marine protected areas, marine turtles, nesting, sand texture, GIS maps

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1 Introduction

There are eight exact sea turtle species in the world (Hays, 2001) and hawksbill turtle, green turtle (*Chelonia mydas*) and olive ridley turtle (*Lepidochelys olivacea*) are three nesting turtle species in the Persian Gulf (Pilcher et al., 2014; Tollab et al., 2015), although nesting by the olive ridley turtle has been confirmed just by one nest recently found in Iran (Tollab et al., 2015). The Persian Gulf shores nonetheless are home to green and hawksbill turtle rookeries in Iran, Qatar, Saudi Arabia, Kuwait and the United Arab Emirates (Pilcher et al., 2014). Hawksbill turtles are dominant turtle species in the Iranian Persian Gulf (Askari Hesni et al., 2016). The most important nesting grounds for hawksbill turtles in Iranian waters of the Persian Gulf include mainland shores of Naiband Marine-Coastal National Park and island shores of Ommolgorm, Nakhiloo, Shidvar and Hendourabi offshore islands (Mobaraki, 2004; Razaghian et al., 2019).

It is thought that Persian Gulf nesting hawksbill turtles, with a mean curved carapace length (CCL) of about 70 cm, are among the smallest in the world (Al-Merghani et al., 2000; Pilcher et al., 2014; Askari Hesni et al., 2016). Females spend about 70% of their time in the foraging grounds mostly situated through southern and southwestern coastal waters of the Persian Gulf. Further, because surface waters typically exceed 30°C during the summers; they are forced to spend 20% of the time undertaking summer migration loops avoiding elevated sea surface temperatures (Pilcher et al., 2014). In the Persian Gulf several factors such as oil pollution, fisheries activities, tourism and coastal development affect hawksbill turtle populations (Mobaraki, 2004; Nabavi et al., 2012; Askari Hesni et al., 2016; Pazira et al., 2016).

During the last two centuries, populations of the hawksbill turtle (*Eretmochelys imbricata*) have experienced dramatic worldwide declines, threatened by exploitation of eggs and

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turtles for food and the tortoiseshell trade, captures in fisheries, marine pollution, and degradation of nesting area and coral reef foraging habitats (Meylan and Donnelly, 1999; Mortimer and Donnelly, 2008). In 1996, this long-lived circum-tropical marine reptile was eventually classified as a Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List of Treated Species (www.iucnredlist.org). Although some protected populations are stable or increasing, the species is still widely threatened, with an overall global declined of 82% the last three generations (IUCN, 2018).

Identification and mapping sea turtles nesting zones through the shores where increasing anthropogenic developments might disrupt nesting are important steps in managing putative negative effects (Maktav et al., 2000). The use of Geographical Information System (GIS) in herpetology has increased during recent years and is increasing even further with the advent of free data sources and open-source GIS software packages available on the internet (Sillero and Tarroso, 2010). Sea turtle biologists likewise use GIS in conservation studies relating to the mapping of nesting grounds of these endangered marine reptiles (e.g., Powell and Mosier, 1999; Wood et al., 2000; Blamires et al., 2001; Fish et al., 2005; Karavas et al., 2005; Fuentes et al., 2010; Walker et al., 2015). Maktav et al. (2000) designated some loggerhead sea turtles nesting sites on the Turkish Mediterranean coasts as protected areas by using mapping and remote sensing methods.

The presence of sandy beaches does not guarantee suitable area for sea turtle nesting, as other physical characteristics of beach sediments affect the nesting behavior of sea turtles. Some factors include beach sand physiognomy, sand temperature, humidity, grain size, sand composition, type of beach (volcanic, calcareous, sandy-mollusca-shell) can influence on nesting behavior (Mortimer, 1990; Eckert et al., 1999; Zavaleta-Lizárraga and Morales-Mávil, 2013). Sea turtles tend to select nesting sites on beaches with fine grain sand, coarse-grained and suitably sandy beaches and they tend to avoid digging egg chambers in area with stones, dry sand, muddy and rocky substrates, because these areas may make difficult for nest excavating (Mortimer, 1990; Wood and Bjorndal, 2000; López-Castro et al., 2004). Areas with suitably sandy beaches and medium sand particle sizes resulted in overall nesting success for loggerhead sea turtle (Karavas et al., 2005; Margaritoulis, 2005). Yalçın-Özdilek et al. (2007) reported that sandy beaches with a mean particle size of 350 μm are suitable for green turtles nesting sites while larger and smaller sizes are not suitable conditions for excavating.

The Persian Gulf, bordered by several wealthy countries, experienced rapid and significant construction along its shores and offshore regions in the form of industrial, infrastructure-based, residential and tourist development activities (Sheppard et al., 2010). However, important sea turtle nesting grounds and densities have never been mapped, nor their sediments characterized in the Iranian Persian Gulf. In this study nest sediment were characterized and important nesting areas and densities were determined by GIS mapping. These analyses will be useful for future management of sea turtle populations in the Persian Gulf.

There are four management categories for natural protected areas in Iran, national parks, protected areas, wildlife refuges and national natural monuments (Iranian Department of Environment, 2016). Protected areas have important complementary roles in the conservation of biodiversity, ecosystems sustainability and socioeconomic development. In this study, we present the results of geographical and geological data analysis linked to hawksbill nesting activities at three Iranian marine protected areas (MPAs) in the mid and northeastern section of the Persian Gulf which have important roles in sea turtle survival and conservation. These sites include the mainland beaches of Naiband Marine-Coastal National Park, beaches on Nakhiloo and Ommolgorm offshore islands in the Dayer-Nakhiloo National Park, and Kharko offshore island in the Kharko National Monument. Information about hawksbill nesting densities and maps indicating beaches with high and low nesting densities in the MPAs are presented. Further, the study presents the first analysis of sand texture in those zones with high nesting density. The results of this study can be used by environmental agencies, sea turtle conservationists and other end users for developing better conservation strategies for critical hawksbill nesting zones in the Iranian Persian Gulf. Further, the maps and nesting numbers presented here can be used as a baseline database and set stage for future research with which to establish temporal and spatial trends.

2 Materials and methods

2.1 *Site descriptions*

All four hawksbill nesting sites surveyed in this study (three small islands and one mainland site) are situated along coastal waters of Bushehr Province in the northern Persian Gulf (Fig. 1), are also designated as marine protected areas (MPAs) by Iranian Department of Environment. The Nakhiloo and Ommolgorm (Ommolkaram) Islands (Table 1; Figs 1 and 2a, b) are situated in Dayer-Nakhiloo National Park (area: 20 434 hm^2) is lying in the south of the Mond River Delta in the northern Persian Gulf. The Kharko Island (Table 1; Figs 1 and 2c), designed as a National Natural Monument (area: 1 843 hm^2), is situated in the northwestern Persian Gulf, 7.3 km far from a larger island called Khark Island. According to nesting sea turtle observations on the Kharko Island, we determined two survey sites in north and south of the island. The only mainland beach surveyed in this study was sandy beach of Naiband Marine-Coastal National Park (NMCNP) (area: 46 687 hm^2), lying in the Naiband Bay, northern Persian Gulf. We observed three nesting sites in this area including Zehdehh, Tineh and Bonood, which were located therefore we patrolled three sites in NMCNP (Table 1; Figs 1 and 2d).

2.2 *Survey method and nest census*

The shores were patrolled on foot during about three months of field surveys (began on February 2 in NMCNP, April 9 in Nakhiloo and Ommolgorm Islands and May 15 in Kharko Island) during the 2015 hawksbill nesting season. These surveys were conducted according to start of nesting season in each area. The shores of NMCNP were patrolled daily with at least two observers at the night and one by day. The beaches of each offshore island were also regularly patrolled an average of 3–4 times per week with at least four observers in each survey session. The survey effort (patrolling h/km) in each nesting ground was calculated as:

$$\text{survey effort} = \left(\sum_{i}^{n} N_i T_i\right) / L,$$

where N_i and T_i are number of observers and patrolling time (h) in ith survey session, respectively; and L is total length of the shore (km). In each site, false crawls (non-nesting emergence) were ignored and only nests with verified egg decomposition were counted and used in the abundance totals. Nesting shores were divided into two categories: (1) shores with 1–3 nests per each 10 m of the shore length, assumed as the zones with low

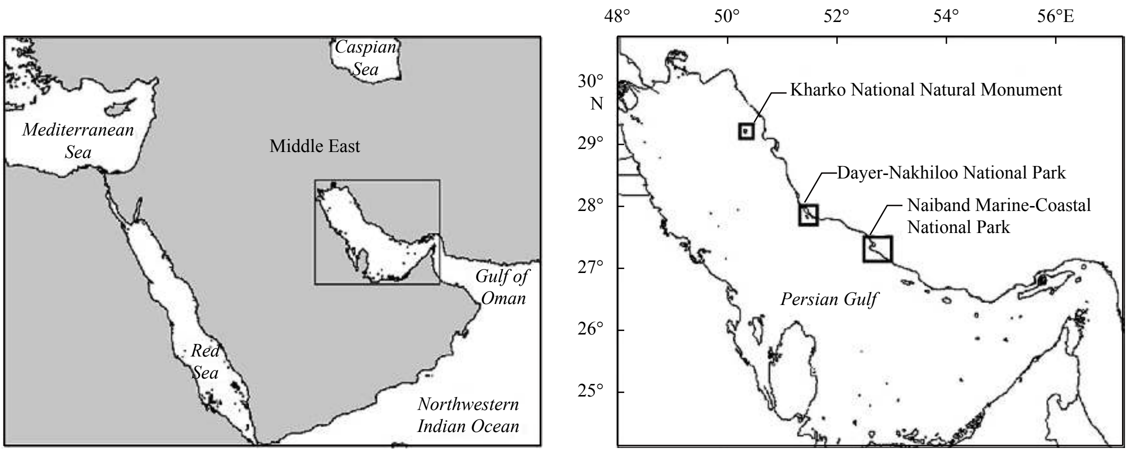

Fig. 1. Map shows location of three Iranian marine protected areas at the Persian Gulf surveyed for hawksbill turtle nesting activities in 2015 nesting season.

Table 1. Characteristics of the four important hawksbill turtles (*Eretmochelys imbricata*) nesting grounds in the northern Persian Gulf surveyed during the 2015 nesting season

Characteristics of the nesting ground	Important nesting grounds in the northern Persian Gulf			
	Naiband (Mainland)	Nakhiloo (Island)	Ommolgorm (Island)	Kharko (Island)
Protection management category	National Park	National Park	National Park	Natural Monument
Total length of coastline/km	13	2.7	4.8	12
Total survey effort/h	648	1 389	781	272
Total number of counted nests	36	183	148	24
Average of nesting density/km^{-1}	15	131	76	7
Minimum nesting density (in 10 m of the shore length)	1	2	2	1
Maximum nesting density (in 10 m of the shore length)	4	6	7	4
Beaches with high nesting density/km (%)	1.94 (14.9)	0.8 (30)	1.2 (25)	1.1 (9)
Beaches with low nesting density/km (%)	0.52 (4)	0.6 (22)	0.74 (15)	2.3 (19)
Beaches without nesting event/km (%)	10.54 (81.1)	1.3 (48)	2.86 (60)	8.6 (72)

nesting density; and (2) shores with more than 3 nests per each 10 m of the shore length, assumed as the zones with high nesting density. The average nesting density in each nesting ground was also calculated by dividing the number of counted nests by the length of nesting shores (km).

2.3 *Mapping nesting grounds*

Once a nest was located, the locations of any effective natural reference points, such as high vegetative density and anthropogenic phenomenon or human activities such as a jetty were observed around nesting areas, were recorded using a global positioning system device (GPS model Garmin 72s). The data points were then separately imported in free/open source Arc GIS software package (Version 9.3). The provided layers were overlaid on georeferenced base maps (sourced from Iranian National Cartographic Center) using the software to create maps of nesting zones.

2.4 *Sediment texture*

About 2 kg sand was collected from each nesting zone at a depth of 10–30 cm. Each sediment sample was dried in oven at 70°C for 24 h, and then passed through a set of sieves of diminishing mesh diameter to divide it into size grades including 4 000, 2 000, 1 000, 500, 250, 125 and 63 μm. The graphical grain size analysis presented by Bird (2008) was used to evaluate sand texture, with sand particle size distribution diagrams were drawn using P (Φ) scale. This scale was calculated by negative logarithmic base 2 transforming of sediment size in millimeters. Finally, the following indices were calculated using the diagrams:

$$\text{mean [the average grain size]} = 0.5\ (P_{16} + P_{84})\ ,$$

$$\text{median} = P_{50},$$

$$\text{sorting [the spread of the sizes around the average; standard deviation]} = 0.5\ (P_{84} - P_{16})\ , \text{median} = P_{50},$$

$$\text{Skewness [the preferential spread to one side of the average]} = (\text{mean} - \text{median})/\text{sorting}.$$

There are identified grain size categories and descriptive categories for both sorting and skewness, which are presented in Table 2.

3 Results

With a total survey effort of 3 090 h/km, 391 nests were counted through all the four hawksbill nesting grounds during the 2015 nesting season. In total, about 9.2 of 32.5 km (28.3%) of these shores were used for nesting by female hawksbill turtles, in which 5.04 km (15.5%) and 4.16 km (12.8%) of them had high and low nesting density, respectively. Maps of the nesting zones and detailed characteristics of the sands in the zones with high nesting density are presented as follows.

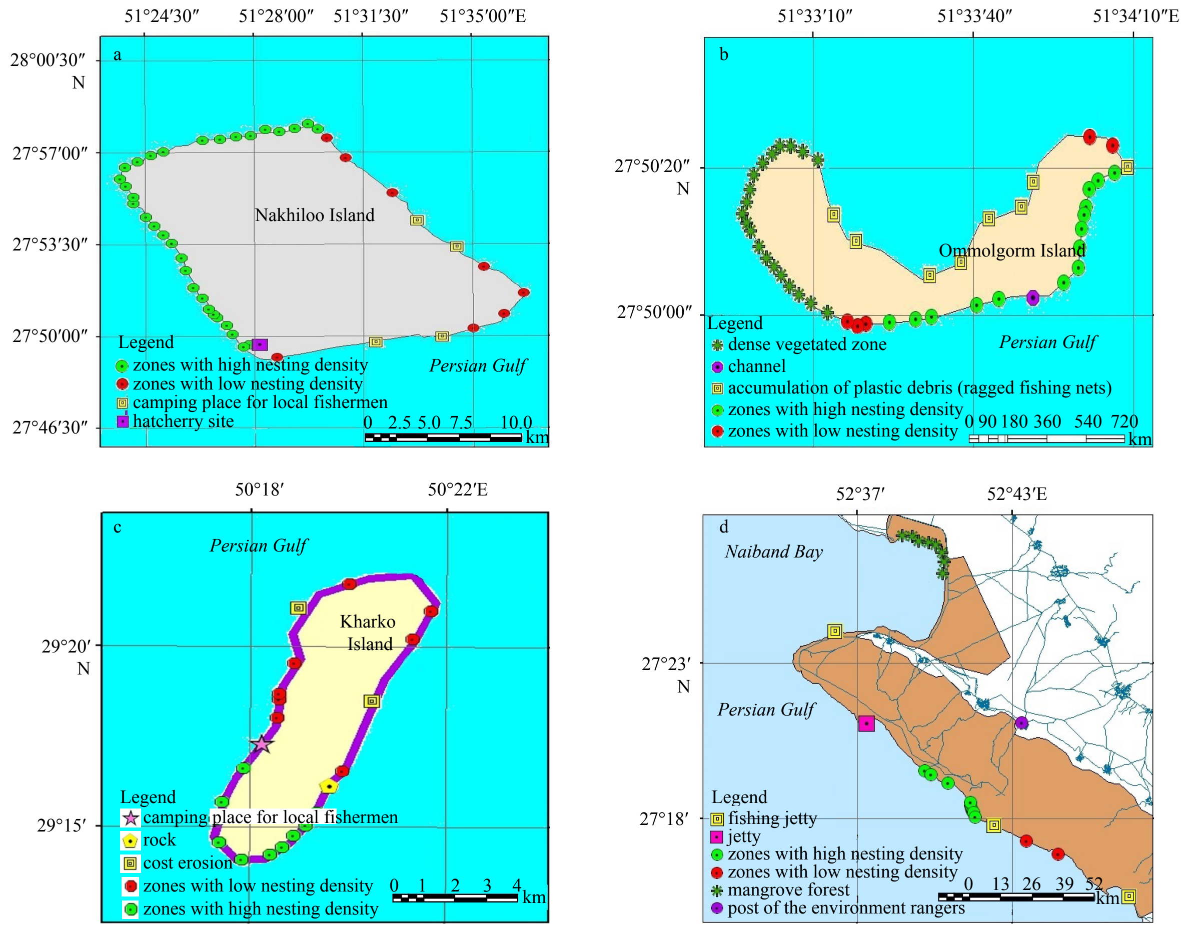

Fig. 2. Map shows hawksbill turtles (*Eretmochelys imbricata*) nesting zones and anthropogenic activities along all beaches around three protected areas in the northern Persian Gulf. a. Nakhiloo Island, b. Ommolgorm Island at Dayer-Nakhiloo National Park, c. Kharko Island at Kharko National Natural Monument, and d. Naiband Marine-Coastal National Park.

3.1 *Nakhiloo Island in Dayer-Nakhiloo National Park*

On this small island, 183 nests were counted by a survey effort of 1 389 h/km. In total, about 1.4 km (52%) of the shore of this nesting ground was used by female hawksbill turtles for nesting (Table 1). High nesting density was recorded in a single zone with 0.8 km length (30%) stretching from the south to the west of the island. Low nesting density was recorded in 0.6 km (22%) of the shore, divided into two small zones at the northwest (0.25 km) and north (0.35 km) of the island. The east shore of the island had no nesting zone, perhaps due to fishing activities by indigenous fishermen during nights. There were also two small zones without nesting events in the west and northwest of the island (Fig. 2a).

The average of nesting density in the nesting shores of this island was 131 nests per km. In the dense zone, highest nesting density was 6 nests per 0.01 km, whereas nesting density was never less than 2 nests per 0.01 km at two nesting zones with low density (Table 1). We also observed nest destruction twice in the dense zone on May 8 and June 7, 2015. In both cases, an older nest had been destroyed by a new nesting female when the nester constructed a body pit during the nesting activity (Fig. 3).

The sand texture in the dense nesting zone consisted mainly of fine, medium, and coarse sands. It was found to be moderately well sorted with a grain size average of 1.3Φ (medium sand) and was also negatively skewed (Table 3; Figs 4 and 5).

3.2 *Ommolgorm Island in Dayer-Nakhiloo National Park*

In total 148 nests were counted in this small remote island by a survey effort of 781 h/km. About 1.94 km (40%) of the shore was served by female hawksbill turtles for nesting. High nesting density was observed through about 1.2 km (25%) of the shore (Table 1) at two zones in the south (0.6 km) and east (0.6 km) of the island (Fig. 2b). There were also two nesting zones with low density with a total length of 0.74 km (15%) situated in the northeast (0.15 km) and southwest (0.59 km) of the island (Fig. 2b). Eastern shore of the island was a non-nesting zone mainly because there was dense vegetation.

The average nesting density in the nesting shores of Ommolgorm Island was 76 nests per km. Highest nesting density in this island was 7 nests per 0.01 km, whereas nesting density was never lower than 2 nests per 0.01 km (Table 1). Nest destruction, the same as reported for the Nakhiloo Island, was observed once in the Ommolgorm Island on May 5, 2015.

Sand in the dense nesting shore of this island consisted mainly of granules, very coarse and coarse sands. Sand texture in this site, with a grain size average of 0.4Φ (coarse sand), was poorly sorted and strongly positively skewed (Table 3; Figs 4 and 5).

3.3 *Kharko Island in Kharko Natural National Monument*

With a survey effort of 272 h/km, 24 nests were counted on this island. About 3.4 km (28%) of the shore length served for nesting activities by female hawksbill turtles. There was just one

Table 2. The categories of the shore grain sizes and descriptive categories for sorting and skewness in the graphical grain size analysis (Bird, 2008)

Grain size categories	Particle diameter (mm) [Φ]
Pebbles	4 to 64 [–2 to –6]
Granules	2 to 4 [–1 to –2]
Very coarse sand	1 to 2 [0 to –1]
Coarse sand	0.5 to 1 [1 to 0]
Medium sand	0.25 to 0.5 [2 to 1]
Fine sand	0.125 to 0.5 [3 to 2]
Sorting	Value
Very well sorted	<0.35
Well sorted	0.35 to 0.5
Moderately well sorted	0.5 to 1
Poorly sorted	1 to 2
Very poorly sorted	2 to 4
Extremely poorly sorted	>4
Skewness	Value
Strongly negatively skewed	–1 to –0.3
Negatively skewed	–0.3 to –0.1
Nearly symmetrical	–0.1 to 0.1
Positively skewed	0.1 to 0.3
Strongly positively skewed	0.3 to 1

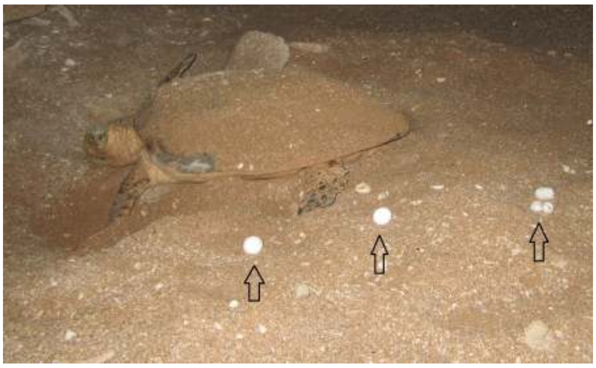

Fig. 3. Nest destruction by another sea turtles in the Nakhiloo Island. The arrow icons indicate the eggs that are left out of the nest.

zone with high nesting density at the south shore of the island (Fig. 2c) with a length of 1.1 km (9%). Three zones with a total length of 2.3 km (19%) had low nesting density (Table 1), that were situated at the south (0.27 km), southwest (1.6 km) and north (0.36 km) of the island (Fig. 2c).

The average nesting density on this island was 7 nests per km. Highest and lowest nesting density through the nesting zones of this island was 4 and 1 nests per 0.01 km, respectively (Table 1).

The sand texture of the northern (low nesting zone) and southern (dense nesting zone) shores of Kharko Island was the same, consisting mainly of coarse sand, and with a grain size average of 0.6Φ (coarse sand), well-sorted and nearly symmetrical in both sites (Table 3; Figs 4 and 5).

3.4 *Mainland shore of Naiband Marine-Coastal National Park*

In total, 36 nests were counted throughout this mainland shore by a survey effort of 648 h/km. About 2.46 of 13 km shore length (18.9%) served by female hawksbills for nesting (Table 1). High nesting density observed in 1.94 km (14.9%) divided in four zones: two small zones with 0.2 and 0.23 km length in the shore of Tineh, another small zone of 0.4 km length in the shore of Zehdeh, and a larger zone with 1.1 km length in the shore of Bonood (Fig. 2d). Further, about 0.52 km (4%) of the shore had low nesting density divided in two small zones with 0.31 and 0.21 km length (Fig. 2d).

The average nesting density in the nesting zones of this mainland shore was 15 nests per km. Highest and lowest nesting density through the nesting zones of this mainland shore was 4 and 1 nests per 0.01 km, respectively (Table 1).

The sand texture in the shores of Zehdeh, Tineh and Bonood consisted mainly of fine sand. It was well-sorted sand with a grain size average of 2Φ (fine sand) in all shores. It was negatively skewed in the shore of Zehdeh and Tineh, but positively skewed in the shore of Bonood (Table 3; Figs 4 and 5).

In total, 19 of 36 discovered nests were lost by flooding of the shore during high tide and all the eggs of the remaining nests (n=17) were moved to a safe hatchery site nearby through a rescue program.

4 Discussion

Iranian nesting population of the hawksbill turtle could be one of the most important in the Indian Ocean (Kinunen and Walczak, 1971; Meylan and Donnelly, 1999; Mortimer and Donnelly, 2008). In this study, 391 nests were counted on the shores of the four Iranian hawksbill nesting grounds at the 2015 nesting season, whereas other Iranian nesting grounds (e.g., Qeshm, Larak, Hormoz, Hengam, Kish, Shidvar, Lavan and Hendurabi Islands) were not involved in this census. This supports the idea that Iranian shores of the Persian Gulf host a large population of the nesting hawksbill turtles (Mobaraki, 2004; Devin and Sadeghi, 2010; Pilcher et al., 2014; Askari Hesni et al., 2016), but further information of the other nesting grounds are also needed to assess the size of this population.

The average nesting density in the island nesting shores of the Nakhiloo and Ommolgorm Islands was about 5–8 times higher than that recorded for mainland nesting shore of NMCNP (Table 1). Mobaraki (2004) suggested that throughout the Iranian Persian Gulf, remote island shores have been considered more important turtle nesting grounds than mainland shores, mainly because there is a lack of egg collection and predation on the islands compared to the mainland. The relatively low nesting

Table 3. Sand particle indices of the zones with high hawksbill nesting density in southern (T1) and northern (T2) Kharko Island, Nakhiloo (T3) and Ommolgorm (T4) Islands, the shore of Zehdeh and Tineh (T5), and the shore of Bonood (T6) in Naiband Marine-Coastal National Park

Sand particle indices	Zones with high nesting density					
	T1	T2	T3	T4	T5	T6
Mean	0.6	0.6	1.3	0.4	2	2
Median	0.6	0.6	1.4	–0.1	2.2	1.9
Sorting (standard deviation)	0.4	0.4	0.7	1.6	0.8	0.8
Skewness	0	0	–0.14	0.31	–0.25	0.13

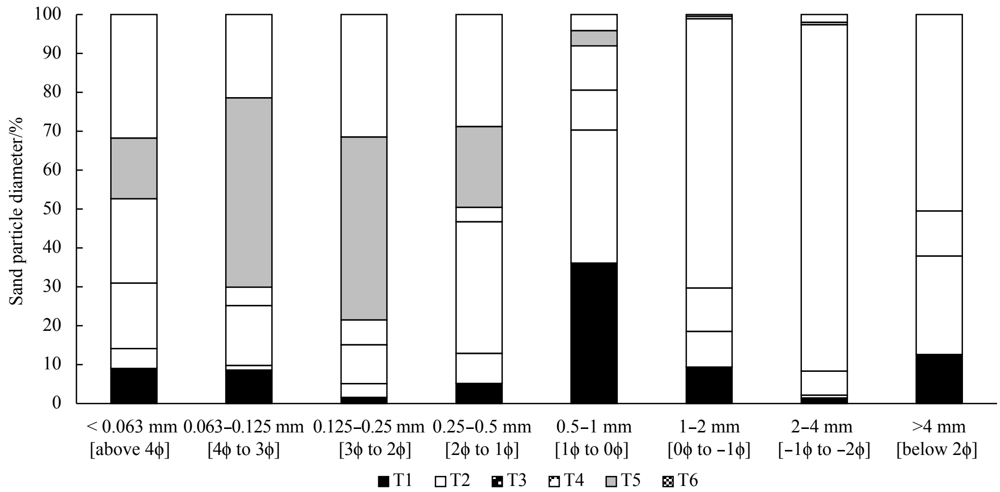

Fig. 4. Sand particle diameter [P scale] (%) of the zones with high hawksbill nesting density in northern (T1) and southern (T2) Kharko Island, Nakhiloo (T3) and Ommolgorm (T4) Islands, the shore of Zehdeh and Tineh (T5), and the shore of Bonood (T6) in Naiband Marine-Coastal National Park.

density in the Kharko Island compared to the Nakhiloo and Ommolgorm Islands may be a result of small effort paid to survey this island (Table 1). It was because surveying was logistically difficult in the Kharko Island due to its large distance from the mainland shore.

We found the average of hawksbill nesting density along the nesting shores of the Nakhiloo and Ommolgorm Islands were found to be higher compared to those reported as the highest hawksbill nesting density in the South Atlantic (an average of about 21 nests per km; Santos et al., 2013). Furthermore, the average nesting densities in all four nesting grounds surveyed in this study were higher than those previously recorded for the shores of El Salvador (6 hawksbill nests per km), which hosts the largest remaining hawksbill nesting population of the eastern Pacific Ocean (Liles et al., 2011). However, we strongly suggest these high nesting densities along the Iranian hawksbill nesting grounds are not only due to the large size of the nesting population, but also could be a result of limited adequate nesting zones on the few narrow shores. Other large nesting aggregations of the hawksbill turtles usually have wider available shores for their nesting activities. For example, the nesting density of about 32 hawksbill nests per km has been reported for the Dense zones on the shores of the northern Bahia, Brazil, where about 1 500 hawksbill nests annually deposit their nests along 214 km of available nesting shores (Santos et al., 2013). In addition, a mean nesting density of about 6 hawksbill nests per km has been recorded for the available nesting shores of El Salvador, where 310 nests had been counted along 51.6 km of its nesting shore in the 2008 nesting season (Liles et al., 2011), however in this study, a total of 391 nests counted along only 9.2 km of the nesting shores (Table 1) explains why nesting density on these shores was found to be much higher compared to many other hawksbill nesting shores throughout the world. Perhaps an Iranian nesting population of the hawksbill turtle previously had wider shores for nesting, which have declined through history and nowadays they have narrower nesting shores. Although anthropogenic activities (e.g., local fishing activities, constructing jetties and artificial lights) limiting hawksbill nesting shores are confirmed and mapped along the shores of our study MPAs (Figs 2a–d), the role of natural phenomena (e.g., rising sea levels) in limiting this process has not been investigated yet. It is not surprising why female hawksbill return to these narrow shores, because nesting hawksbill turtles show strong site fidelity to the specific nesting grounds and return to them at 2–5 year intervals during their reproductive years (Amorocho, 1999).

Any reason (increasing number of nesters in the recovered populations or limiting nesting shore because of anthropogenic activities or natural phenomena) can directly affect hatching success of that population (Honarvar et al., 2008). In the literature, these effects are known as nesting density-dependent effects. For example, Honarvar et al. (2008) found that in the olive ridley (*Lepidochelys olivacea*) Arribada at Playa Nancite, Costa Rica, higher nesting density led to lower oxygen and higher carbon dioxide in the nests, which could affect embryonic life stage of the population. Another example of density-dependent effects on sea turtles nesting activities is nest destruction, which we observed in this study at both Nakhiloo and Ommolgorm Islands (see the subsections related to these two islands in Section 3; Fig. 3). Nest destruction has been also recorded for the nesting aggregation of olive ridley turtles at the shores of Playa Nancite and Playa Ostional (Cornelius et al., 1991), green turtles at the shore of Tortuguero in Costa Rica (Tiwari et al., 2006), and leatherback turtles (*Dermochelys coriacea*) at the shore of French Guiana (Girondot et al., 2002; Caut et al., 2006). Nonetheless, density-dependent effects on sea turtle nesting shores have been not studied extensively. To the best of our knowledge, three cases of nest destruction observed in this study are the first documented reports for hawksbill turtles. However, these three cases of nest destruction were observed by chance as investigating nesting density-dependent effects was not an objective of this preliminary survey.

Sand texture is mentioned as one of the important beach characteristics influencing sea turtle nesting activities (Mortimer, 1990). Nonetheless, data on the role of sand texture in sea turtle nesting site selection are limited. Karavas et al. (2005) found that nesting loggerhead turtles (*Caretta caretta*) in Greece prefer to nest on well-sorted sand particles. On the other hand, Horrocks and Scott (1991) found no relationship between sand particle size and hawksbill nest success, clutch size and emergence success in Barbados, West Indies. Although, these two authors had a rough approach to estimate particle size effect on sea turtle nesting

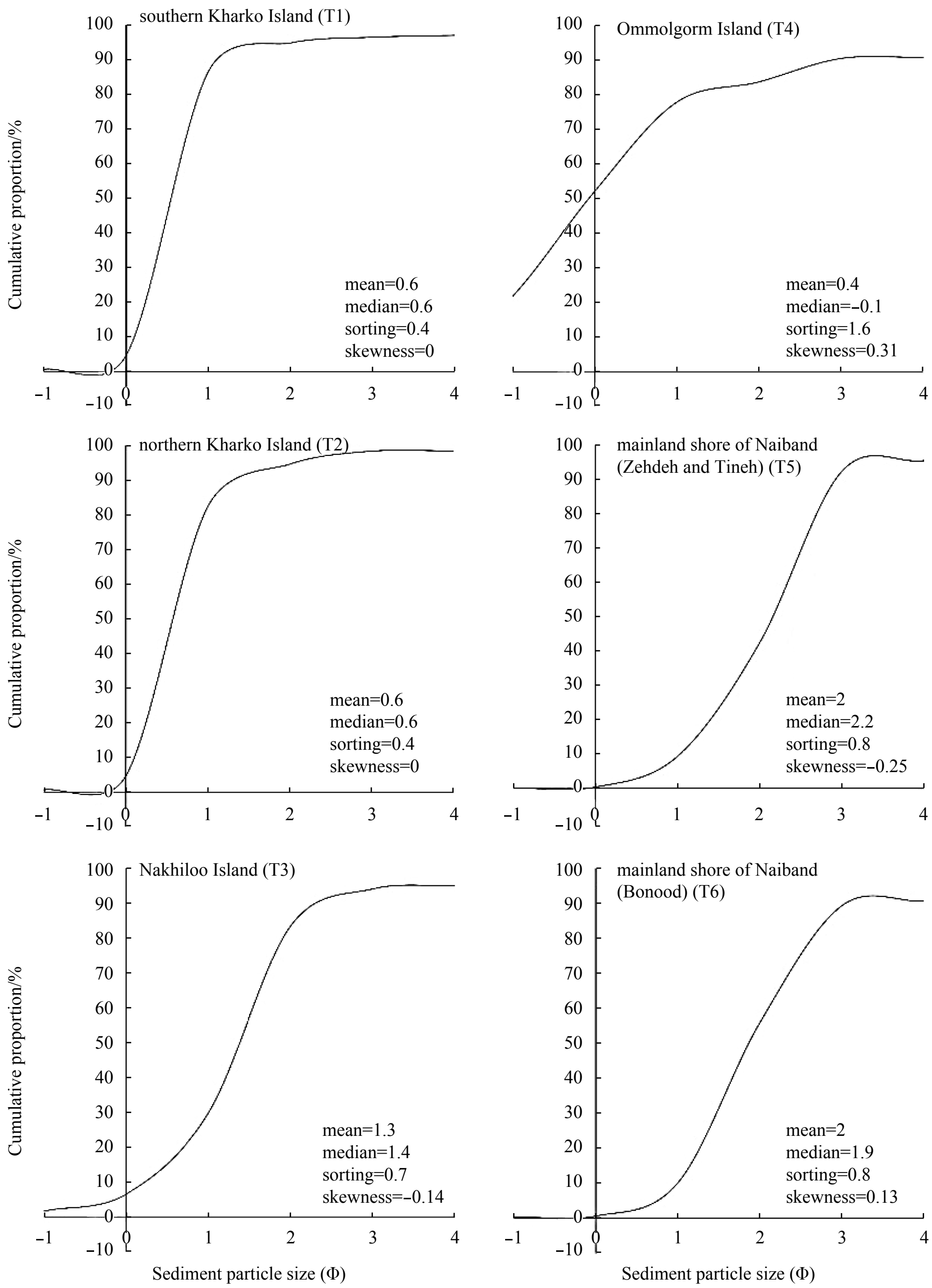

Fig. 5. Sand particle size distribution diagrams. Values of sand particle size are presented in phi (Φ) scale calculated by negative logarithmic base 2 transforming of sand size in millimeter.

activities as they used just the percent of the sample with particles larger than 425 μm in diameter as the index of particle size (Horrocks and Scott, 1991). However, Mortimer (1990) collected sand samples from 34 green turtle (*Chelonia mydas*) nesting shores along Atlantic, Indian and Pacific Oceans and analyzed them to estimate more detailed sand characteristics (e.g., mean particle size, particle size distribution, sorting and skewness of sand particles), and found that green turtles nest in varied sands around the world. Our results in this study confirm these findings, as Iranian hawksbill turtles nested in sands that were varied (Figs 4 and 5). Karavas et al. (2005) mentioned that female loggerhead turtles prefer to nest in well sorted sand because sand is not coarse. Mortimer (1990) also mentioned that both nesting success and hatching success of green turtles are reduced in coarse sands. In this study, sands of dense hawksbill nesting shores in all nesting grounds, except Ommolgorm Island, were found to be well sorted (Figs 4 and 5), which may result high hawksbill nesting and hatching success. However, future investigations are needed to confirm this hypothesis.

5 Further critical studies

The important hawksbill nesting grounds along the Iranian Persian Gulf were mapped in this study with the goal of establishing a preliminary database. We believe establishing a comprehensive and applied conservation manual for these important hawksbill nesting grounds in the Persian Gulf will be possible only after some further studies.

(1) A zoning program using the maps presented here in this

study seems critical to protect available nesting shores against any anthropogenic activity. Preventing local activities (fishing, camping, etc.) along the shores of these areas may need a long-term awareness program. It is late because total length of adequate nesting shores for hawksbill turtles in all these areas is already narrow. Therefore, limiting these activities to the shores without nesting and isolating hawksbill nesting shores in protected zones could be a temporary solution.

(2) Modeling density-dependent effects on hawksbill hatching success in these four nesting grounds is also suggested. Density-dependent nest destruction (observed in this study at both Nakhiloo and Ommolgorm Islands) and other such effects should be identified, quantified, and modeled to define how much available nesting shores in these areas are vulnerable.

(3) For these four nesting grounds, it is suggested to estimate the rate of destruction of nesting shores over time related to anthropogenic developments (e.g., constructing jetties) and putative natural phenomena (e.g., projected sea level rise) using GIS methods.

(4) Here, only sand texture was evaluated in the dense hawksbill nesting shores. It is suggested to study all putative factors influencing hawksbill turtle nesting activities in these nesting grounds.

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