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Effects of Temperature on Nest Success of Hawksbill Sea Turtles, *Eretmochelys imbricata* (Linnaeus, 1766), in the Persian Gulf Islands

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ABSTRACT

Aims: Temperature is one of the factors that can affect the survival of sea turtle hatchlings. As a critically endangered species, the Hawksbill sea turtle nests in several Iranian islands including Kish and Qeshm. Few studies have so far been conducted on the effect of temperature on the nesting success of this species in the Persian Gulf. The objective of this study is to investigate the effects of temperature on the survival of turtle hatchlings in two nesting areas.

Materials & Methods: The temperature of the sand and the nest was recorded and analyzed using thermochron data loggers for several consecutive years from 2019 to 2021 in four nesting areas (Qeshm, Kish, Nakhiloo, and Nayband Bay) from the beginning of the nesting season until the emergence of hatchlings. Three factors of nest success including hatching success (percentage of hatchlings that hatch from the eggs), mortality (percentage of dead hatchings), and emergence success (percentage of hatchlings that emerge from the nest) were chosen as indicators to evaluate nest success in Kish and Qeshm Islands.

Findings: The lowest annual mean sand temperature was related to Kish Island. The annual mean nest temperature in Kish and Qeshm Islands showed a significant difference. In Kish Islands, the annual mean temperature of the nests was at a level higher than the thermal tolerance threshold (33 to 35°C) for less than five days. Examining the success of the nests showed Kish has a higher mean hatching success than Qeshm, but this result does not hold true for the other two criteria.

Conclusion: Although checking the temperature of the sand and the nest can provide useful information regarding the survival of the turtle hatchlings and the implementation of protection decisions, investigating other factors besides temperature can be helpful as well.

Keywords: Hawksbill sea turtle; Nest success; Sand temperature; The persian gulf.

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Introduction

Sea turtles rely on sandy beaches to lay their eggs. After mating, the females migrate to certain beaches and dig their nests in the sand [1]. The sandy substrate is considered the interface between the environment and the growing embryos in the nest [2, 3]. Therefore, there is a relationship between hatching success and some physical characteristics of sandy beaches, especially temperature [4]. Temperature influences embryo survival and determines the ratio of male to female offspring produced [5]. The fluctuations in sand temperature can be affected by the incubation period and mortality of pre-emergent hatchlings, thereby reducing the hatching success [6]. The high temperature of the sand may hamper the action of the hatchlings' muscles in climbing out of the nest [7]. The high temperature may also reduce the oxygen level in the nest. On the other hand, the decrease in oxygen level due to the increase in metabolic heat reaches its peak in the incubation period [8]. These factors can increase the mortality rates of hatchlings even before hatching. As for green sea turtles, hatchlings usually emerge at night, and their mortality is partially controlled by nocturnal decreases in sand temperature [9, 10]. After the eggs hatch, the newly born hatchlings move closer to the sand surface, where daily temperature changes may increase their mortality.

The thermal tolerance threshold for embryonic development is 33°C to 35°C, and sand temperature below 32.95°C increases nesting success [11, 12]. If the temperature exceeds the thermal tolerance threshold of 33°C, mortality and morphological abnormalities increase. In addition, due to their small body size and reduced movement efficiency, the increase in temperature makes sea turtle hatchlings more vulnerable to hunting and reduces the possibility of their survival [13, 14].

The nest success of sea turtles has been measured in several ways. In some cases, hatching success (percentage of hatchlings that hatch from the eggs), emergence success (percentage of hatchlings that emerge from the nest), clutch size, and incubation conditions have been considered [15, 16]. In some other studies, mortality in the final stages (the percentage of hatchlings that die in the final stages of development) has been chosen as a suitable measure to determine nest success [17, 18, 19].

In 2002, the effect of seasonal fluctuations in sand temperature on the mortality rate of Loggerhead sea turtle hatchlings was investigated. In this study, many of the hatchlings died before leaving the nest, mostly in the hottest part of the season. Emergence success was correlated with mean sand temperature for the four days before emergence, indicating that mortality could be caused by heat [6]. In another study on this species, the researchers investigated the effect of the nest temperature on the characteristics of the hatchlings. They found that there is no correlation between hatching and emergence success and the temperature of the nest, but that the high temperature reduces the body size of hatchlings and decreases their movement efficiency [14]. The effects of sand temperature on the incubation period, hatching success, and emergence percentage of green sea turtle hatchlings in Costa Rica were analyzed by Segura and Cajade (2010). The findings of this study showed that the increase in the sand temperature shortened the length of the incubation period. Also, there was a negative relationship between the percentage of emergence success and the mean sand temperature at a depth of 40 cm before hatching [20].

Hawksbill sea turtles are often seen along the coasts of Iran, Qatar, Saudi Arabia, Kuwait, and the United Arab Emirates [21]. As a

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dominant nesting species, it nests in several Iranian islands and the Persian Gulf coasts [22- 25, 26]. They are one of the seven remaining species of sea turtles in the world. All species are listed in the IUCN Red List as critically endangered species. No study has so far been conducted on the effect of temperature on the nesting success of this valuable species in the Persian Gulf. The purpose of this study is to investigate the effect of the temperature on the hatchling's survival for this species in two important nesting areas. These two islands have acceptable conservation monitoring, with more than 10 years of data for nesting success.

Materials & Methods

Study Area

The Persian Gulf is located between the northeast of the Arabian Peninsula and Iran's plateau, which is 1000 km long and 300 km wide. Geographically, this gulf is located in the subtropical region between 24 and 30° N latitude and 48 and 57° E. Among the four studied areas, a small uninhabited island (Nakhiloo Island, 27° 49' 11'' N, 51° 28' 22'' E) and a gulf (Nayband Bay, 27° 18' 00'' N, 52° 41' 28'' E) are located next to the coastal waters of Bushehr province in the north of the Persian Gulf. These two areas have been protected as marine national parks by Iran's environmental organization. In the north of the Persian Gulf, two other islands, namely Qeshm (Shib Deraz; 26° 41' 19'' N, 55° 56' 11'' E) and Kish (Turtle protected beach; 26° 29' 54'' N, 54° 00' 41'' E), are located along the coasts of Hormozgan province, where the nesting beaches of these islands are also under conservation management (Figure 1).

Measuring the Temperature of Sand and Nest

To measure the temperature of the sand and the nest in four of the most important nesting areas of the Persian Gulf (i.e., Qeshm, Kish, Nayband, and Nakhiloo), several thermologgers (DS1921G-F5# thermochron ®ibutton®) were used, and their accuracy and precision were 1 and 0.5°C, respectively [27, 28]. The temperature was recorded for several consecutive years from 2019 to 2021 (three to five months every year) during the nesting season until the emergence of the hatchlings. First, the thermologgers were calibrated and settings were made to record the temperature for one-hour intervals. Then, the thermologgers were placed in waterproof bags and embedded at a depth of 45 cm [29]. In this study, the data recorded by 10 thermologgers (n = 2, Qeshm; n = 6, Kish; n = 1, Nakhiloo; n = 1, Nayband Bay) were analyzed. The period of temperature recording for Nakhiloo Island was from May to Jul 2020, Nayband Bay from April to June 2019, Kish Island from April 2019 to August 2021, and Qeshm Island from May 2020 to May 2021. The average number of days recorded by the thermologger is 105.1 days (standard deviation: 17.33, minimum: 62 days, maximum: 153 days).

Meteorological data were also used to predict the sand temperature in unrecorded years and months [29, 30]. For this purpose, the nearest meteorological station was chosen, and the data related to air and soil temperature from a depth of 50 cm were received from the base of the Iran Meteorological Organization. Finally, a linear regression model was established to determine the relationship between the daily mean sand temperature in the study area and the daily mean air and soil temperature of the meteorological data. Two linear regression models were used to predict sand temperature: 1) air temperature and 2) soil temperature. After selecting the best model for the nesting area, the sand temperature was predicted for the missing years.

Nest Success (Hatching, Emergence, and Mortality)

In this study, the data of 733 nests (n = 299, Kish; n = 434, Qeshm) were used to evaluate

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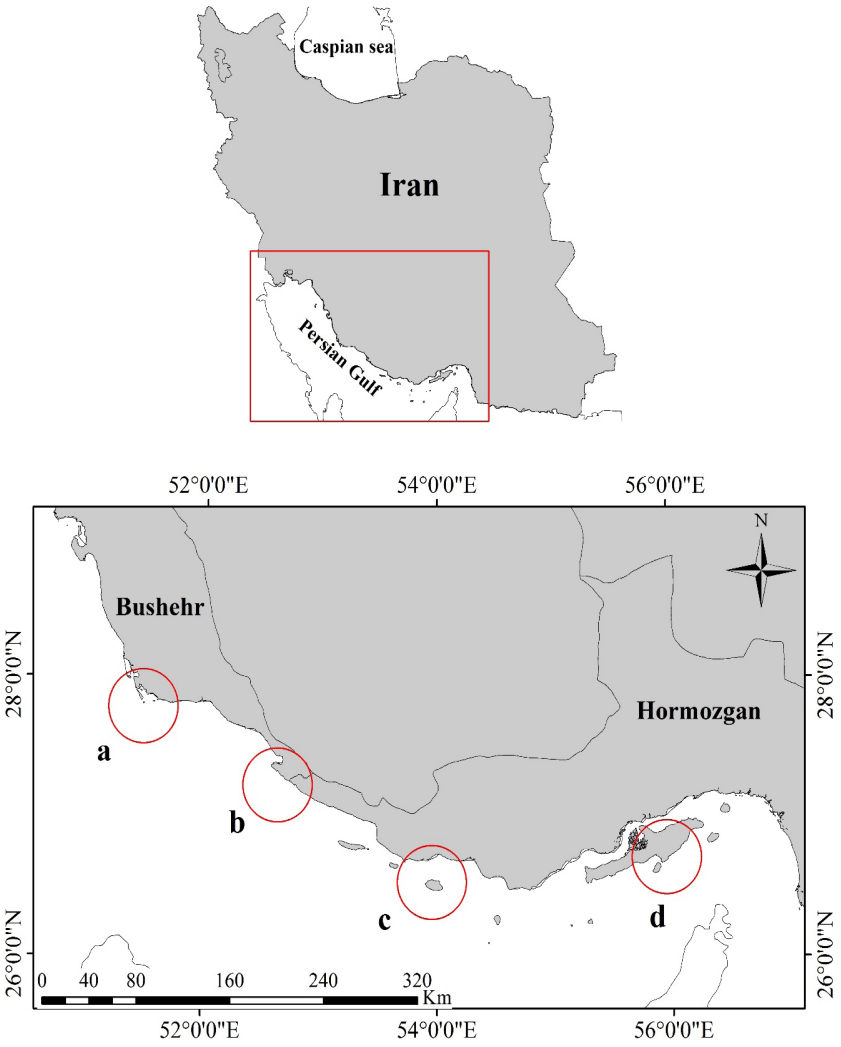

Figure 1) The location of the studied islands and coasts in the Persian Gulf: a) Nakhiloo Island b) Nayband Bay c) Kish Island d) Qeshm Island.

the nest success and the effects of temperature on it. According to previous studies, three factors have been chosen to evaluate the nest success regarding Eqs. (1, 2, 3) [15, 16].

$$\text{Hatching success} = \left(\frac{\text{Number of live hatchlings} + \text{Number of dead hatchlings}}{\text{Number of healthy eggs}}\right)\times 100 \quad \text{Eq. (1)}$$

$$\text{Emergence success} = \left(\frac{\text{Number of live hatchlings}}{\text{Number of healthy eggs}}\right)\times 100 \quad \text{Eq. (2)}$$

$$\text{Mortality} = \left(\frac{\text{Number of dead hatchlings}}{\text{Number of healthy eggs}}\right)\times 100 \quad \text{Eq. (3)}$$

Findings

Linear Regression

During the years under examination, comparing the correlation between two meteorological data, i.e., air and soil temperature with the recorded sand temperature, showed that, with a higher coefficient of determination, the soil temperature has a better correlation with the sand temperature in different regions.

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Kish Island and Nayband Bay explained more than 90% ($R^2 > 0.95$) of the changes in the sand temperature. This rate was more than 85% (R^2=0.87) for Nakhiloo Island. (Figure 2, Table 1)

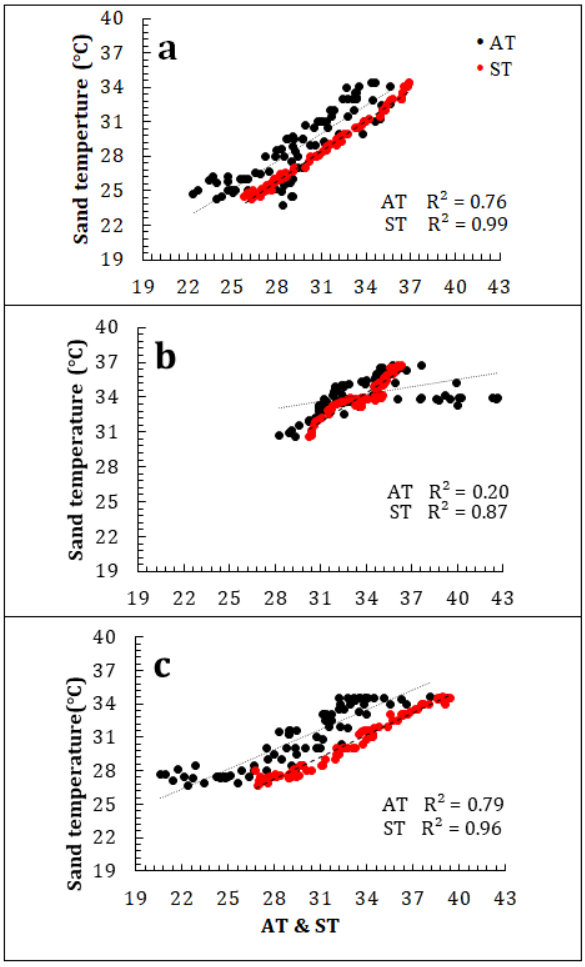

Figure 2) The relationship between daily mean air temperature-sand temperature and soil temperature-sand temperature in the studied areas: a) Nakhiloo Island; b) Nayband Bay; and c) Kish Island. Linear fittings to the regression for meteorological data are shown by dashed lines. AT: air temperature, ST: Soil Temperature.

Sand Temperature

In a reproductive period of five months during three years (2019 to 2021), the annual mean sand temperature showed an increasing trend in all areas from the beginning to the end of the reproductive season. This temperature difference was 15°C. In total, compared to other nesting habitats, the lowest annual mean sand temperature was related to Kish Island. Three other Islands and beaches (i.e., Qeshm, Nayband, and Nakhiloo) did not show significant differences (Figure 3). In the comparison of the studied areas, the difference in the annual mean temperature of the sand at the beginning of the reproductive season was 1.2°C and 1.6°C at the end of the period, which was reduced at the end of the season. In the same period, the annual mean sand temperature in Qeshm Island reached the threshold of tolerance earlier than in other areas. For other areas, compared to Qeshm Island, this process occurred after six to 19 days (Figure 4a). The annual mean sand temperature for the peak of nesting activity was27.66 °± 1.80C for Qeshm Island, 29.48±1.10°C for Nayband Bay, and 26.59±1.21°C for Kish Island.

Nest temperature

There was a meaningful difference between the annual mean nest temperature in Kish and Qeshm Islands. During the nesting period, the annual mean sand temperature and the annual mean nest temperature did not show any significant difference in Qeshm Island. On Kish Island, however, this difference was 0.2°C, which showed a significant difference. At the beginning of the season, these temperature differences were more significant and decreased during the period until a temperature overlapping was observed. This process was different from the temperature regime of Qeshm Island. The sand temperature of Qeshm Island reaches the tolerance threshold on May 21, i.e., three weeks earlier than June 9 for Kish Island (Figure 4b).

Nest success

During the study period, four factors were calculated for each nest. Among these factors, the annual mean of hatching and the percentage of emergence were considered

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Table 1) ANOVA table's linear regression statistics for R^2, F, and P-value for air temperature, soil temperature, and sand temperature.

	Kish Island			Nakhiloo Island			Nayband Bay		
	R^2	F	P	R^2	F	P	R^2	F	P
AT~Sand	0.76	284.98	<0.001	0.20	18.26	<0.001	0.79	583.71	<0.001
ST~Sand	0.99	9331.93	<0.001	0.87	509.91	<0.001	0.97	7817.17	<0.001

Table 2) The calculated values for the success of the nests in the protected beaches of Kish and Qeshm in the two situations of the whole period and the peak of the period. The averages of hatching and emergence success and mortality of the hatchlings have been calculated.

Total Nesting Duration								
	Qeshm Island (5 years)				Kish Island (11 years)			
	n	Mean	SD	SE	n	Mean	SD	SE
Clutch Size	434	117.35	26.48	1.27	299	74.29	2.70	0.15
Hatch Success (%)	111	67.62%	7.02	0.66	121	74.00%	5.25	0.47
Mortality (%)	111	6.88%	8.79	0.83	121	17.94%	6.54	0.59
Emergence Success (%)	204	63.99 %	12.25	0.85	299	58.79%	11.24	0.65
The Incubation period (day)	38	56.30	7.63	1.24	311	58.90	8.44	0.47
Nesting Peak Duration								
	n	Mean	SD	SE	n	Mean	SD	SE
Clutch Size	281	111.33	42.91	2.55	191	74.47	4.02	0.29
Hatch Success (%)	70	75.19%	0.51	0.06	72	76.81%	8.91	1.05
Mortality (%)	70	4.90%	5.72	0.68	72	15.74%	8.66	1.02
Emergence Success (%)	133	71.28%	4.06	0.35	191	63.03%	12.58	0.91
The Incubation Period (day)	29	52.79	3.24	0.60	204	57.28	5.27	0.36

measures of the nest's success (Table 2).

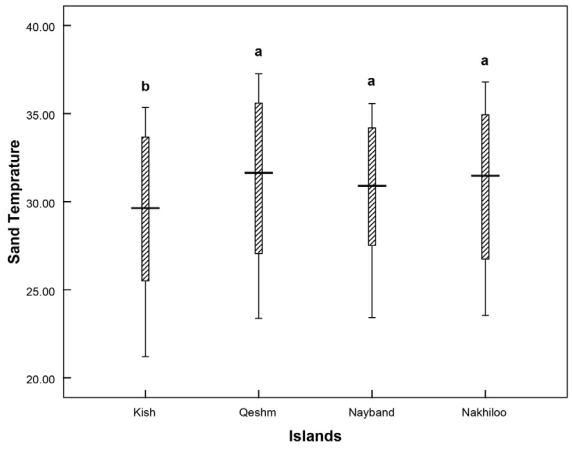

Figure 3) Boxplots of sand temperature in the reproductive season for the four main nesting areas of the Hawksbill sea turtle in the Persian Gulf.

Discussion

The length of the incubation period has an inverse relationship with the nest temperature [6, 11]. The results of the study showed that there is a negative correlation between the mean sand temperature and the incubation period. Due to the warming of the sand temperature in Qeshm Island (Figure 4), the length of the incubation period in the nesting season is shorter in Kish Island. During the peak of the nesting season, the mean incubation period on Kish Island was five days longer than on Qeshm Island (Table 2).

High sand temperature reduced nesting success for sea turtle species. The issue of temperature increase is so important that

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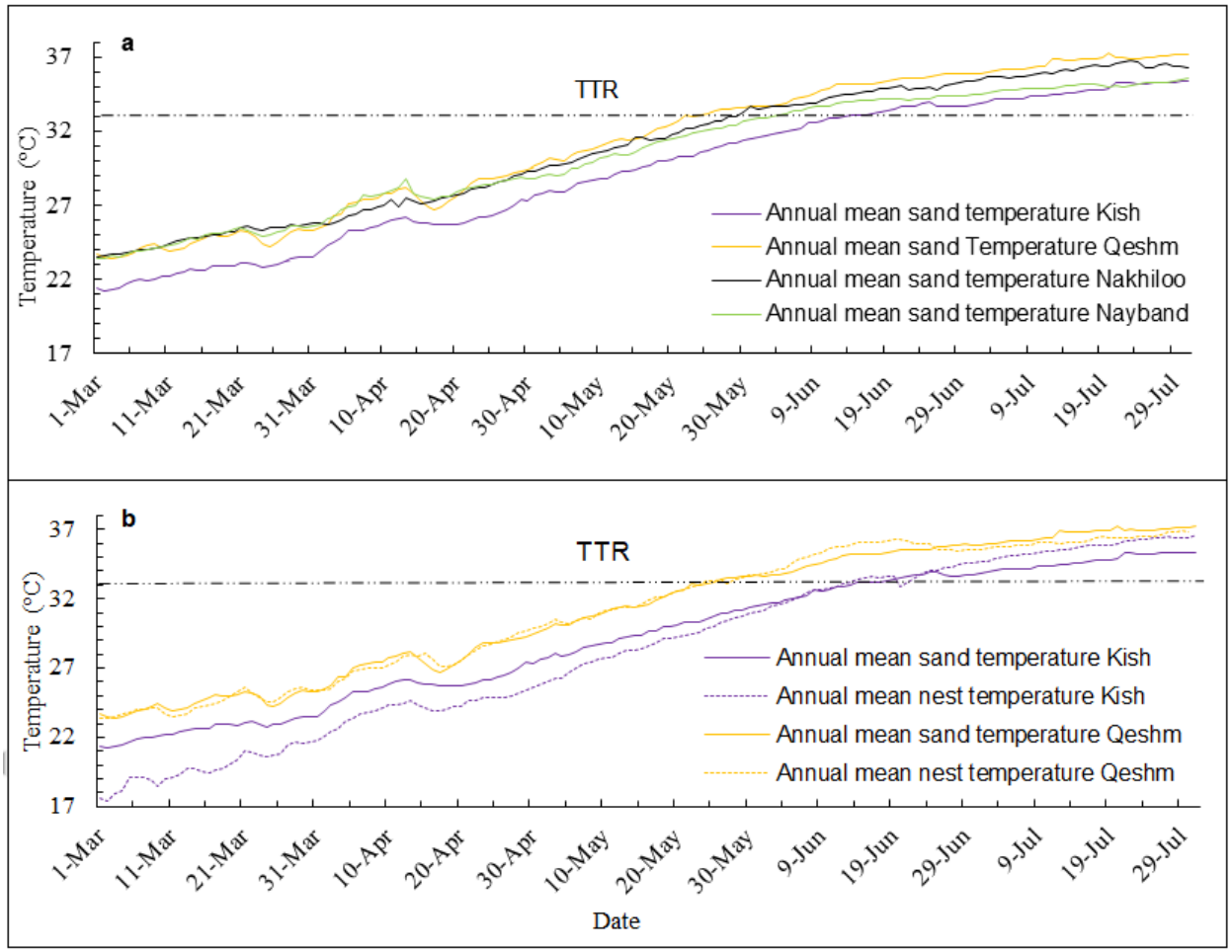

Figure 4) (a) Annual mean sand temperature (degrees Celsius) during nests' incubation period (2019 to 2021) in each of the four nestings (b) areas mean annual nest temperature with mean annual sand temperature of each of the two nesting beaches. The thermal tolerance range (TTR) of 33°C [11] has been shown by horizontal dashed lines.

shading the nest is used to control harmful effects. Some studies show to achieve both short-term conservation objectives and long-term population sustainability, nest shading should be deliberately employed to maximize hatchling production with natural sex ratios [31,32]. In some islands of the Pacific Ocean, the range of nesting activity continues for up to 7 months, and the rate of nesting success (hatch percentage) decreases at the end of the nesting season, which occurs at the same time as the temperature rises [33]. In the Iranian islands, the length of the nesting season is about 4 months, and the temperature trend is upward during the nesting period. The comparison of the nesting activity with sand temperature fluctuations showed Kish Island has the lowest temperature range (26.59 1.21 ±°C to 33.11 0.85 ±°C) at the peak of the nesting activity until the end of the incubation period. The sand temperature recorded in Nayband Bay (29.48 1.10 ±°C to 34.0 64.36 ±°C) in the above-mentioned period was higher than in Qeshm Island (27.66 1.80 ±°C to 34.16 ± 1.25°C) (Figure 4). Many previous kinds of research have shown that sea turtles hatch well in a narrow temperature range from 26 to 33°C [4, 34, 35, 36, 37]. The nests that were built during the peak of the reproductive season in Kish Island, Qeshm Island, and Nayband Bay reach the threshold of tolerance in 52,

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36, and 30 days, respectively. These nests experienced an increase in temperature by 6.50, 6.52, and 5.16°C, respectively, from the nesting peak to the end of the incubation period. This may confirm why the hatching success rate is higher on Kish Island.

On Kish Island, the nests were above the temperature tolerance limit for only less than five days, which was much less compared to Qeshm Island (16 days) and Nayband Bay (30 days). The results showed that Qeshm Island has a lower mean nest success than Kish Island, in terms of hatching success. Despite the suitable nesting depth of rocky shores on Qeshm Island [38,39], it seems that this factor cannot reduce the effects of temperature increase.

Conclusion

In this study, the effect of temperature, as one of the most important determining factors in the survival of hatchlings, was investigated on the success of Hawksbill turtle nests in two islands in the Persian Gulf. On both islands, hatching success is higher during the peak of nesting activity than during the average nesting season. Although Kish Island had a higher incubation rate during the peak of the nesting period, it also had a higher mortality rate than Qeshm Island, which could be caused by other environmental factors. According to other studies, the mortality of hatchlings during the pre-emergence period is significant, which is driven by factors other than sand temperature. For example, the moisture and compression of sand may hamper the emergence of hatchlings in other sea turtle species [39, 40]. In the present study, the density of sand on Kish Island is higher than on Qeshm Island due to its fineness, which enables the substrate to retain more moisture. This high humidity and high compression will probably increase mortality and reduce the emergence of hatchlings. Examining more areas for nesting points with a greater number of thermologgers and recording other environmental parameters such as humidity, oxygen levels, and clutch sizes can be helpful and give us a correct understanding of the conditions.

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Conflict of Interest: All authors declare they have no conflict of interest.

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