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Foraging habitat characterization of green sea turtles, *Chelonia mydas*, in the Cenderawasih Bay, Papua, Indonesia: Insights from satellite tag tracking and seagrass survey

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Abstract. *Tapilatu RF, Wona H, Mofu B, Kolibingso D, Alzair N, Erdmann M, Marunaya B. 2022. Foraging habitat characterization of green sea turtles,* Chelonia mydas*, in the Cenderawasih Bay, Papua, Indonesia: Insights from satellite tag tracking and seagrass survey. Biodiversitas 23: 2783-2789.* The distribution area of green turtles is not yet known in Cenderawasih Bay. On 20 November 2020, two satellite transmitters were attached to two female green turtles (*Chelonia mydas* Linnaeus, 1758) on Kalilemon, Southwest Cenderawasih Bay, Papua Province, Indonesia. Kalilemon area and Mangga Island as part of Kwatisore waters are the major foraging areas for this species and are under threat of turtle opportunistic poachers. The results show that the two turtles (Mary and Nona) dispersed and used limited but consistent and different foraging grounds during the tracking period through the satellite tags between November 2020-April 2021 at Mangga Island and Kalilemon. The composition of seagrass at both stations consisted of the same five species belonging to the families Cymodoceae and Hydrocharitaceae, with relatively different qualitative abundances. Overall, the mean chlorophyll-a content during the study period from November 2020-April 2021 ranged from 0.25-0.55mg/m^3 at both foraging grounds (Mangga Island and Kalilemon). The mean SST during the study period ranged from 30.61-31.77°C in both locations. Before the next tracking attempt, more data on seasonal foraging and nesting activities are required. The result of this research is vital to determine the foraging grounds for green turtles related to the seagrass species with its abundance and key environmental factors in the management and conservation of sea turtles in the Cenderawasih Bay area.

Keywords: Chlorophyll-a, foraging ground, green turtle, Kalilemon, Mangga, Satellite transmitter, SST

INTRODUCTION

Cenderawasih Bay National Park (CBNP), Papua, Indonesia, has a coastline of ±500 km and is located at coordinates 134°06'-135°10'E and 01°43'-03°22'S. CBNP has an area of about 1,453,500ha, consisting of 68,000ha of land covering 12,400ha (0.85%) of the coast, 55,800ha (3.84%) of land on a group of islands, and an ocean of 1,385,300ha composed of over 80,000ha (5.5%) of coral reefs and an ocean area of 1,305,300ha (89.8%) (TNTC 2022). Cenderawasih Bay has 1,000 species of fish, and there are various types of mollusks (Tapilatu et al. 2021), mammals, seabirds, and marine reptiles (TNTC 2022). Sea turtles are one type of animal that can be found in Cenderawasih Bay due to the presence of natural habitats such as coral reefs, seagrass beds and sandy beaches (Rahayu et al. 2016; Tapilatu et al. 2017). Four of the seven turtle species in the world distribute in Cenderawasih Bay and the Bird's Head Seascape (BHS) in general (Mangubhai et al. 2012; Tapilatu et al. 2017). The four turtle species are the green turtle (*Chelonia mydas* Linnaeus, 1758), hawksbill turtle (*Eretmochelys imbricata* Linnaeus, 1766), olive-ridley turtle (*Lepidochelys olivacea* Eschscholtz, 1829), and leatherback turtle (*Dermochelys coriacea* Vandelli, 1761). All are listed as vulnerable to extinction, threatened, or critically endangered according to the IUCN Red List of Threatened Species (IUCN 2021).

Green turtles are distributed throughout Bird's Head Seascape and Cenderawasih Bay, but generally remain in coastal waters where, presumably, they inhabit shallow water and foraging areas. Nesting has been documented in multiple islands of Cenderawasih Bay (Tapilatu et al. 2017), and also on the mainland of Bird's Head surrounding Cenderawasih Bay, where the majority of nesting occurs on Waurundi Island (Tapilatu et al. 2017), but little is known or quantified for the island and remainder of the Bird's Head - Papua coast. Green turtle nesting is primarily reported for Piai and Sayang Islands-Raja Ampat (Tapilatu and Ballamu 2015), Venu Island in Kaimana (Tapilatu et al. 2017, 2020), Berau bay (Kahn et al. 2006), and Mapia Atoll (Erdmann and Tapilatu 2019). Unfortunately, there are no ongoing monitoring programs at other sites to provide estimates of annual nester abundance. Green turtles are also reported to nest in low numbers along the north coast of Bird’s Head (Tapilatu 2017; Tapilatu et al. 2017).

Historically, green turtle populations in Papua were much larger than those today (Tapilatu et al. 2017), and seagrass systems in areas such as the Cenderawasih Bay likely existed abundantly as feeding habitats for green turtle and dugong. The main threats faced by sea turtles in this area include hunting and trading eggs and body parts, damage to nesting habitat due to development in coastal areas, and threats at sea from fishing activities (Tapilatu et al. 2017). Many community members in this area hunt turtle eggs for sale and consumption, even though marine turtles are protected animals in Law Number 5 of 1990 concerning Conservation of Biological Natural Resources and Their Ecosystems. Hunting for turtles is carried out to take their carapace and make accessories such as bracelets, and pendants, until they are preserved for display (Fukuda et al. 2012; Febrianto et al. 2020). This greatly affects the turtle population in this area, so awareness activities need to be carried out before all turtle species scattered in these waters are drastically reduced and even no longer found.

Knowledge about the movement patterns of green turtles is currently still very minimal in the Bird's Head Seascape (BHS) area. Research on turtle movement patterns in the Bird's Head Seascape (BHS) has been carried out intensively at the nesting beaches of Jamursba Medi and Wermon for leatherback turtles (Benson et al. 2011, 2015; Bailey et al. 2012; Seminoff et al. 2012), a few olive ridley turtles (Doi et al. 2019), the nesting beaches of Piai Island and Sayang in Raja Ampat for green turtles (Gearheart 2005). Apart from Papua, Indonesia, studies on the movement of green turtles were also carried out in several other areas in Indonesia and Papua New Guinea. Therefore, this research was carried out in the distribution area of green turtles in Cenderawasih Bay to add to the scientific repertoire of green turtle movements in the Bird's Head Seascape area. The Argos satellite tracking can provide key data for movement patterns and conservation of *C. mydas*. Tracking individuals via the Argos satellite system can provide excellent-scale analysis of the pelagic movements of this species that regularly emerges at sea level for breathing, enabling identification of feeding areas, breeding areas, and migration pathways. This more locally-restricted movement assessment is conducted at a sub-level of Regional Management Units, or RMUs. The RMU framework is key to the challenge of managing sea turtle populations in protection units above the nesting population level, but below the species level, within local and regional stakeholders that perhaps on independent evolutionary pathways. The current recognized Regional Management Unit of green sea turtles in Cenderawasih Bay is the West Central Pacific Ocean (IUCN-SSC MTSG 2022). A clear understanding of local distribution is necessary to develop targeted and prioritized management and conservation action. This study will serve as the basis for developing a focused management strategy for green turtle conservation at Cenderawasih Bay.

Previous efforts to characterize habitats for widely dispersed pelagic organisms have been hindered by a lack of positional, synoptic, and biologically relevant environmental data. However, with recent advances in technology, particularly satellite-mediated tagging and accessibility to various environmental data products through remote sensing, more information is now available about the distribution and movement of individuals and their exposure to important environmental variables (Seminoff et al. 2012). We have tagged two wild-caught female green sea turtles in Kalilemon (Table 1) in the south of Cenderawasih Bay National Park and tracked them with Argos-linked satellite tags since November 2020 via the collaborative efforts of Kwatisore marine conservation group. Sets of this satellite tag dataset have been used to explore their exposure to the characterization of foraging habitat and oceanographic conditions (Sea Surface Temperature, SST, and Chlorophyll-a). In this study, we inventoried seagrass species naturally in areas of seagrass distributions where sat-tagged green sea turtles distribute to understand two components. (i) The diversity of the seagrass; (ii) Oceanographic factors where green turtles were present and presumably fed seagrasses in the area.

MATERIALS AND METHODS

Study site

This study was conducted at the Kwatisore Customary Sea Area (Figure 1), from November 2020 to April 2021. Kwatisore waters are one of the areas in the Cendrawasih Bay National Park (CBNP), Papua, Indonesia. We surveyed the seagrass at two sites within the customary area: Mangga Island (3°09′39″S 134°53′40″E) and Kalilemon (3°13′20″S 134°57′58″E).

Satellite tracking

Initial studies on satellite tags (sat-tag) on sea turtles focused on breeding females because they come ashore to nest, allowing individuals to be restrained relatively simply for tag attachment. However, currently, the development of sea turtle capturing methods makes it possible for research to be carried out on both adult and immature turtles, especially male turtles, which typically stay at sea (Hays and Hawkes 2018). Therefore, turtles have been outfitted with Wildlife Computers (Redmond, WA, USA) model SPOT6 Argos-linked satellite transmitters attached to the carapace. SPOT tags are highly versatile, cost-effective satellite transmitting tags designed for tracking horizontal movements of free-ranging marine animals such as sea turtles (Wildlife Computers 2021). Here, we assessed the distribution of two wild-caught (one mature and one immature) female green sea turtles tagged in this study, as summarized in Table 1.

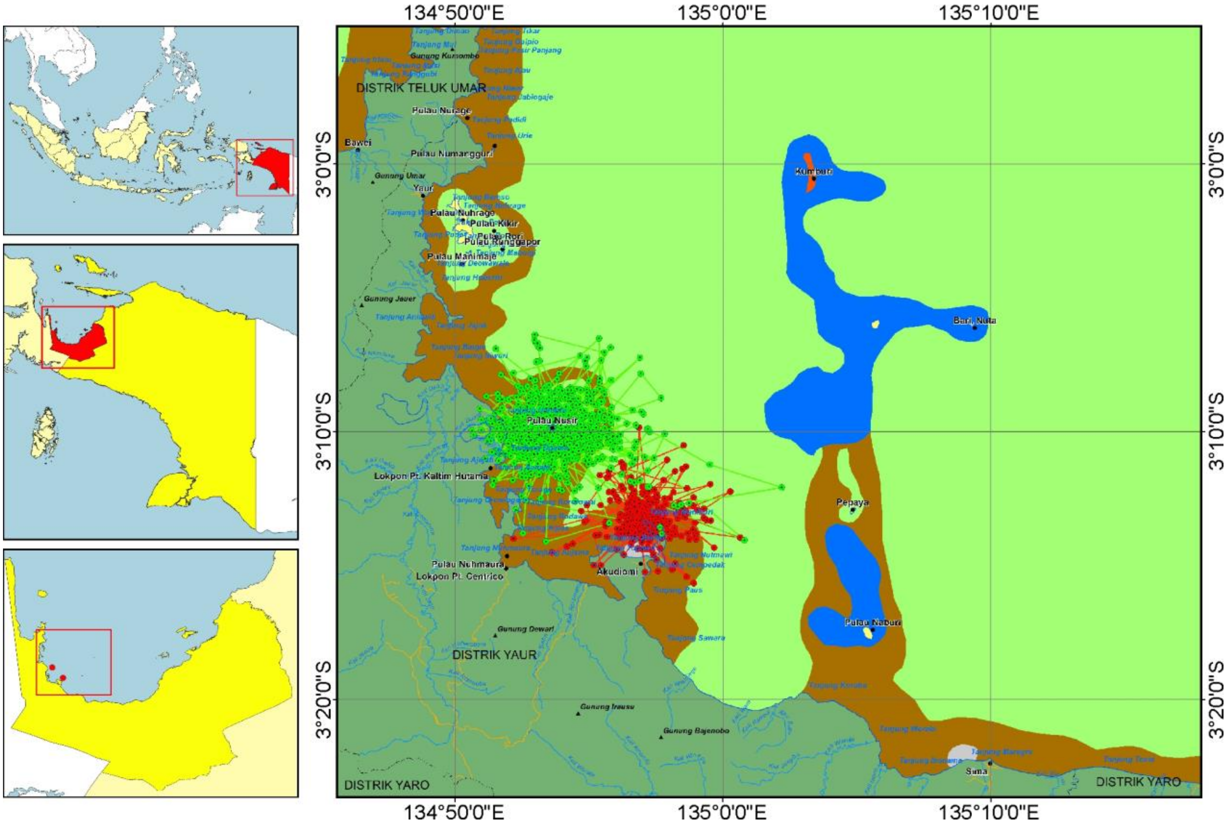

Figure 1. Map of study area showing Southwest of Cenderawasih Bay, Papua, Indonesia and foraging distribution of Nona (*green*) and Mary (*red*) dots and lines

Table 1. Biodata of the two female green turtles sat-tagged in Kalilemon, Papua, Indonesia

Turtle name	Date and hour of tagging	Location (Lat, Long)	Behavior when first seen	CCL (cm)	PTT/ Argos-ID
Mary	20/11/2020, 10.20 am	03º13’43.44”S, 134º57’43.76”E	Logging	54	177530/18U1475
Nona	20/11/2020, 11.40 am	03°09'49.9"S, 134°53'38.9"E	Logging	47	177531/18U1476

Only high-resolution position data were stored. The position data show when sat-tagged turtles stay on the surface and are visually shown. When at the surface, SPOT tags send out short transmissions to the Argos satellite system. Consecutive transmissions received in a single satellite pass are used to calculate the location of the transmitter. Locations are available in near-real-time with accuracies as high as 250 meters. Global coverage by the Argos system allows animals to be tracked over long distances and in remote areas. We would see a live map of sea turtle tracks, with positions color-coded by the time since deployment (Wildlife Computers 2021).

Seagrass surveys

Seagrass data collection was carried out at two stations. Station 1 is on the coast of Mangga Island, and station 2 is on the Kalilemon Coast (Figure 1). Both stations have located the Southwest of Cenderawasih Bay. We inventoried seagrasses by snorkeling at a depth of 1-2 m randomly three times on Mangga Island and four times in Kalilemon. Each snorkeling was about 30 minutes, including taking photos of seagrasses encountered. In addition, we qualitatively categorized abundance of each species of seagrass based on video recording during snorkeling (Stoner and Lewis III 1985).

Environmental data products

To understand the seagrass distribution in relation to the oceanographic condition, this study used two oceanographic parameters that consist of chlorophyll-a and sea surface temperatures (SSTs) as supporting data. These two parameters were selected because the role in influencing seagrass growth is very important. In addition, these two parameters also have an unstable condition, and these values would change periodically in a short time.

Chlorophyll-a is one of the parameters that really determines primary productivity in the sea. In addition, chlorophyll-a is a likely key variable for pelagic habitat since it may indicate forage availability for sea turtles. The distribution and high and low concentrations of chlorophyll-a are closely related to oceanographic conditions of waters. The data collected in this study is from the website of the data provider Ocean color and literature studies. SST and chlorophyll-a image data were obtained from the Aqua satellite MODIS level 3 with 4 km x 4 km (pixel) resolution with image between November 2020 and April 2021 (6 months). Chlorophyll-a and SSTs image data were obtained from the official NASA website (http://oceancolor.gsfc.nasa.gov). After both data were collected, corrections were made for visualizing the distribution of chlorophyll-a and SSTs.

RESULTS AND DISCUSSION

Foraging grounds

The results show that the two turtles (Mary and Nona) dispersed and used limited but consistent and different foraging grounds during the tracking period through the sat-tags between November 2020-April 2021 (Figure 1). The Nona turtle spreads around the Mangga and Nusir islands and has a longer tracking point and period (November 2020-April 2021) than the Mary turtle distributes around Kalilemon and has a shorter tracking point and period (November 2021-January 2021) (Figure 1).

Substrate and seagrass

The observations of substrate particles showed that the sand substrate fraction dominated the turtle's distribution at both locations, while the mud or clay fractions only made up a small part. The substrate in both sites comprises calcium carbonate sediments colonized by mixed assemblages of seagrasses.

The composition of seagrass at both stations consisted of the same five species belonging to the families Cymodoceae and Hydrocharitaceae, with relatively different qualitative abundances (Table 2). There are two species in the family of Cymodoceae, namely *Cymodocea rotundata* Asch. & Schweinf. and *Halodule uninervis*, (Forssk.) Boiss. which have a higher abundance than other species at both stations.

Oceanographic parameters (Chlorophyll-a and Sea Surface Temperatures, SST)

Overall, the mean chlorophyll-a content during the study period from November 2020 to April 2021 ranged from 0.25-0.54mg/m^3 in Mangga Island, the lowest during the period between February and April 2021 and the highest in December 2020. Chlorophyll-a content ranged from 0.23-0.55mg/m^3 in Kalilemon, with the lowest content in February 2021, and the highest was the same as on Mangga Island in December 2020 (Table 3). The mean SST during the study period ranged from 30.61-31.77ºC on Mangga Island, with the lowest in November 2020 and the highest in April 2021. In contrast, the mean SST in Kalilemon ranged from 30.89 to 31.73ºC, with the lowest in November 2020, similar to Mangga Island, and highest in December 2020 (Table 3).

Discussion

Foraging areas of green turtles at Cenderawasih Bay have been derived from satellite telemetry of two females from Kwatisore area in the southwest of Cenderawasih Bay (Figure 1). Since only two females green sea turtles were sat-tagged during this study, thus containing limited data, the results do not reflect green sea turtle movements more widely in Cenderawasih Bay and neighboring areas. As such, there is not likely substantial movement of this species northwest and northeast into other Papua sites. All foraging areas linked to these green turtles by satellite tracking lie within Kwatisore in the southwestern of Cenderawasih Bay. This appears to be a very locally-restricted foraging distribution. Limited foraging distributions of green turtles from this area highlight the linkages of this turtle stock to the RMU of the West Central Pacific Ocean and indicate that turtles remain in coastal waters for most of the time and spend most of their time in Papuan waters (Figure 1). In other studies at the same RMU, key foraging areas for western Australian green turtles lie predominantly close to the Australian mainland (Ferreira et al. 2021). Hoenner et al. (2015) reported that post-nesting female hawksbill turtles tagged within the Gulf of Carpentaria remained in the Gulf, suggesting minimal dispersal of adult females. In contrast, post-nesting female green turtles at Piai Is of Raja Ampat moved far away to the south of Bird’s Head until the Arafura-Timor Sea (ATS) (Gearheart 2005).

Table 2. Species and qualitative abundance of seagrass in Kalilemon and Mangga Island, Papua, Indonesia

Seagrass	Qualitative abundance	
	Kalilemon	**Mangga Island**
Cymodoceae		
Cymodocea rotundata	High	High
Halodule uninervis	High	High
Hydrocharitaceae		
Enhalus acoroides	Medium	Low
Halophila ovalis	Low	Medium
Thalassia hemprichii	Low	Low

Table 3. Chlorophyll-a content and SST (Mean+SD) in feeding grounds of green turtles (Mangga Island and Kalilemon) at Cenderawasih Bay, Papua, Indonesia, during the study period between November 2020-April 2021

Parameter	Sites	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21
Chlorophyl-a (mg/m3) (Mean±SD)	Mangga	0.26±0.05	0.54±0.14	0.31±0.05	0.25±0.01	0.25±0.07	0.25±0.04
	Kalilemon	0.29±0.04	0.55±0.14	0.3±0.02	0.23±0.03	0.30±0.07	0.31±0.13
SST (oC) (Mean±SD)	Mangga	30.61±0.34	31.7±0.19	31.02±0.18	31.08±0.25	31.23±0.15	31.77±0.17
	Kalilemon	30.89±0.29	31.73±0.20	30.97±0.15	31.03±0.23	31.36±0.10	31.65±0.14

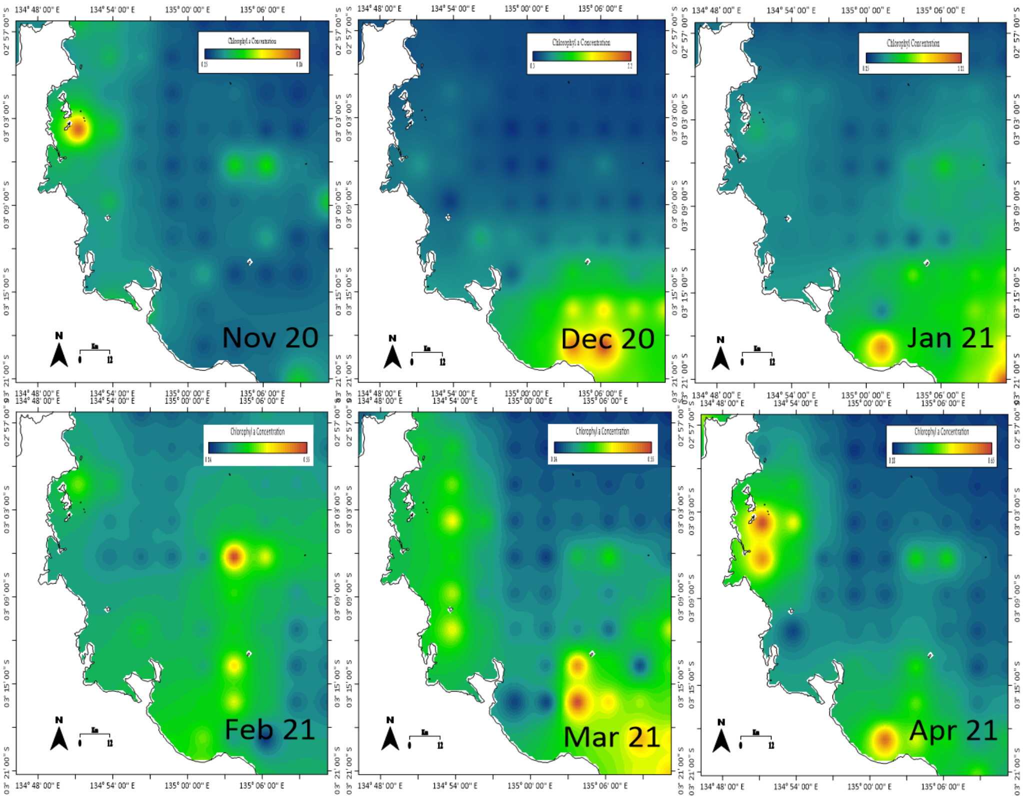

Figure 2. Chlorophyll-a content (mg/m^3) in Southwest part of Cenderawasih Bay, Papua, Indonesia, during the study period between November 2020-April 2021

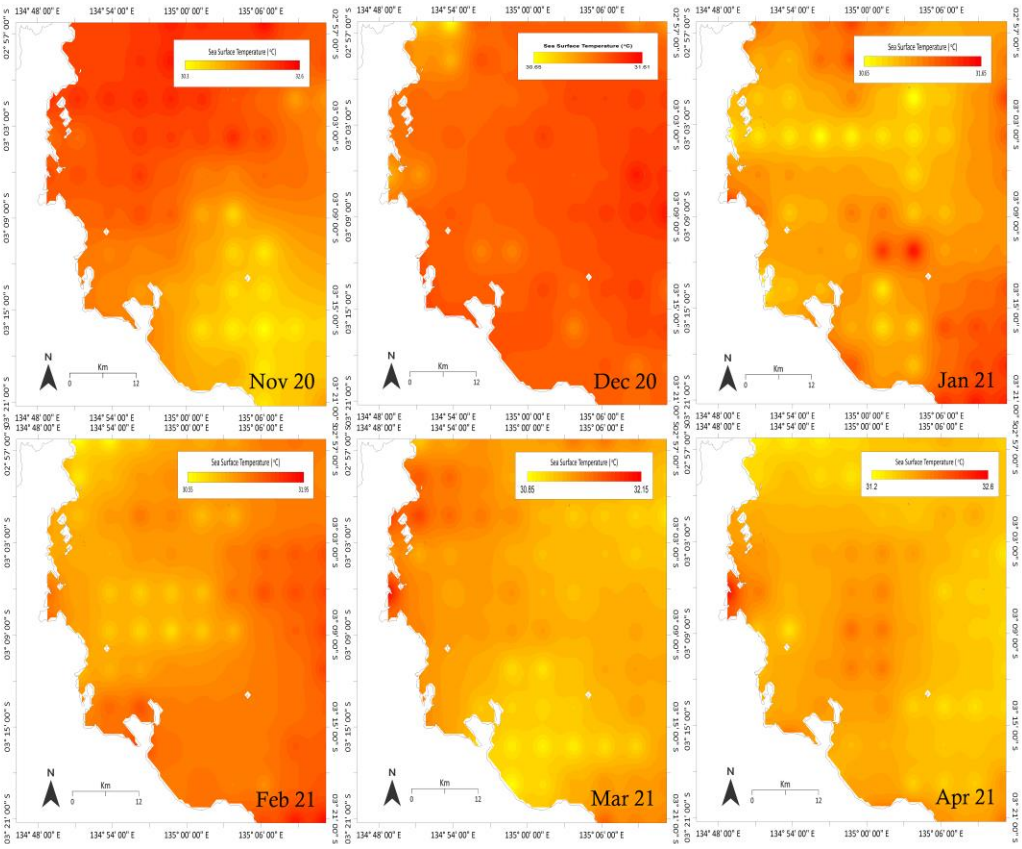

Figure 3. Sea Surface Temperatures (SSTs, ºC) in Southwest part of Cenderawasih Bay, Papua, Indonesia, during the study period between November 2020-April 2021

Green turtles prefer areas with coral reefs and rocky bottoms as resting places. Based on observations, the location of the turtle's distribution is in the reef flat area which is covered with seagrass. At sea, turtles are usually found in coral reefs and seagrass ecosystems. It is known that Cenderawasih Bay in the eastern part of Bird's Head lies in the center of biodiversity for seagrass (Short et al. 2007), with 11 species reported by McKenzie et al. (2007). In addition, TNTC (2022) mentioned that Cenderawasih Bay has extensive lagoonal seagrass beds in the southwestern area of the Bay (including Mangga Island and Kalilemon), which were reported to support dugongs and green turtles. Research conducted by Reisser et al. (2013) on Arvedo Island, Brazil, found that green turtles prefer rocky areas as a place to forage at depths between 0 to 5 m, where there are still abundant seagrass and macroalgae.

Seagrass species found in the foraging grounds on Mangga Island and Kalilemon (*C. rotundata*, *H. uninervis*, *Enhalus acoroides* (L.f.) Royle, *Halophila ovalis* (R.Br.) Hook.f., and *Thalassia hemprichii* (Ehrenb. ex Solms) Asch.) are seagrass species thought to be eaten by green turtles (Stokes et al. 2019). This is in accordance with Aragones (2000), that the seagrass genera eaten by green turtles are *Thallassia*, *Enhalus*, *Halodule*, *Cymodecea*, *Halophila*, and *Thalassodendron*. Nontji et al. (2012) mentioned that *H. uninervis* would be found in mixed vegetation stands with *E. acoroides*, *C. rotundata*, *C. serrulata* (R.Br.) Asch. & Magnus, *Syringodium isoetifolium* (Asch.) Dandy, and *T. hemprichi* on the sandy substrate in nature. Several studies have shown that green turtles prefer seagrass species of *Thallasia*, *Halophila*, *Cymodecea*, and *Halodule*. Based on this, it was concluded that the seagrass species *T. hemprichi* was the preferred species of seagrass by green turtles, which caused its abundance to decrease due to grazing. In research at Shoalwater, Australia, Arthur et al. (2009) found a seagrass species *Halodule* spp., and *H. ovalis* in the stomach of the green turtle. The green turtle's preference for this type of seagrass is related to the nutritional content of the two types of seagrasses.

Seagrasses are typically the main primary producers in coastal areas. It is known that light is identified as the main factor controlling the distribution and abundance of seagrasses. In addition, seagrasses have high light requirements than other major aquatic producers with much lower light requirements. Chlorophyll is needed by seagrass for photosynthesis to allow plants to obtain energy from light. Thus, measuring chlorophyll is one of the important parameters in water. The comparison of the mean chlorophyll content in Halodule leaves from different environments, temperatures and light illustrate the adaptive limits of optical plasticity in seagrass leaves (Wagey 2013). In the research, Wagey (2013) found differences in the results of chlorophyll pigments showing that chlorophyll pigments vary greatly according to various conditions.

The life and growth of seagrass are very dependent on water conditions. The overall range of SST found, 30.61-31.77ºC, lies within the thermal tolerance and is still in the range of optimal growth for tropical seagrass species 23ºC-32ºC (Lee et al. 2007). In addition, the study period between November to April lies within the northwest monsoon that extends from November to March (Mangubhai et al. 2012) and is characterized by warmer SSTs (Figure 3). In contrast, the southeast monsoon that takes place between May and October is characterized by cooler SSTs (Mangubhai et al. 2012). However, the parameter was not presented here. One of the impacts of climate change that has the potential to inhibit growth and even kill seagrass is thermal stress due to rising sea temperatures (Björk et al. 2008; Edwards 2021; Sondak and Kaligis 2022). Thermal stress is most likely to occur in tropical and subtropical environments and in bays with limited circulation where atmospheric warming warms seawater and salinity increases due to evaporation. Seagrass mortality has been recorded to associate thermal stress in areas such as Australia (Nowicki et al. 2017). Therefore, understanding the response of seagrasses to thermal stress due to elevated SST is critical for seagrasses, particularly those that grow close to their thermal tolerance limits (Unsworth et al. 2015).

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