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Nesting selection of hawksbill turtles, *Eretmochelys imbricata* (Linnaeus, 1766), in Kepulauan Seribu, Indonesia, in response to sea surface temperatures

Nurhaliza Putri Nabila[1], Mohamad Isnin Noer[1*], Endang Tatang Hidayat[2], and Tessalonica Christianty Andreina[1]

[1]Program Studi Biologi. Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta. Jl Rawamangun Muka, East Jakarta 13220, Jakarta, Indonesia. Tel.: +62-214-894909.

[2]Balai Taman Nasional Kepulauan Seribu. Jl. Salemba Raya No. 9, Lt. III. Jakarta Pusat 10440, Jakarta, Indonesia. Telp/Fax: (021) 3915773

*Corresponding author: mohamadisnin@unj.ac.id

ABSTRAK

*Penyu sisik diklasifikasikan sebagai jenis yang terancam punah secara kritis akibat penurunan populasi yang disebabkan oleh berbagai faktor, termasuk perubahan iklim. Suhu permukaan laut telah berperan signifikan dalam keberhasilan penetasan penyu sisik sebagai spesies poikilotermik; oleh karena itu, pemilihan lokasi sarang yang tepat sangat krusial bagi penyu laut. Tujuan studi ini adalah untuk mengamati pemilihan lokasi bertelur penyu sisik (*Eretmochelys imbricata *Linnaeus, 1766) sebagai respons terhadap suhu permukaan laut (SST) di SPTN II, Kepulauan Seribu, Jakarta, Indonesia. Data SST diperoleh dari citra satelit AQUA-MODIS, sementara indeks hijau berlebih sebagai proxy penutup kanopi diukur menggunakan orthomosaic yang diambil oleh DJI Mavic Pro 3 pada ketinggian 100 m. Hasil menunjukkan bahwa SST di wilayah studi berfluktuasi antara 29,02°C dan 31,5°C, dengan suhu tertinggi tercatat pada September 2024. Tidak terdapat korelasi signifikan antara SST dan lokasi yang dipilih oleh penyu sisik berdasarkan fitur tutupan vegetasi. Namun, tren korelasi antara SST dan fitur tutupan vegetasi menunjukkan fleksibilitas penyu sisik dalam memilih lokasi yang lebih teduh seiring meningkatnya SST. Temuan ini menyoroti pentingnya tutupan vegetasi dalam mitigasi dampak negatif kenaikan suhu di habitat peneluran penyu sisik.*

Kata kunci: Indeks hijau, penyu sisik, perubahan iklim, tutupan kanopi, UAV

ABSTRACT

*Hawksbill turtles are listed as a critically endangered species due to decreasing population caused by various factors, including climate change. Sea surface temperatures have significantly contributed to the hatchling success of hawksbill turtles as poikilothermic species; thus, selecting the proper location to nest is crucial for sea turtles. The purpose of this study was to observe the nest selection of hawksbill turtle (*Eretmochelys imbricata *Linnaeus, 1766) in response to sea surface temperature (SST) in SPTN II, Kepulauan Seribu, Jakarta, Indonesia. SST data were extracted from AQUA-MODIS satellite imagery, while the excess green index as a proxy of canopy cover was quantified using orthomosaics captured by the DJI Mavic Pro 3 at 100 m high. The results showed that SST in the study area fluctuated between 29.02°C and 31.5°C, with the highest temperature recorded in September 2024. There was no significant correlation between SST and sites selected by hawksbill turtles based on vegetation cover features. However, the correlation trend between SST and vegetation cover features indicated the plasticity of hawksbill turtles in selecting more shaded locations as SST increases. This*

finding highlighted the importance of vegetation cover to mitigate the detrimental effects of rising temperatures in hawksbill turtles' nesting habitats.

Keywords: Canopy cover, climate change, green index, hawksbill, UAV

INTRODUCTION

In recent decades, the earth has experienced dramatic climate changes, resulting in significant increases in earth's surface temperatures. This phenomenon is known as global warming, which is caused by many factors, such as greenhouse gas emissions, fossil fuels, industrial activities, deforestation, and other anthropogenic factors. All these factors synchronously contribute to the substantial increase in both land and sea surface temperatures (Keniah, 2023). In the marine environment, global warming would significantly elevate surface temperatures higher than land, as the increase in atmospheric temperatures is due to its nature that absorbs 90% of the heat from the atmosphere (Scott-Buechler & Greene, 2019). The dramatic shift in ocean temperatures would undoubtedly disrupt the natural patterns of weather and climate within this ecosystem (Habibie & Nuraini, 2014).

Global warming is crucial for marine organisms, including sea turtles, since these creatures are strongly dependent on the marine ecosystem as their foraging habitat. The increased sea surface temperature (SST) would alter the abundance and distribution of the resources required by sea turtles. Hawksbill turtles are no exception; this endangered species of marine turtles might be significantly interrupted by the increase in sea surface temperatures. Global warming is likely not only affecting their foraging habitat but also influencing their nesting habitat (Simantiris, 2024), as reported by Fuentes et al. (2009) that sea surface temperature is linked to sand temperature, which are critical for hatching success. Nesting habitat is crucial for hawksbill turtles since their successful emergence is strongly dictated by suitable sites that provide appropriate temperature and protection (Mancino et al., 2023a; Simantiris, 2024). Inappropriate temperatures may have consequences on the survival and development of their hatchlings, including altering the sex ratio (Fuentes et al., 2024). All these responses would contribute to the decreasing population of hawksbill turtles globally (Fuentes et al., 2009).

Marine turtles in general, including hawksbill turtles, have been reported to be capable of modifying their nesting behavior in response to an increase in temperature. This behavioral plasticity is shown in their nesting strategies by choosing a higher place to avoid the risk of sea level rise on their eggs. To mitigate the high exposure to the prevailing temperature, sea turtles have been reported selecting places under vegetation to ensure good incubation for their offspring's development (Kamel, 2013; Stokes et al., 2024). In addition, a study has reported that sea turtles modify their nesting phenology by shifting their nesting periods into the cooler season to maintain optimal temperatures for their offspring.

Vegetation cover is the most cited variable that has been reported so far in studying nesting plasticity of hawksbill turtles in response to climate change. Vegetation cover plays a role in reducing excess heat derived from surface temperatures up to optimal ranges required for eggs to be successfully hatched (Hernández-Cortés et al., 2018). Moreover, a wide range of vegetation cover has been utilized by hawksbill turtles across numerous studies, indicating that

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the site selection behavior is a means to mitigate the detrimental impact of climate change (Kelly et al., 2017; Liles et al., 2015).

Considering the population status of hawksbill turtles, which has been depleting significantly during the recent decade by up to 80%, a study evaluating the impact of sea surface temperatures on the nesting behavior of hawksbill turtles is urgently required (Mortimer & Donnelly, 2008; Nugroho et al., 2017) . One of the nesting habitats that is relatively prone to climate change is regions that consist of a chain of small islands. Small islands are subjected to sea level rise and excess heat, both for land and sea surface temperatures. Thus, a study carried out on a small island would gain understanding about the nesting behaviour of hawksbill turtles. Here, we carried out a study in Kepulauan Seribu, a region composed of a chain of small islands that is ideal as a model for studying the impact of sea surface temperatures on the nesting behavior of hawksbill turtles (Noer et al., 2024). The islands within Kepulauan Seribu are characterized by low-lying islands (Setiawati et al., 2023) which some have undergone significant vegetation degradation.

METHODOLOGY

Study Sites

The study was carried out on the island of Kayu Angin Bira and Peteloran Timur, located within the core zone of the national park boundary. As islands under the protection of the National Parks agency, these two islands are unoccupied areas with restricted access to human activities. Kayu Angin Bira and Peteloran Timur were chosen as locations for this study since the number of nesting activities was quite high during several years (Noer et al., 2024). The study was conducted from July to October 2024, coinciding with the dry season.

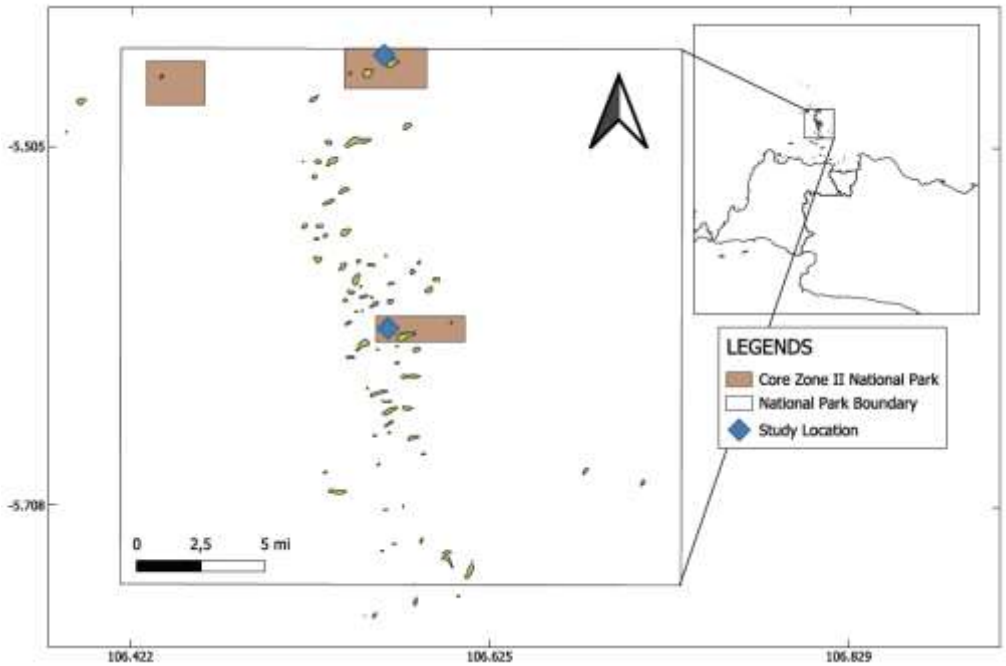

FIGURE 1. Map of two islands used in studying the nest selection of hawksbill turtles.

Nest surveys

We conducted routine patrols and monitoring in Kayu Angin Bira and Peteloran Timur, ranging from three to four times a month, with approximately a 1-week interval between events.

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Trained and expert staff of the National Park Authority were in charge of conducting nest detection. We recorded the precise location using *Avenza* maps and checked cautiously for all detected nests to avoid spatial deviation due to signal issues.

Drone survey

The *DJI mavic Pro* was used to quantify nest attributes in this study. Flight configurations were set following procedures. The drone was flown 100 meters high above the ground and set to capture images automatically every 2 seconds using normal speed (15m/s). The drone flight height set to ensure minimum disturbance to animals (Duporge et al., 2021). This configuration would produce 12 MP images with an overlapping rate of more than 70%. Since most islands are small, the drone was programmed to capture the entire island area. We consistently collected spatial features of all islands between 09:00 and 12:00 on the day. The island profiles were captured once at the beginning of the survey periods.

Drone image processing and analysis

All the images collected by the DJI Mavic Pro were converted into high-resolution true color orthomosaics using WebODM. Five ground control points from each island were used to adjust the spatial position of generated orthomosaics. Excess Green Index (EGI) used as an indicator of vegetation cover was extracted by splitting red, green, and blue rasters from RGB images using r.rgb tool in QGIS. The EGI raster of Kayu Angin Bira and Peteloran Timur was then used as a base raster to characterize the vegetation cover of all recorded nests. We applied a 5 x 5m square buffer around each nest to represent the vegetation cover of each nest. The zonal statistic plugin in QGIS was used to handle this task by setting the mean value of EGI of all nests.

Sea surface temperature extraction

Sea surface temperature (SST) was used as an indicator of local temperature changes during the study period. This temperature information was acquired from the AQUA-MODIS satellite raster accessed at https://oceancolor.gsfc.nasa.gov/l3/. The AQUA-MODIS provides high resolution raster that can run properly in reading temperature information in a small region. Temperature information was extracted according to the time when the nest was built to accurately characterize the response of hawksbill turtles toward ongoing temperatures. Zonal statistic plugin was performed to extract temperature data from AQUA-MODIS raster by applying the polygon of the National Park boundary.

Data Analysis

We run Kendall time series analysis to determine significant temperature variation among times when nests were built. All the temperature data recorded were also presented in descriptive statistics to estimate the minimum and maximum temperatures observed in these nesting grounds. This finding could provide information about climate change warnings in Kepulauan Seribu in general. Nesting behavior of hawksbill turtles was evaluated based on a theoretical approach by correlating the ongoing temperature when the nests were built to the vegetation cover of selected sites. We performed non-linear regression to determine the correlation between ongoing sea surface temperatures and the EGI score of selected sites.

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RESULTS AND DISCUSSION

Sixteen nests were recorded in this study in both Peteloran Timur and Kayu Angin Bira, however, the number of nests collected from Peteloran Timur was relatively higher than from Kayu Angin Bira. The high number of nests documented in Peteloran Timur is likely determined by the distance to the mainland of Jakarta, high elevation, and good accessibility to reach the preferred sites for nesting. The nest distribution map indicated that nest selection was random in Peteloran Timur (Figure 2). As indicated in Figure 3, our findings showed that temperatures during our study period have experienced significant fluctuations (tau = 0.536, $p < 0,05$), falling between 29,02°C-31,5°C. The lowest temperature was recorded on August 12 at 29,02 °C, while the highest was on September 20 at 31,5°C. The temperature data supports the representativeness of our study period to evaluate nesting behavior of hawksbill turtles, since the data includes quite extreme high temperatures (Mrosovsky et al., 1992).

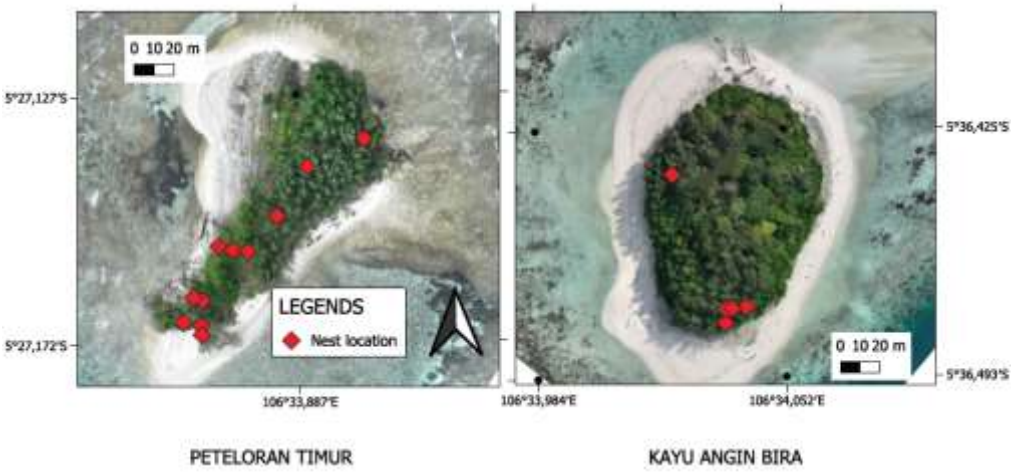

FIGURE 2. Distribution of sixteen nests in Kayu Angin Bira and Peteloran Timur

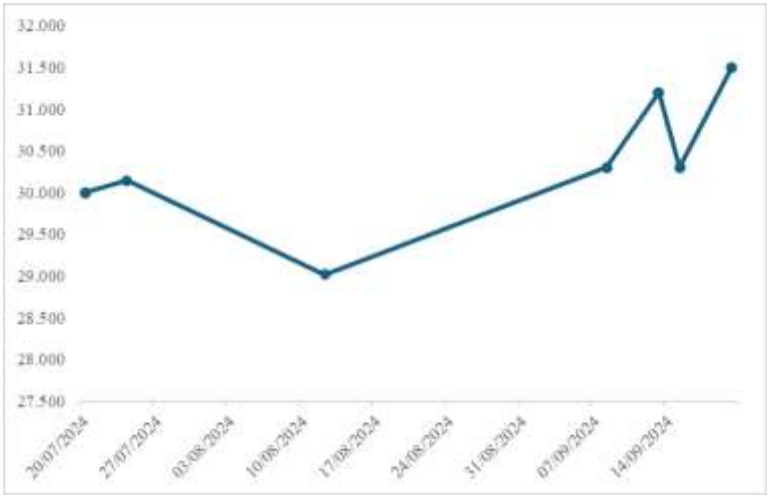

FIGURE 3. Temperature variation was recorded at seven different times when the nests were built. The study period covers a substantial variation of temperature up to 2^0C between nesting occurrences.

We found a positive correlation, but not statistically significant, between sea surface temperature and EGI score ($R = 0,41$; $p > 0,05$), as indicated in Figure 4. However, the correlation trend built from non-linear regression indicated that adaptation as a response to change in temperature was likely present.

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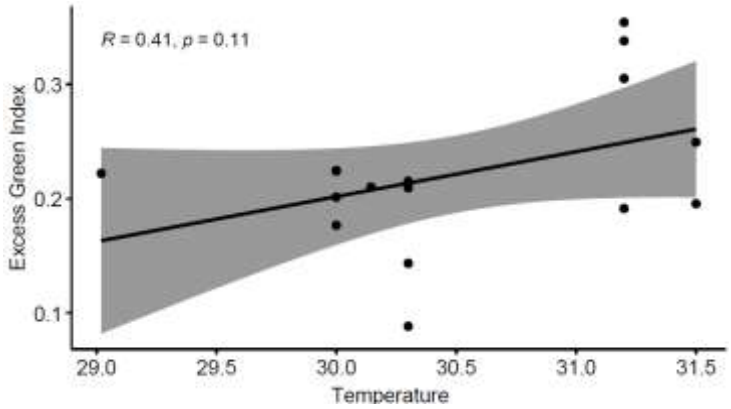

FIGURE 4. Non-linear regression between sea surface temperature and EGI score for sixteen recorded nests in this study.

Sea surface temperatures are subjected to fluctuations across space and time, the variations can even occur between days and depend primarily on prevailing conditions in a particular region (Azizah & Wibisana, 2020; Hamuna et al., 2018). This variation is likely caused by both land surface temperatures and heat radiation from sea surface temperatures that absorb up to 90% of heat from the atmosphere (Scott-Buechler & Greene, 2019). This phenomenon is more prevalent in small islands where the island's temperature is dictated by its surrounding environment. Thus, studying the impact of sea surface temperature on small islands is crucial in providing baseline information to cope with climate change. Based on our findings, temperature data during 3 months of study demonstrated significant fluctuations with a delta between nesting events up to 2 ^{0}C. This temperature variation probably would be higher within a larger extent of the survey period, encompassing extreme dry seasons. However, the increase of 2 ^{0}C is seemingly catastrophic for some sensitive organisms, including marine turtles (Flores-Aguirre et al., 2023; Mrosovsky et al., 1992; Wood & Bjorndal, 2000).

Temperature is crucial for sea turtles, especially during egg development, due to its role in influencing metabolism and hormonal regulation of sea turtles' offspring (Flores-Aguirre et al., 2023; Mickelson & Downie, 2010; Mrosovsky et al., 1992). In general, the optimum temperature for the survival of many marine organisms ranges from 18°C -30°C (Daeng & Tangke, 2023). Our study reported that on at least one occasion, temperature has attained 31°C (1 degree higher than expected), thus, concerns about rising temperatures toward marine organisms in general and specifically the hawksbill turtles' nesting ground deserve to be seriously considered. A previous study demonstrated that the slight increase in temperature during egg development is adequate for skewing the male-female ratio of sea turtles (Tanabe et al., 2020).

Considering the significance of temperature on egg development and offspring survival, female sea turtles must carry out adaptation as mitigation to reduce the fatal consequences of changing temperature (Fuentes et al., 2024). Adaptation could be done by shifting the nesting activities to a more suitable season. However, this adaptation is likely not quite effective since the duration and intensity of the suitable season were not always broadly available. Many studies have reported that hawksbill turtles select a high degree of vegetation cover as their nesting location across space and time. This information could be assumed as a mechanism implemented by sea turtles to deal with variation in temperatures. For sea turtles in a hot

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climate, selecting sites that provide a substantial degree of shading could potentially regulate temperature during incubation, thus reducing the risk of hatchling failures (Kiss et al., 2024).

Our findings demonstrated the plasticity of hawksbill turtles in selecting locations to deposit their eggs according to the prevailing temperature conditions. Hawksbill turtles selected open beaches or sites with lower vegetation cover when the temperature during the nesting period was relatively low. Otherwise, they would select locations provided with a high degree of vegetation cover. Overall, analysis of correlation trends suggests that some hawksbill turtles have adapted to rising temperatures by selecting shaded nesting sites indicated by EGI scores. However, to better understand the significance of these correlations, further research using more comprehensive and extensive datasets is needed. Beyond data completeness, various environmental factors may also influence this nesting behavior, including predation, sea level rise, beach morphology, microbial infections (Veelenturf et al., 2022), sand depth, and moisture (Flores-Aguirre et al., 2023), and coastal erosion events (Costa et al., 2023). These challenges necessitate complex adaptive strategies to ensure the successful incubation and hatching of eggs. Common strategies include selecting nest locations under vegetation cover (Kiss et al., 2024), in open areas (Ibrahim et al., 2016), or at higher elevations (Whitesell et al., 2022)."

CONCLUSIONS

This study highlights the behavioral plasticity of hawksbill turtles (*Eretmochelys imbricata*) in response to rising sea surface temperatures (SST) within SPTN II, Kepulauan Seribu, Indonesia. Although no statistically significant correlation was found between SST and nest site selection based on vegetation cover, the observed trend suggests a tendency for turtles to choose more shaded nesting locations as SST increases. These findings underscore the potential role of vegetative cover in mitigating thermal stress and emphasize the ecological importance of maintaining coastal vegetation to support the reproductive success of this critically endangered species amidst ongoing climate change.

AUTHOR CONTRIBUTIONS

MIN: research ideas and conception, statistical analysis, writing final manuscripts, NPZ: writing manuscript and collecting data, ETH: data collection and methodology, TCA: satellite data analysis

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CONFLICTS OF INTEREST STATEMENT

The authors declare no conflict of interest

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REFERENCES

Azizah, A., & Wibisana, H. (2020). Analisa temporal sebaran suhu permukaan laut tahun 2018 hingga 2020 dengan data citra Terra Modis. *Jurnal Kelautan: Indonesian Journal of Marine Science and Technology*, *13*(3), 196–205. https://doi.org/10.21107/jk.v13i3.7550

Costa, L. L., Bulhões, E. M. R., Caetano, J. P. A., Arueira, V. F., de Almeida, D. T., Vieira, T. B., Cardoso, L. J. T., & Zalmon, I. R. (2023). Do coastal erosion and urban development threaten loggerhead sea turtle nesting? Implications for sandy beach management. *Frontiers in Marine Science*, *10*, 1242903. https://doi.org/10.3389/fmars.2023.1242903

Daeng, R. A., & Tangke, U. (2023). Hubungan Suhu Permukaan Laut dan Hasil Tangkapan Ikan Teri di Perairan Teluk Dodinga. *Jurnal Ilmiah Agribisnis Dan Perikanan (Agrikan UMMU-Ternate) Vol*, *16*(1). https://doi.org/10.52046/agrikan.v16i1.1582

Duporge, I., Spiegel, M. P., Thomson, E. R., Chapman, T., Lamberth, C., Pond, C., Macdonald, D. W., Wang, T., & Klinck, H. (2021). Determination of optimal flight altitude to minimise acoustic drone disturbance to wildlife using species audiograms. *Methods in Ecology and Evolution*, *12*(11), 2196–2207. https://doi.org/10.1111/2041-210X.13691

Flores-Aguirre, C. D., Díaz-Hernández, V., Moreno, D. A., & de la Cruz, F. R. M. (2023). Effect of moisture, temperature, and maternal influence on the hatching, phenotype, and performance of hawksbill turtles *Eretmochelys imbricata*. *Endangered Species Research*, *50*, 217–234. https://doi.org/10.3354/esr01229

Fuentes, M., Maynard, J. A., Guinea, M., Bell, I. P., Werdell, P. J., & Hamann, M. (2009). Proxy indicators of sand temperature help project impacts of global warming on sea turtles in northern Australia. *Endangered Species Research*, *9*(1), 33–40. https://doi.org/10.3354/esr00224

Fuentes, M., Santos, A. J. B., Abreu-Grobois, A., Briseño-Dueñas, R., Al-Khayat, J., Hamza, S., Saliba, S., Anderson, D., Rusenko, K. W., & Mitchell, N. J. (2024). Adaptation of sea turtles to climate warming: Will phenological responses be sufficient to counteract changes in reproductive output? *Global Change Biology*, *30*(1), e16991. https://doi.org/10.1111/gcb.16991

Habibie, M. N., & Nuraini, T. A. (2014). Karakteristik dan tren perubahan suhu permukaan laut di Indonesia periode 1982-2009. *Jurnal Meteorologi Dan Geofisika*, *15*(1). https://doi.org/10.31172/jmg.v15i1.171

Hamuna, B., Tanjung, R. H., & MAury, H. (2018). Kajian kualitas air laut dan indeks pencemaran berdasarkan parameter fisika-kimia di Perairan Distrik Depapre, Jayapura. *Jurnal Ilmu Lingkungan*, *16*(1), 35–43. https://doi.org/10.14710/jis.%25v.%25i.%25Y.633-644

Hernández-Cortés, J. A., Núñez-Lara, E., Cuevas, E., & Guzmán-Hernández, V. (2018). Natural beach vegetation coverage and type influence the nesting habitat of hawksbill turtles (*Eretmochelys imbricata*) in Campeche, Mexico. *Chelonian Conservation and Biology*, *17*(1), 94–103. https://doi.org/10.2744/CCB-1280.1

Kamel, S. J. (2013). Vegetation cover predicts temperature in nests of the hawksbill sea turtle: implications for beach management and offspring sex ratios. *Endangered Species Research*, *20*(1), 41–48. https://doi.org/10.3354/esr00489

Kelly, I., Leon, J. X., Gilby, B. L., Olds, A. D., & Schlacher, T. A. (2017). Marine turtles are not fussy nesters: a novel test of small-scale nest site selection using structure from motion beach terrain information. *PeerJ*, *5*, e2770. https://doi.org/10.7717/peerj.2770

Keniah, J. (2023). Global warming: A Comprehensive examination. *International Journal of Science and Society*, *5*(4), 2023. https://doi.org/10.54783/ijsoc.v5i4.771

Kiss, I., Erdélyi, G., & Szabó, B. (2024). Nest site selection and fidelity of European pond turtle (*Emys orbicularis*) population of Babat Valley (Gödöllő, Hungary). *Frontiers in Zoology*, *21*(1), 20. https://doi.org/10.1186/s12983-024-00541-3

DOI: 10.21009/bioma.v21i1.54401

Liles, M. J., Peterson, M. J., Seminoff, J. A., Altamirano, E., Henríquez, A. V, Gaos, A. R., Gadea, V., Urteaga, J., Torres, P., & Wallace, B. P. (2015). One size does not fit all: importance of adjusting conservation practices for endangered hawksbill turtles to address local nesting habitat needs in the eastern Pacific Ocean. *Biological Conservation*, *184*, 405–413. https://doi.org/10.1016/j.biocon.2015.02.017

Mancino, C., Hochscheid, S., & Maiorano, L. (2023a). Increase of nesting habitat suitability for green turtles in a warming Mediterranean Sea. *Scientific Reports*, *13*(1), 19906. https://doi.org/10.1038/s41598-023-46958-4

Mancino, C., Hochscheid, S., & Maiorano, L. (2023b). *Some like it (very) hot: the effects of climate change on nesting distribution of green turtles in the Mediterranean Sea*. Research Square Platform LLC. https://doi.org/10.21203/rs.3.rs-3342262/v1

Mickelson, L. E., & Downie, J. R. (2010). Influence of incubation temperature on morphology and locomotion performance of Leatherback (*Dermochelys coriacea*) hatchlings. *Canadian Journal of Zoology*, *88*(4), 359–368. https://doi.org/10.1139/Z10-007

Mortimer, J. A., & Donnelly, M. (2008). *Eretmochelys imbricata. The IUCN Red List of Threatened Species 2008: e. T8005A12881238*. https://www.iucnredlist.org/species/pdf/12881238/attachment

Mrosovsky, N., Bass, A., Corliss, L. A., Richardson, J. I., & Richardson, T. H. (1992). Pivotal and beach temperatures for hawksbill turtles nesting in Antigua. *Canadian Journal of Zoology*, *70*(10), 1920–1925. https://doi.org/10.1139/z92-261

Noer, M. I., Prakoso, Y. A., & Sedayu, A. (2024). Assessing the consistency of hawksbill nest selection between two nesting habitats in Kepulauan Seribu, Jakarta, Indonesia: Implication for conservation practices. *AIP Conference Proceedings*, *2982*(1). https://doi.org/10.1063/5.0183049

Nugroho, A. D., Redjeki, S., & Taufiq-SPJ, N. (2018). Studi Karakteristik Sarang Semi Alami Terhadap Daya Tetas Telur Penyu Hijau (Chelonia mydas) di Pantai Paloh Kalimantan Barat. *Journal of Marine Research, 7*(1), 42-48. https://doi.org/10.14710/jmr.v7i1.25886

Scott-Buechler, C. M., & Greene, C. H. (2019). Role of the ocean in climate stabilization. *Bioenergy with Carbon Capture and Storage*, 109–130. https://doi.org/10.1016/B978-0-12-816229-3.00006-5

Setiawati, M. D., Chatterjee, U., Djamil, Y. S., Alifatri, L. O., Nandika, M. R., Rachman, H. A., Supriyadi, I. H., Hanifa, N. R., Muslim, A. M., & Eguchi, T. (2023). Seribu islands in the megacities of Jakarta on the frontlines of the climate crisis. *Frontiers in Environmental Science*, *11*, 1280268. https://doi.org/10.3389/fenvs.2023.1280268

Simantiris, N. (2024). The impact of climate change on sea turtles: Current knowledge, scientometrics, and mitigation strategies. *Science of The Total Environment*, 171354.

Stokes, H. J., Esteban, N., & Hays, G. C. (2024). Nest site selection in sea turtles shows consistencies across the globe in the face of climate change. *Animal Behaviour*, *208*, 59–68. https://doi.org/10.1016/j.anbehav.2023.12.001

Tanabe, L. K., Ellis, J., Elsadek, I., & Berumen, M. L. (2020). Potential feminization of Red Sea turtle hatchlings as indicated by in situ sand temperature profiles. *Conservation Science and Practice*, *2*(10), e266. https://doi.org/10.1111/csp2.266

Whitesell, M. J., Hunter, E. A., Rostal, D. C., & Carroll, J. M. (2022). Direct and indirect pathways for environmental drivers of hatching success in the loggerhead sea turtle. *Marine Ecology Progress Series*, *701*, 119–132. https://doi.org/10.3354/meps14197

Wood, D. W., & Bjorndal, K. A. (2000). Relation of temperature, moisture, salinity, and slope to nest site selection in loggerhead sea turtles. *Copeia*, *2000*(1), 119. https://doi.org/10.1643/0045-8511(2000)2000[0119:ROTMSA]2.0.CO;2

DOI: 10.21009/bioma.v21i1.54401