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The Indian Ocean Turtle Newsletter was initiated to provide a forum for exchange of information on sea turtle biology and conservation, management and education and awareness activities in the Indian subcontinent, Indian Ocean region, and south/southeast Asia. The newsletter also intends to cover related aspects such as coastal zone management, fisheries and marine biology.

The newsletter is distributed free of cost to a network of government and non-government organisations and individuals in the region. All articles are also freely available in PDF and HTML formats on the website. Readers can submit names and addresses of individuals, NGOs, research institutions, schools and colleges, etc. for inclusion in the mailing list.

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Cover photograph: Green sea turtles with satellite transmitters at The Scientific Centre Kuwait prior to release.

Photo Courtesy: ALan F. Rees

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EDITOR'S NOTE

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The IOTN team welcomes all readers to the first issue of 2023. We bring to you a snapshot survey of stranded turtles on a beach adjacent at an important fishing port in Iran, a systematic review of methods to assess changes in sea turtle nesting phenology with climate change, and a photoessay about a new satellite telemetry study in Kuwait.

In a few months, the international sea turtle community will be meeting for the first time since before the COVID-19 pandemic. Cartagena, Colombia, is a long migration for researchers from the Indian Ocean region and Southeast Asia but we hope to see some of you at the regional meeting before the symposium starts. Safe travels!

CALL FOR SUBMISSIONS

The Indian Ocean Turtle Newsletter was initiated to provide a forum for the exchange of information on sea turtle biology and conservation, management and education and awareness activities in the Indian subcontinent, Indian Ocean region, and south/southeast Asia. If you would like to submit a research article, project profile, note or announcement for Issue 38 of IOTN, please email material to iotn.editors@gmail.com before 1st June 2023. Guidelines for submission can be found on the last page of this newsletter or at http://www.iotn.org/submission.php.

ARTICLES

SEA TURTLE STRANDINGS AT BANDAR-E TANG BEACH, IRAN: A SNAPSHOT SURVEY

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INTRODUCTION

Strandings- in which sea turtles wash ashore dead or alive- can occur for many reasons. These include accidental capture in fisheries (including abandoned, lost or otherwise discarded fishing gear, commonly known as ghost gear), and shark control gear, vessel strike, ingestion of foreign materials such as plastics, disease, illegal take, development activities such as dredging, freshwater discharge into marine environments after intense rainfall, severe storms, and low water temperatures resulting in cold stunning (Pandav *et al*., 1997; Orós *et al*., 2005; Chaloupka *et al*., 2008; Tómas *et al*., 2008; Casale *et al*., 2010; Corsini-Foka *et al*., 2013; Poli *et al*., 2014; Behera *et al*., 2016; Nicolau *et al*., 2016; Flint *et al*., 2017; Başkale *et al*., 2018; Sönmez, 2018; Yaghmour *et al*., 2018; Cheng *et al*., 2019; Griffin *et al*., 2019; Belmahi *et al*., 2020; Cantor *et al*., 2020; Kettemer *et al*., 2022). Surveys for stranded sea turtles can contribute to understanding species distribution, population structure, shifts in size- and age-classes, scale of local threats, and effectiveness of management actions (see Hamann *et al*., 2010; Rees *et al*., 2016). Hence, studying stranded turtles can be useful to understand populations where in-water studies are challenging and additional knowledge is required to guide future research and inform and/or assess potential conservation or management actions.

MATERIALS AND METHODS

The Gulf of Oman (also known as the Sea of Oman) is located in the northwestern Arabian Sea and connects the Indian Ocean to the Persian Gulf via the Hormuz Strait. Bandar-e Tang (59.8740° N, 25.3576° E; Figure 1) is a village near Chabahar and one of the most important fishing ports in the Sistan and Baluchestan

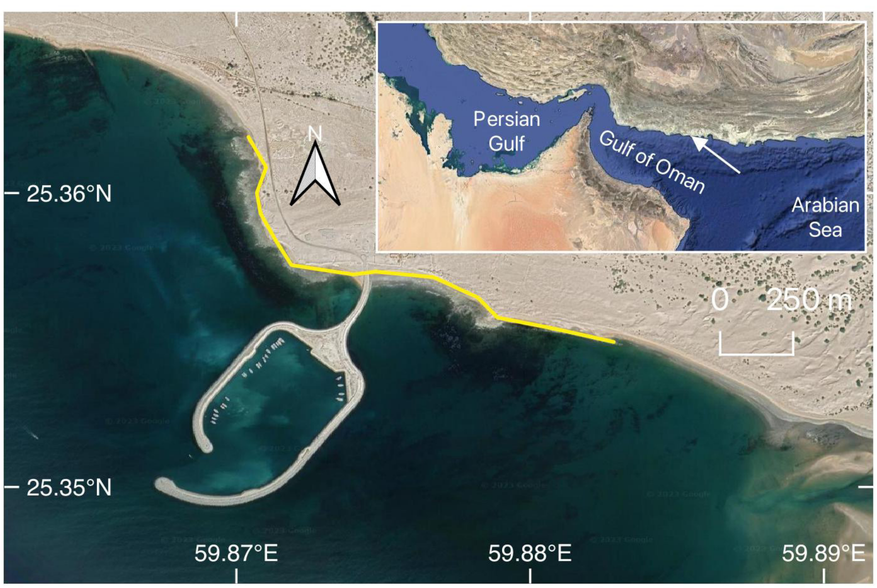

Figure 1. Location of Bandar-e Tang (arrow in inset map) in a regional context.

province of Iran (Iran Marine Statistics, 2016) on this Gulf. The Iran fisheries organisation in Bandar-e Tang reports > 200 boats use the port (Mobaraki, unpubl.).

Low-density nesting of green (*Chelonia mydas*) turtles has been recorded on the surrounding coastline, and local fishers' ecological knowledge and scientific field surveys have identified nearby foraging areas for green and olive ridley (*Lepidochelys olivacea*) turtles. Stranded turtles have also been observed at this location in the past (Mobaraki, 2004) and so it was selected for this study.

A snapshot survey was conducted on 1st May 2021, in which the ~1.5km of sandy beach (Figure 1) adjacent to Bandar-e Tang was physically searched for live and dead stranded sea turtles. Turtles found during the survey were identified to species and sex (by the extension of the tail beyond the carapace; Bolten 1999), and the curved carapace length (CCL) measured with a flexible tape measure to the nearest 0.1cm. Green turtles were assigned to the following size classes based on CCL: juvenile (CCL <55cm), subadult (55-93cm) or adult (CCL >93cm) (see Pilcher *et al*., 2015; Mobaraki *et al*., 2020; Al Ameri *et al*., 2022) and olive ridley turtles as immature (comprising juveniles and subadults; <60cm) or adult (>60cm) (Shanker *et al*., 2004; Tripathy, 2008; Rees *et al*., 2012a). Some stranded turtles were photographed on site and the stage of decomposition was later categorised according to Flint *et al*. (2009). Necropsies were not performed.

RESULTS

Species and size-class

A total of 39 stranded sea turtles, comprising 38 green turtles and one olive ridley turtle, were found on the survey date; all were dead. The majority of green turtles were juveniles (52.6%) (Table 1). The sex of the single adult green turtle could be established (male), but all subadults had short tails and males could not be reliably distinguished from females using external characteristics only. The one stranded olive ridley turtle was a subadult of undetermined sex (Table 1).

Table 1. Species and size classes of stranded sea turtles found at Bandar-e Tang beach.

Size Class	% of Stranded Turtles	
	Green Turtle (n=38)	Olive Ridley Turtle (n=1)
Juvenile	52.6	100.0
Subadult	18.4	
Adult	2.6	-
Not determined	26.3	-

Carcass condition

Twenty-four dead turtles were photographed to determine stage of decomposition, which ranged from D3 (carcass in fair condition; decomposition with internal organs intact) to D6 (disarticulated bones; no soft tissue remaining), with the majority at stages D4 (carcass in poor condition; advanced decomposition with internal organs falling apart) to D5 (mummified carcass; skin holding bones together) (Table 2; Figure 2). The head, flippers, and/or internal organs had been removed from some carcasses (Figure 2), presumably by scavengers.

Table 2. Stage of decomposition (see Flint *et al*., 2009) of stranded sea turtles found at Bandar-e Tang beach.

Stage of Decomposition	% of Stranded Turtles	
	Green (n=23)	Olive Ridley (n=1)
D3	13.0	-
D3-D4	8.7	-
D4	39.1	-
D4-D5	4.3	-
D5	21.7	-
D5-D6	8.7	100.0
D6	4.3	-

Cause of mortality

None of the carcasses showed macroscopic signs of trauma or injury that could have contributed to the turtle mortality.

DISCUSSION

The snapshot survey described in this study reveals variation in the species and size-class of dead stranded turtles at Banda-e Tang beach on 21st May 2022. The stage of decomposition suggests that the turtles stranded as individuals. Potential cause/es of mortality were not established, but the number of stranded turtles (n=39) found on a short length of coast (1.5km) in a single day in comparison to reports (e.g., 4-45 turtles on ~26km over 1-4mo, Lagueux and Campbell, 2005; 69 turtles on ~200km coastline over 3mo, Kannan *et al*., 2005; 209 turtles on 180km coastline per year, Levy *et al*., 2015; 63 turtles on >1600km coastline over 2yr, Belmahi *et al*., 2020) from areas without a large nesting population in the area indicates the need for a longer study to determine the cause of mortality.

Figure 2. Carcass condition from left to right: D3, D4, D5, D6, scavenged. (Photo credits: Asghar Mobaraki)

Species and size-class

All but one of the 39 stranded turtles were green turtles, with ~70% in the juvenile and subadult size classes. A study of foraging turtles in nearby waters also found predominantly juvenile and subadult green turtles (Mobaraki *et al.*, 2020), potentially the result of size-class partitioning due to habitat requirements and/or risk of predation as observed in other green turtle populations (Bresette *et al.*, 2010). These green turtles are likely part of the Oman nesting stock (Mobaraki *et al.*, 2020). Oman hosts the most important nesting population of green turtles in the northern Indian Ocean (see Phillott & Rees, 2021; Pilcher *et al.*, 2021), with ~7,000 nesting females per annum in 1979 (Ross & Barwani, 1982). However, there have been no recent estimates of the nesting population size and the population trend over time is unknown (Willson *et al.*, 2021). Green turtles in the northern Indian Ocean are categorised as Vulnerable on the IUCN Red List (Mancini *et al.*, 2019), and the loss of these immature green turtles should be considered in context of the regional population status.

Only one olive ridley turtle was found at Bandar-e Tang beach, which is unsurprising as reports of the species from Iranian waters in the Gulf of Oman are less common. Foraging individuals have been observed (Kami, 1997) and recorded as bycatch (Mobaraki, 2004; Mobaraki & Abtin, 2021), and a few post-nesting olive ridley turtles have been tracked on their return breeding migration from Oman into the Persian Gulf (Rees *et al.*, 2012b). Hence, the single dead olive ridley turtle at Bandar-e Tang beach likely represents the low abundance of this species in local waters and not a lesser vulnerability to bycatch.

Similarly, the absence of stranded loggerhead (*Caretta caretta*) turtles likely reflects low numbers of foraging loggerheads in the Gulf of Oman (Baldwin *et al.*, 2003) and post-nesting loggerhead turtles migrating from Oman into the Gulf of Oman and Persian Gulf (Rees *et al.*, 2010). No stranded hawksbill (*Eretmochelys imbricata*) turtles were found during this snapshot survey. Hawksbill turtles are the most common nesting sea turtle in countries bordering the Persian Gulf (e.g., Iran, Kuwait, Qatar, Saudi Arabia, United Arab Emirates; see Phillott & Rees, 2021) but this species does not often migrate through the Hormuz Strait (Pilcher *et al.*, 2014). A large population of hawksbill turtles nest on the Dimaniyat Islands of Oman in the Gulf of Oman and turtles forage around the same islands (Willson *et al.*, 2021), but there are no in-water or nesting reports of the species from the Iranian coast of the Gulf of Oman (Mobaraki, 2004).

Carcass condition

Time of death cannot be conclusively established from carcass condition (stage of decomposition) due to variables like submersion period and drift duration, temperature, predation etc (see Santos *et al.*, 2018; Schultz *et al.*, 2022). The varied stages of decomposition among stranded turtles in this study from D3 to D6 suggest that mortality was likely due to individual events and not an anthropogenic activity or environmental factor that resulted in mass mortality.

Cause of mortality

As green turtles have a Type 2 life history pattern, moving from oceanic to neritic habitats at a size of ~20-35cm CCL to complete their development (Bolten, 2003), the immature turtles found in this survey were more likely to encounter the cause of their stranding in comparatively shallower waters, such as coastal fisheries. Sea turtle mortalities are often attributed to interactions with fisheries, which is one of the five major threats to the taxa worldwide (Mast *et al.*, 2005) and a major threat in the region (Phillott & Rees, 2021), and drowning after entanglement or hooking in fishing gear is the most likely cause of mortality of the turtles found in this study. However, strandings should only be conclusively attributed to fisheries if indicative signs of entanglement, hooking, drowning, or decompression sickness are found (see Phillott & Godfrey, 2019). Any subsequent studies can look for expanded lungs containing fluid, and thick white /pale pink foam being expressed from the nostrils or present in the trachea, bronchi or lungs in fresh carcasses to indicate drowning (Wolke & George, 1981; Stacy *et al.*, 2017), or fishing line protruding from the mouth and/or cloaca, or puncture wounds on the shoulder and/or neck as evidence of hooking (Watson *et al.*, 2005; Archibald & James, 2018).

The cumulative contribution of coastal and small-scale fisheries to bycatch can exceed that of industrial fisheries (Peckham *et al*., 2007; Alfaro-Shigueta *et al*., 2011; López-Barrera *et al*., 2012). Iranian fishers in the coastal and near offshore national waters of the Gulf of Oman mainly operate small to medium-sized motorised wooden vessels locally called *lench* or fiberglass vessels. Depending on the species and season, drift nets, gill nets, and long lines are usually used to target mackerel species such as Spanish mackerel (*Scomberomorus commerson*), Indo-Pacific king mackerel (*Scomberomorus guttatus*), tuna species including longtail tuna (*Thunnus tonggol*) and yellowfin tuna (*Thunnus albacares*), and black promfret (*Parastromateus niger*). Depending on the target species and vessels, different types and sizes of nets are used. Mesh size of gill and drift nets is up to 15cm and the length may be >10km, while longlines can exceeds hundreds of metres (Iran Marine Statistics, 2016). Sea turtles worldwide are known to be vulnerable to bycatch in these type and dimensions of fisheries gear (see Lewison *et al*., 2013).

If stranding at Bandar-e Tang beach are the result of interaction with fisheries, the mortality probably reflects individual bycatch events and not mass-bycatch events, as observed in the Odisha state of India (Pandav *et al*., 1997; Behera *et al*., 2016). Sea turtles are classified as 'Endangered' in Iran and deliberate catch and consumption of bycatch is forbidden and can result in a heavy fine (Department of Environment, 2004). As a result, most fishers check their nets frequently to reduce the risk of accidental capture and drowning (Mobaraki, pers.obs.) and bycatch turtles are released at sea or, if dead, left on the landing beach such as the location of this study. There are no seasonal or spatial closures to limit fisheries activities during the sea turtle nesting season or in foraging areas due to knowledge gaps about the ecology of sea turtle in Iranian coastal waters (Mobaraki, 2021).

Studies on a larger temporal and spatial scale are required to identify the cause/s of sea turtle strandings on the Iranian coast of the Gulf of Oman and determine if conservation actions are required. If field work for this purpose is challenging, then interviews to collate fishers' ecological knowledge, participatory mapping, and confirmation of species through fishers' photographs of bycatch turtles would provide further information about resident and bycatch species, size class, and sex, preferred habitats, population trends, and threats (Phillott & Chandrachud, 2021).

CONCLUSION

A snapshot survey of the 1.5km beach at Bandar-e Tang, Iran, found 39 dead sea turtles, most of which were juvenile and subadult green turtles. This reflects the species and size-class of sea turtles found in local waters. The most likely cause of mortality was drowning after entanglement in fishing gear, although this was not conclusively determined. As the turtle carcasses were at different stages of decomposition, it is unlikely that the turtles died *en masse*. More information about the sex and cause of death of dead turtles could be obtained through necropsies by trained personnel. Interviews with local fishers could also reveal bycatch rates and the ecology of local sea turtles. Further study on a larger temporal and spatial scale is recommended to assess the size of this potential threat and determine if conservation action is required.

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THE IMPACTS OF CLIMATE CHANGE ON SEA TURTLES, AND METHODS TO ASSESS POTENTIAL CHANGES IN NESTING PHENOLOGY

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INTRODUCTION

Anthropogenic climate change is one of the primary threats to the environment and human society (Pecl *et al*., 2017; Lenton *et al*., 2019). This planetary-level modification has had unprecedented effects on ecosystems and biodiversity (Newson *et al*., 2009; Walther, 2010). Numerous species have already demonstrated alterations in their distribution and phenology, amongst other responses (Walther, 2010; Feeley *et al*., 2017; Piao *et al*., 2019). For example, mobile species like tropical fish have responded to climate change by migrating to more habitable regions, usually poleward or to deeper water, in order to find their preferred range of oxygen availability or water temperature (Munday *et al*., 2008). Milder winters have caused a significant increase in brown plumage in populations of tawny owls, allowing them to blend in better with the surrounding forest, in Europe (Karell *et al*., 2011). Moreover, fruit flies in southern, high-latitude areas of Australia are demonstrating genetic mutations common to more northern populations of the country as the species has adapted to drier and hotter conditions. Scientists have attributed these changes to climate change and have observed similar trends in Europe and North America as well (Umina *et al*., 2005).

Sea turtles are another taxon likely to be affected by climate change, across all their life stages. The predicted impacts include:

1. Sex ratios: As sea turtles have temperature-dependent sex determination, increase in incubation temperatures at nesting beaches may result in the feminisation of some populations (e.g., Janzen, 1994; Santidrián Tomillo *et al*., 2015a; Jensen *et al*., 2018) and decreased egg fertilisation rates (Glen & Mrosovsky, 2004; Lalöe *et al*., 2014; Jensen *et al*., 2018; Phillott & Godfrey, 2020).
2. Embryo development: Embryo development is faster at higher temperatures, reducing the incubation

period and allowing less time for embryo growth (Reid *et al.*, 2009). The result is smaller hatchlings, with implications for predation rates and performance.

3. Hatching success: Even small increases at the upper range of incubation temperatures can negatively affect hatching success (the proportion of eggs that hatch to produce hatchlings; Miller, 1999). For example, an increase from 30°C to 31°C mean incubation temperature can decrease hatching success by up to 25% (Howard *et al.*, 2014). Changes in average precipitation may also affect hatching success (Santidrián Tomillo *et al.*, 2012; Rafferty *et al.*, 2017; Montero *et al.*, 2018), with heavy rainfall increasing hatching success at drier nesting sites and the opposite or variable effects occurring at high-precipitation sites. (Santidrián Tomillo *et al.*, 2015b; Montero *et al.*, 2019). Lower hatching success will have implications for population recruitment and resilience.

4. Hatchling survival and performance: As incubation temperatures increase above 32°C, hatchlings perform more poorly on tests to assess their crawling, self-righting, and swimming abilities. Decreased locomotor performance at sea will make hatchlings more vulnerable to predation (Booth, 2017, 2018).

5. Movements and distribution at sea: Being ectothermic, sea turtles are affected by seawater temperature (Milton & Lutz, 2003). For example, Kemp's ridley (*Lepidochelys kempii*) turtles that disperse further north to forage with warmer sea surface temperatures (SSTs) during autumn months, then retreat too slowly from cold waters in winter, are at greater risk of cold-stunning (Griffin *et al.*, 2019). Some populations are already adapting to changing ocean temperatures, such as Eastern Pacific olive ridley (*Lepidochelys olivacea*) turtles that forage more northwards during an El Niño year to avoid warm waters and seek more productive upwelling areas (Plotkin, 2010), and hawksbill (*Eretmochelys imbricata*) turtles in the Arabian/Persian Gulf that move out of shallow, coastal foraging areas during the summer months when aquatic temperatures exceed 33°C (Pilcher *et al.*, 2014; Marshall *et al.*, 2020).

6. Reproductive output: The size of adult hawksbill turtles in the Arabian/Persian Gulf and Red Sea may be restricted by relatively poor foraging habitat and/or success due to extreme thermal environments. A smaller body size will limit clutch size in nesting females (Chatting *et al.*, 2018; Mobaraki *et al.*, 2022). There are indications that the number of yolkless eggs, comprising only an eggshell and egg white or albumen, laid by hawksbill turtles in these extreme environments are greater than that in other populations worldwide; the statistical likelihood and biological implications of this have yet to be determined (Mobaraki *et al.*, 2022).

7. Nesting habitat: Many current nesting beaches utilised by sea turtles will likely be reduced in area by sea level rise, with beaches in developed regions being the most vulnerable (Fish *et al.*, 2005; Baker *et al.*, 2006; Fuentes *et al.*, 2010). Coastal development can prevent the natural movement of sediment to replenish beaches, causing coastal squeeze, thus, exacerbating the impacts of sea level rise (Fish *et al.*, 2008; Mazaris *et al.*, 2009a; Biddiscombe *et al.*, 2020).

8. Geographic range: In response to climate change, sea turtles may shift their nesting (Mancino *et al.*, 2022) and foraging (Patel *et al.*, 2021) habitat. Range shift in the form of range expansion (as opposed to contraction), that exposes sea turtles to greater human activities, lesser quality habitat, and other threats, could form an ecological trap (Pike, 2013; Maffucci *et al.*, 2016). Range shift could also be beneficial, although thoroughly validated examples have not yet been reported in the published literature.

9. Emerging diseases and pathogens: Outbreaks of infectious diseases in some marine taxa have increased in the last few decades, likely driven by anthropogenic climate change (Fisher *et al.*, 2012; Altizer *et al.*, 2013; Sanderson & Alexander, 2020). In sea turtles, warmer waters could increase the rate of tumour growth in animals with fibropapillomatosis (Herbst, 1994, 1995; Foley *et al.*, 2005) and the pathogenicity, transmission pathways, and host susceptibility in any disease (see Mashkour *et al.*, 2020). The association of climate change with emerging diseases in the terrestrial environment, such as sea turtle egg fusariosis (Gleason *et al.*, 2020), has not been conclusively determined. Loss of nesting area with climate change-driven sea level rise will likely increase nest density (Patricio *et al.*, 2019) with implications for microbial load in sea turtle nests (Honarvar *et al.*, 2016) and the spread of pathogens among adjacent clutches (Sarmiento-Ramirez *et al.*, 2017). Foraging habitats, including seagrass meadows (Sullivan *et al.*, 2018) and coral reefs (Precht *et al.*, 2016; Tracy *et al.*, 2019), may also be impacted by disease and/or pathogens.

10. Nesting phenology: Alterations in the timing

of seasonal activities among animals and plants is a commonly observed ecological response to environmental perturbations like climate change (Walther *et al.*, 2002). Oceans have absorbed ~80% of the heat added to the environment (IPCC, 2007), impacting parameters like sea surface temperature (Hoegh-Guldberg *et al.*, 2007), biogeochemical composition (Harley *et al.*, 2006), and sea level (Meehl *et al.*, 2005). Ocean temperature affects the onset of nesting, duration of the nesting season, nest abundance, clutch size, mean nesting date, and other parameters of the nesting phenology of loggerhead (*Caretta caretta*) sea turtles in Florida (Lamont & Fujisaki, 2014). However, patterns are not always consistent. For example, higher annual SST adjacent to nesting beaches (Weishampel *et al.*, 2004, 2010; Pike *et al.*, 2006; Hawkes *et al.*, 2007; Mazaris *et al.*, 2008, 2013; Lamont & Fujisaki, 2014; Patel *et al.*, 2016) and at foraging sites (Mazaris *et al.*, 2009b, Monsinjon *et al.*, 2019) have both been correlated with earlier nesting. Longer (Weishampel *et al.*, 2010; Lamont & Fujisaki, 2014) and shorter nesting seasons (Pike, 2009; Weishampel *et al.*, 2010), and reduced inter-nesting intervals (Weber *et al.*, 2011; Valverde-Cantillo *et al.*, 2019), have been recorded in warmer years. Higher SST at nesting locations has also been associated with fewer total clutches, primarily as a result of fewer turtles nesting (Mazaris *et al.*, 2009b; Reina *et al.*, 2009; Patel *et al.*, 2016). Earlier nesting is predicted to mitigate exposure of eggs to lethal temperatures (Almpanidou *et al.*, 2018) and strongly female-biased sex ratios (e.g., Abella Perez *et al.*, 2016) that are predicted to occur with higher environmental temperatures due to climate change.

We note that the El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation are known or predicted to affect nesting in some sea turtle populations (e.g., Limpus & Nicholls, 1988; Chaloupka *et al.*, 2008; Saba *et al.*, 2008; Quiñones *et al.*, 2010; Mortimer, 2012; Arendt *et al.*, 2013; Bruno *et al.*, 2020; Santidrián Tomillo *et al.*, 2020; Hays *et al.*, 2022) but not others (Ariano-Sánchez *et al.*, 2020; Santidrián Tomillo *et al.*, 2020; Hays *et al.*, 2022). However, the impact of climate change on ENSO is still uncertain in the face of contradictory findings (e.g., Yang *et al.*, 2018; Alizadeh, 2022; Geng *et al.*, 2022); therefore, we do not include this in the above list.

The impacts of climate change on sea turtles, and its mitigation, were identified as a priority research area to inform conservation and management of sea turtles by Hamann *et al.* (2010). Subsequent reviews examined topics on which research has focused at a global scale, and found a growing body of knowledge, predominantly in the terrestrial phase of the sea turtle life cycle (Rees *et al.*, 2016; Patricio *et al.*, 2021). However, recent regional reviews found the impacts and/or mitigation of climate change on sea turtles were not well studied in the northwestern Indian Ocean and the east coast of Africa despite it being regarded by experts as an increasing threat (Al Ameri *et al.*, 2022; van de Geer *et al.*, 2022).

While studies on all the potential impacts of climate change on sea turtles deserve attention, understanding how nesting phenology may be affected is important, as changes in timings of migration and the onset and duration of nesting have the potential to exacerbate or mitigate the impacts of climate change (Pike *et al.*, 2006; Mazaris *et al.*, 2008; Pike, 2009; Weishampel *et al.*, 2010; Patel *et al.*, 2016). For example, the timing of the nesting season has implications for the exposure to climatic conditions and hatching success (Santidrián Tomillo *et al.*, 2012) and offshore currents facilitating hatchling dispersal and in-water survival (Shillinger *et al.*, 2012; Le Gouvello *et al.*, 2020). Hence, we conducted a systematic review of methods used worldwide in published studies examining alterations in sea turtle nesting phenology with climate change, e.g., changes in sea surface temperature, to identify the most common methods of collecting data and the variables examined. The findings of the review can inform and guide researchers in the Indian Ocean and Southeast Asia region (and beyond) who are interested in monitoring potential changes in nesting phenology at their study site/s.

METHODS

Google Scholar was used as the search engine to identify empirical studies, based on primary data, on the research topic. We performed a literature search using the key words/phrases "sea" OR "marine" AND "turtle" AND "nesting phenology". The search was restricted to literature published in peer reviewed journals and professional newsletters (e.g., Indian Ocean Turtle Newsletter, Marine Turtle Newsletter) to date in the 21st century (2000-2021). Results were screened through 1) review of title and abstract; then, 2) review of methods and results for relatedness to the research topic. The reference list of relevant literature was also examined to identify further studies pertinent to the topic that had not been identified through the search on Google Scholar.

After close reading of the texts, common themes and categories of data of interest were identified (emergent coding). Data about the focus species, geographic region, study objective, source and collection frequency of environmental data, metric/s of sea turtle nesting phenology, and finding/s were extracted from each paper and descriptive statistics used to summarise the proportion of studies within each code.

RESULTS AND DISCUSSION

From a total of 407 search results, filtering identified 15 publications that met our criteria and were included in the systematic review: Weishampel *et al*. (2004, 2010), Pike *et al*. (2006), Hawkes *et al*. (2007), Mazaris *et al*. (2008, 2009b, 2013), Pike (2009), Hassine *et al*., (2011), Dalleau *et al*. (2012), Lamont & Fujisaka (2014), Neeman *et al*. (2015), Patel *et al*. (2016), Monsinjon *et al*. (2019), and Valverde-Cantillo *et al*. (2019). All examined changes in nesting phenology in association with SST.

Loggerhead (73.3%) and green (*Chelonia mydas*; 26.7%) turtles were the subject of all but one of the nesting phenology studies examined. No studies considered flatback (*Natator depressus*), hawksbill, Kemp's ridley, or olive ridley turtles (Table 1). Most research was conducted in the northwest Atlantic (53.3%) and Mediterranean (33.3%) regions; this geographic bias led to the species bias, as loggerhead and green turtles predominantly nest in these regions. Only one study, in the southwest Indian Ocean (Dalleau *et al*., 2012), examined the impacts of climate change on nesting phenology in the Indian Ocean basin and no studies from Southeast Asia were found. The geographic and species bias indicates a knowledge gap in understanding the potential for climate change-driven changes in sea turtle nesting phenology in the Indian Ocean region, especially as sea turtles in the northwest Indian Ocean experience extreme nesting and foraging environments (e.g., Pilcher *et al*., 2014; Marshall *et al*., 2020; Chatting *et al*., 2021), key foraging grounds in Southeast Asia seas are threatened by marine heatwaves (Konsta *et al*., 2022), and other regional management units for species in the region are at risk from the threat of climate change or insufficient data is publicly available to predict the risk (Wallace *et al*., 2011). The knowledge gap can also be the result of challenges in collecting data, especially over a long time period, and the scarcity of baseline data for comparison.

Table 1. Sea turtle species and geographic region in studies (n=15) assessing the variation in nesting phenology with sea surface temperature. Totals exceed 100% as some studies examined more than one parameter.

Sea Turtle	% Studies	Region	% Studies
Loggerhead	73.3	Northwest Atlantic	53.3
Green	26.7	Mediterranean	33.3
Leatherback	6.7	East Pacific	6.7
		Southwest Atlantic	6.7
		Southwest Indian	6.7

Of the parameters of nesting ecology investigated, the most common were the start/onset and the length/duration of the nesting season (53.3% each), followed by the median day of the nesting season (46.7%; Table 2). Identifying the date on which the nesting season begins and ends, and calculating the median date, may require few resources and be potentially more accurate than ongoing monitoring of beaches throughout the nesting season to estimate peak nesting date, inter-nesting period, and start of hatchling emergence. Note that Patricio *et al*. (2021) suggests using the 2.5th percentile of the nesting date as a proxy for the commencement of nesting, to avoid any outlying data for populations with seasonal nesting. (The 2.5th percentile is the date before which 2.5% of nesting events occurred.) Researchers should also be aware that these metrics can be impractical for assessing shifts in nesting phenology in populations that have bimodal or year-round nesting (Dalleau *et al*., 2012).

Table 2. Parameter of nesting ecology examined in studies (n=15) assessing variation in nesting phenology with sea surface temperature. Totals exceed 100% as some studies examined more than one parameter.

Parameter Investigated	% Studies
Start/onset of nesting season	53.3
Length/duration of nesting season	53.3
Median day of nesting season	46.7
Peak nesting date	13.3
Length of inter-nesting period	6.7

SST data used in the studies we examined was primarily derived from central data sources (80.0%) at monthly intervals (50.0%) (Table 3). For instance, Pike *et al*. (2006) sourced their SST data from an automated data logger attached to buoy 41009 of the National Data Buoy Center. Similarly, Weishampel *et al*. (2004) obtained SST values from a National Oceanic and Atmospheric Administration (NOAA) buoy (Station 41009). Using environmental data from a central source removes the need for researchers to purchase and place data loggers at individual study sites. Future research could utilise satellite-derived SST data (see O'Carroll *et al*., 2019; Momin *et al*., 2022).

Table 3. Source, interval, and location of sea surface temperature data in studies (n=15) assessing the variation in nesting phenology with sea surface temperature.

Source	% Studies	Interval	% Studies	Location	% Studies
Central data source	80.0	≤60min	20.0	Nesting beach	60.0
Study data logger	20.0	6-12hr	6.7	Foraging grounds	26.7
		Daily	13.3	Both nesting and foraging habitat	13.3
		Weekly	6.7		
		Monthly	53.3		
		Annually	6.7		

Examining SST data from waters adjacent to nesting beaches alone was the most common approach (60.0%) (Table 3), potentially since nesting beaches are known locations and foraging areas for individuals in a nesting population may be broadly distributed geographically. Only two studies (13.3%) used SSTs at both foraging areas and nesting beaches to understand variation in nesting phenology with SSTs at different habitats. Their findings were different, but complementary. Loggerhead turtles in Brazil started their migration in response to environmental cues at foraging areas, which determines the onset of the nesting season (Mosinjon *et al*., 2019), whilst loggerhead turtles in Greece nested earlier after an increase in SST at the nesting site (Patel *et al*., 2016).

The majority of studies assessed potential changes in nesting phenology at only one nesting location (73.3%; Table 4). Data sets across all studies ranged from 1-36 years in length; studies at single locations examined data from a Mean±StDev duration of 16.6±7.3yr (range 4-26yr). This area of research would potentially benefit from broad acceptance of the standards for appropriate baseline data and temporal scale of data needed to determine changes in nesting phenology with appropriate statistical power.

Finally, we emphasise that comparison of findings among studies can be challenging (Patricio *et al*., 2021). The onset of nesting may reflect atypical events (outliers) and the median nesting date can also be ambiguous given that it is affected both by the onset and duration of the nesting season (Mazaris *et al*., 2013) as well as survey effort (Patricio *et al*., 2021). Changes in sea turtle nesting phenology parameters in response to SST has also been found to vary with latitude (Mazaris *et al*., 2013).

Table 4. Number of nesting sites in studies (n=15) assessing the variation in nesting phenology with sea surface temperature.

# Nesting Sites	% Studies
1	73.3
3	13.3
6	6.7
223	6.7

SUMMARY

Sea turtle populations in the Indian Ocean and southeast Asia are threatened by climate change, and some are data deficient on the potential impacts of this threat (see Phillott & Rees, 2021). We have summarised the methods used in worldwide studies that assessed changes in nesting phenology with climate change published from 2000-2021 to inform researchers interested in similar studies at their nesting and/or monitoring sites. Our summary does not imply that the same method(s) would be the most suitable for all locations, but the information we present can be used as a starting point for researchers new to the field of study. We also remind researchers to be cautious and not to assume climate change-induced changes in sea turtle nesting phenology, since reproductive ecology depends on many factors, including resource availability and acquisition, environmental cues at foraging and breeding sites, courtship, population demographics, and geography (Patricio *et al*., 2021).

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PHOTOESSAY

SEA TURTLES IN KUWAIT: A NEW TRACKING STUDY

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In a step considered the first of its kind at the national level, and as part of efforts to preserve wildlife and fulfil its obligations towards international conventions, the Environment Public Authority supervised release of two green sea turtles with satellite transmitters in August 2022. The project is carried out in cooperation with the Kuwait Foundation for the Advancement of Sciences, Kuwait University, Scientific Center Kuwait, Kuwait Environment Lens Team, and Senyar Dive Team.

The goals of the project are multifold. The first is to track the movements of green turtles identify their home ranges and inform development of integrated plans to protect their habitats as nature reserves. Another goal is to determine if human activities concentrated near nesting beaches changes use of the area by turtles and maybe drives them to nest on other beaches or other areas. Educating the public about sea turtles and their natural habitat is another project goal. Hence, the data will be used at local, regional, and international levels to conserve sea turtles and their habitats in accordance with Kuwait's commitments to international treaties on biodiversity.

This photoessay demonstrates the preparation for tracking the first two turtles under this new initiative. Both green turtles were rescued from water cooling tanks in the southern industrial area several months prior and sent to the Scientific Centre of Kuwait where they received veterinary care and were rehabilitated back to full health. Once deemed fully recovered and ready for release, the turtles were fitted with Wildlife Computers' Argos satellite tags (Figure 1). The turtles were then retained overnight to ensure they had adjusted to swimming with the tags on their carapaces.

The next day, in temperature-controlled environmental conditions, the turtles were moved to Qaruh Island for release (Figure 2 and 3). The turtles were released on the cooler sand, close to the water's edge (Figure 4) and immediately swam towards open waters (Figure 5). We hope to remotely track them for up to two years using the attached transmitters.

Figure 1. Turtles were equipped with satellite tags and had small sections of tissue sampled for genetic analyses while under the care and supervision of the Scientific Centre of Kuwait. (Photo credit: ALan F. Rees)

Figure 2. Assembling for the turtle release on Qaruh Island, southern Kuwait. (Photo credit: ALan F. Rees)

Figure 3. The project team, including representatives of the Kuwait Environment Public Authority, Kuwait University, the Scientific Center of Kuwait, the Coast Guard, and others, at the moment of release of the smaller of the two green turtles. (Photo credit: Senyar Dive Team)

Figure 4. A turtle's first encounter with the sea after several months of rehabilitation. (Photo credit: Senyar Dive Team)

Figure 5. The turtles wasted no time in returning to their natural habitats. (Photo credit: ALan F. Rees)

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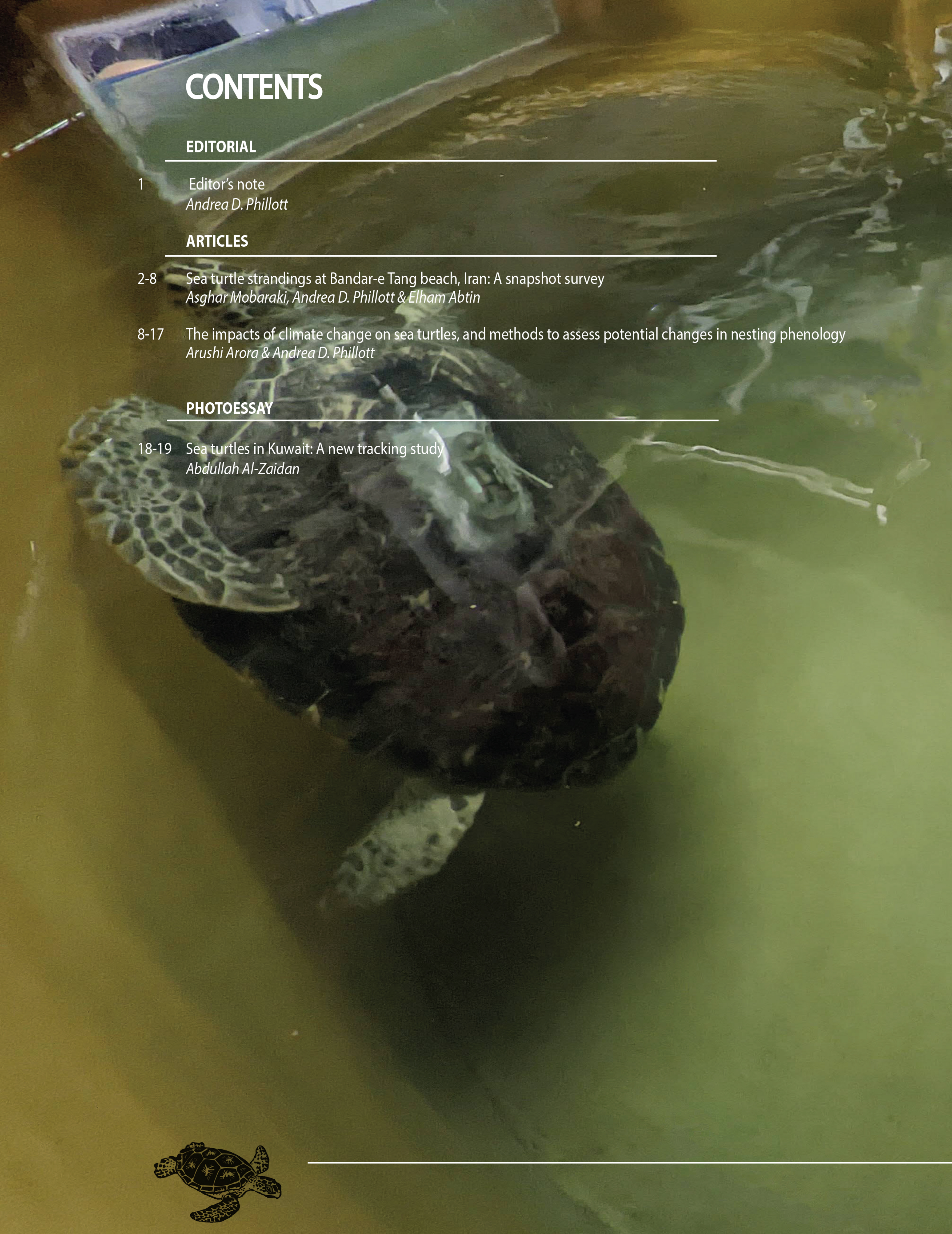

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