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Increasing dolphin occurrences during Extreme Upwelling Events: Potential nonharmful and sustainable marine wildlife tourism at Mulut Kumbang Strait, Alor Kecil Village, Alor Island, Indonesia ☆

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ABSTRACT

An Extreme Upwelling Event (EUE), denoted by the sudden drop of sea surface temperature to less than 15 °C in a relatively short period, is a unique and recently reported oceanographic phenomenon. One and possibly the only place with confirmed EUE is the Mulut Kumbang Strait, Alor Kecil Village, Alor Island, Indonesia, since the phenomenon has never been reported in other tropical seas. The EUE occurred from August to November and lasted for 1 to 4 days, with a duration of only about an hour. The dramatic temperature drops during EUE caused small fish to become unconscious and attracted dolphins to come and feed. This is the first study to observe and quantify the dolphin sighting during EUE using closed-circuit television (CCTV). Full month observations were initially conducted in May and September 2022, which represented the months without and with EUE, respectively. In May 2022, the daytime minimum temperature was 24 °C (on May 19, 2022), with a total of 54 dolphin occurrences. In September 2022, the temperature reached 17.34 °C (on September 13, 2022), and the total dolphin occurrences increased to 87. With prior knowledge from 2022 EUEs, we conducted two additional EUE observations in 2023, focused around September: 2–4 September 2023 (period 1) and 30 September – 2 October 2023 (period 2). The temperatures in September and October 2023 were much lower than those in September 2022, with a minimum temperature of ~ 12 °C. The total dolphin sightings in periods 1 and 2 of 2023 increased to 105 and 90, respectively, and both occurred within one hour during the peak of EUE. The frequent dolphin sightings during EUE have a potential to be developed as sustainable marine wildlife tourism, since people can watch dolphin occurrences only from the seashore along the Alor Kecil Village.

1. Introduction

Indonesia is one of the countries with the largest biodiversity of cetaceans in the world, with 36 species currently reported, representing around 40 % of the global cetacean species (Carwardine, 2020; Jefferson et al., 2015; Sahri et al., 2020a; Mustika et al., 2015a). Within the country, the Lesser Sunda ecoregion, including the Savu Sea and particularly the seas and channels around the Lesser Sunda islands, are the hotspots and presumed migration paths for cetaceans and other megafauna traveling from the Indian Ocean to the Pacific Ocean and

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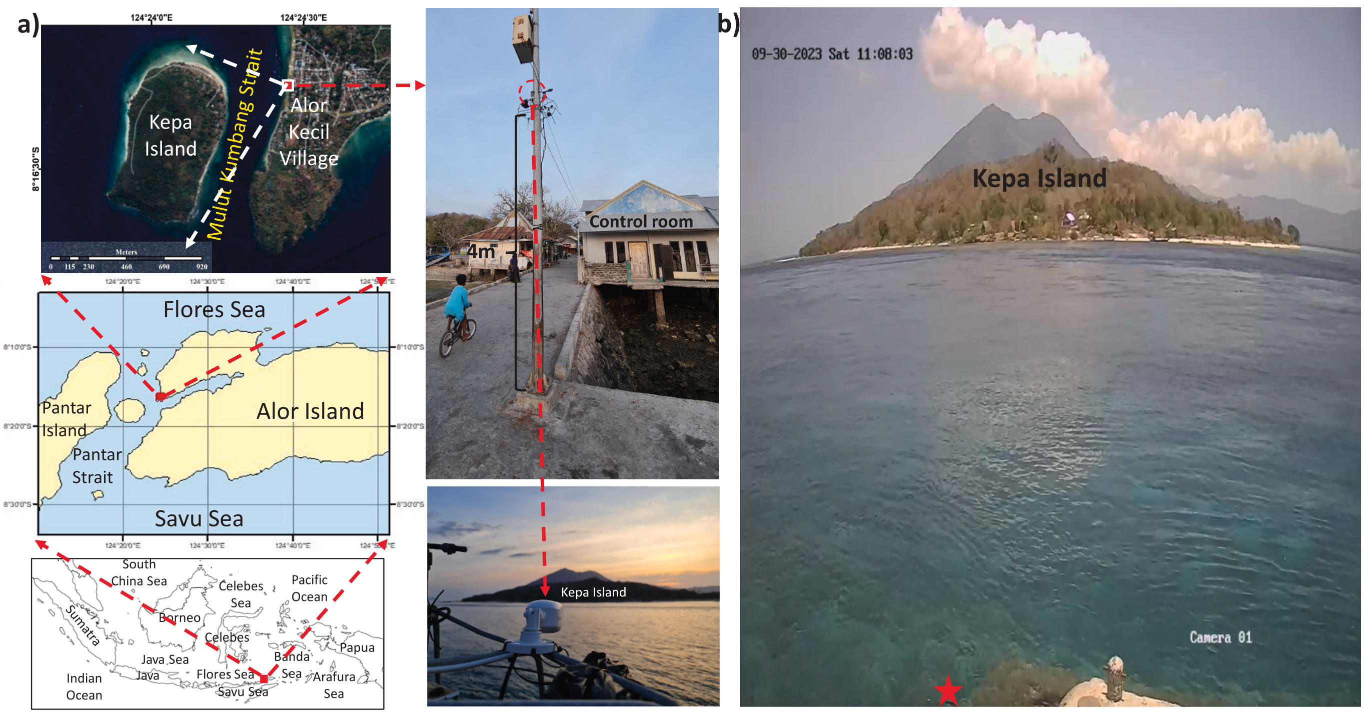

Fig. 1. a) The location of the Mulut Kumbang Strait, Alor Kecil Village and the position of closed-circuit television (CCTV) at the pier of Alor Kecil Village. The white arrows denote the angle of view of the CCTV. b) Example image captured by CCTV as pointed by the white arrows in a). The red star in b) denotes the position of the temperature logger. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

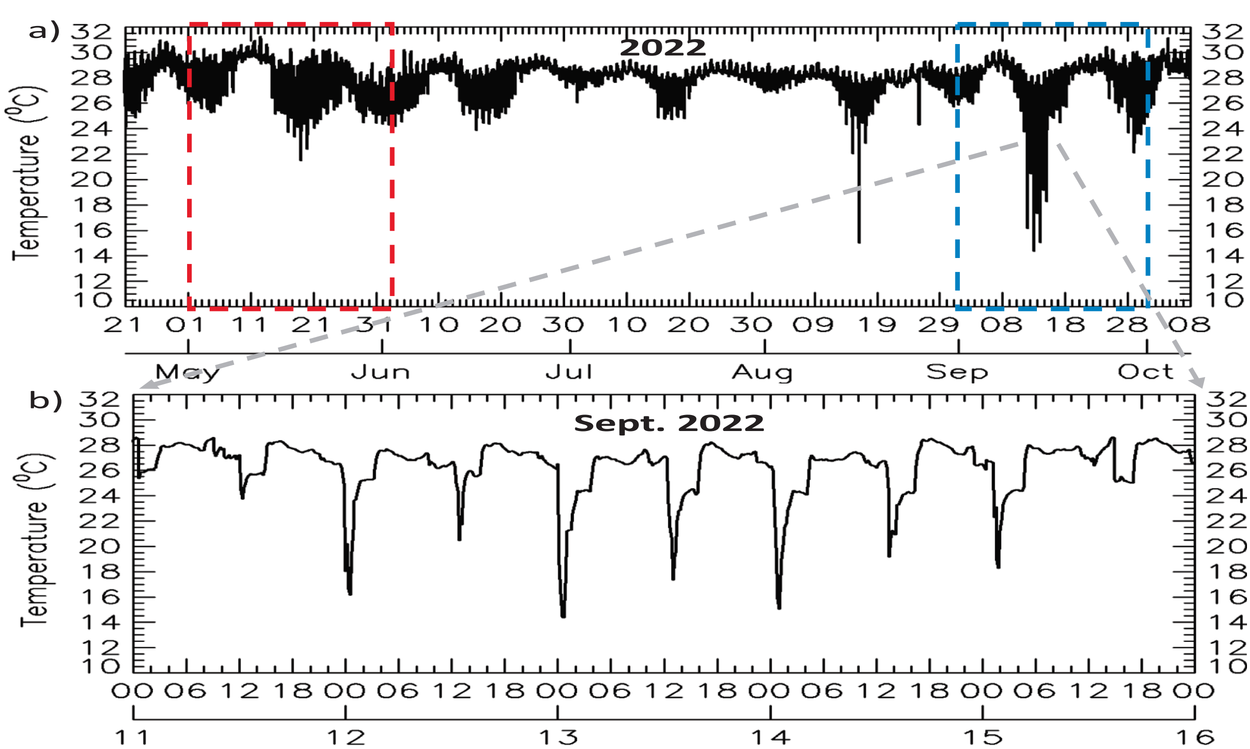

Fig. 2. a) Sea water temperature at the seas of Alor Kecil from 21 April to 8 October 2022. Red and blue dashed boxes denote the period of our observation without and with EUE occurrences, respectively. b) Detail sea water temperature fluctuations from September 11 to 16, 2022. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

vice versa (Klinowska, 1991; Womersley et al., 2022).

Of the cetaceans, Odontocetes (i.e., toothed dolphins and whales) are the most abundant group found in the Lesser Sunda ecoregion, including the Important Marine Mammal Area (IMMA) of the Savu Sea and surrounding waters. This IMMA is an important area for diverse cetacean species and migratory corridors for vulnerable Sperm whales and endangered Pygmy Blue Whales, providing critical habitats including feeding and nursery areas for various species (IUCN-MMPATF, 2022).

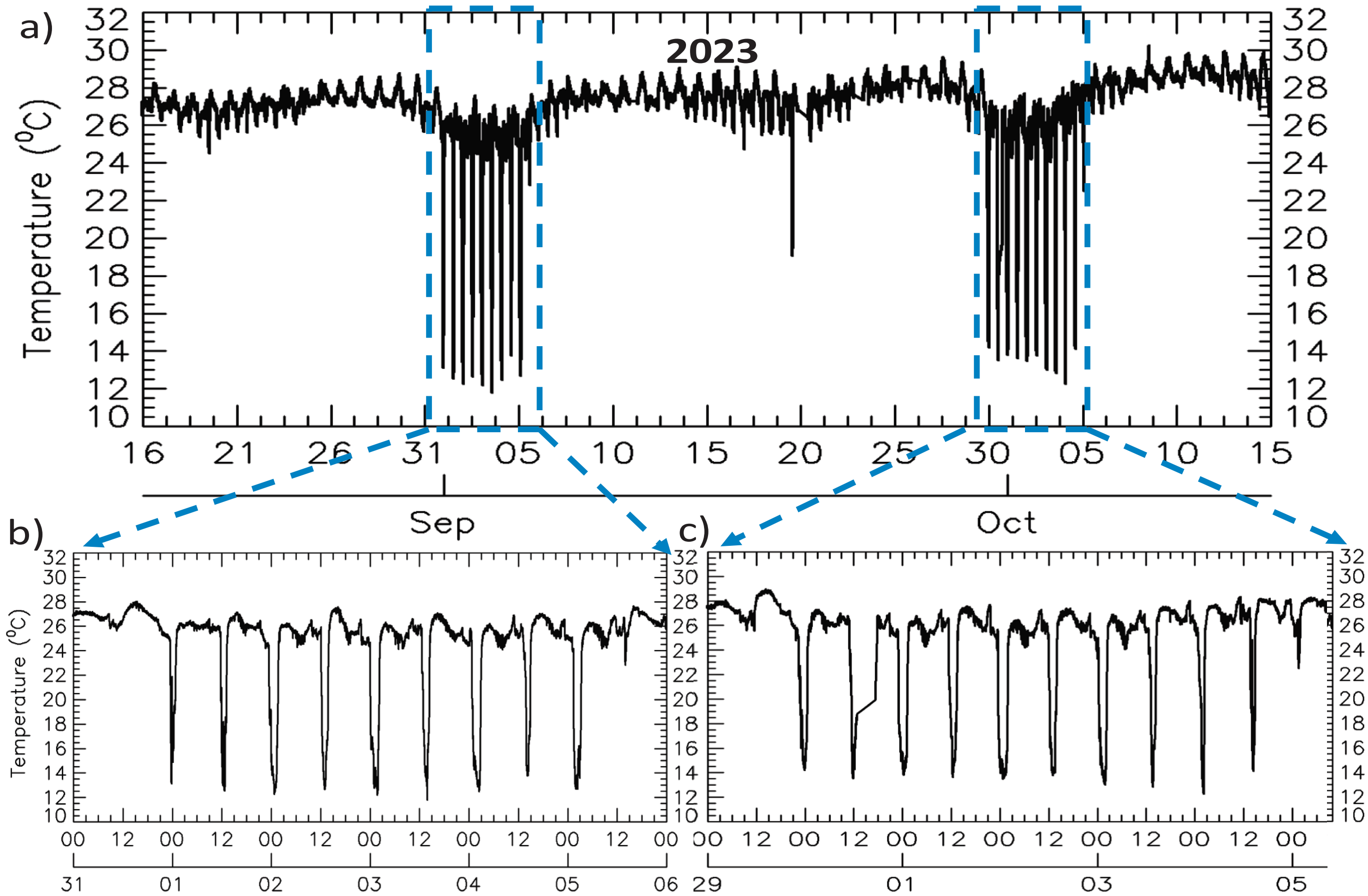

Fig. 3. a) Sea water temperature at the seas of Alor Kecil from September 16 to 15 October 2023. Blue dashed boxes denote the two periods of our observation in 2023. b) Detail sea water temperature fluctuations from August 31 to 6 September 2023 (left panel) and from September 29 to October 5, 2023 (right panel). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Sahri et al. (2021) reported 28 cetacean species inhabiting the ecoregion, with 21 Odontocetes species, while the remaining 7 species belong to the Mysticetes group (baleen whales). It means that more than three-quarters of Indonesian cetacean species can be found in these areas (Sahri et al., 2021; Dharmadi et al., 2010). Spinner dolphin (*Stenella longirostris*) and Pantropical spotted dolphin (*Stenella attenuata*) are the two most abundant Odontocetes species found in the region (Sahri et al., 2021; Mujiyanto et al., 2017).

The occurrence of dolphins in their natural habitat can potentially provide economic benefits for the local community through the development of marine wildlife tourism. Wildlife tourism is defined as "tourism based on encounters with non-domesticated animals in their natural environment" (Higginbottom, 2004), including dolphin watching. Watching dolphins in their natural habitat is an interesting attraction for tourists and has become the tourism industry in many countries. To illustrate, O'Connor et al. (2009) found that the industry associated with whale and dolphin watching attracted 13 million tourists in 119 countries and contributed US$ 2.1 billion to the global economy in 2008. In Sanniang Bay, China, for example, dolphin watching has become a community-based marine ecotourism initiative, where local fishers offer dolphin-watching experiences. This approach is proposed to supplement or even replace traditional fishing activities, providing a sustainable economic alternative while promoting conservation efforts of local dolphin populations (Wu et al., 2024). In Indonesia, one of the first and most established dolphin watching tourism sites is Lovina Beach in the north of Bali. Lovina dolphin watching tourism was developed in the late 1980s by the local artisanal fishermen and now becomes the most famous dolphin watching destination in the country (Hoyt 2001, Mustika 2011). Moreover, the global expansion of cetacean tourism, which includes dolphin watching, contributes significantly to the tourism economy, particularly in developing countries where it is rapidly growing (Mustika et al., 2016). Successful dolphin-watching operations can lead to a sustainable model of tourism that balances economic benefits with ecological and social responsibilities, making it a lucrative and responsible option for coastal economies.

Dolphin watching activities, however, have been reported to cause a negative impact on the targeted populations since the presence of extensive tour boats that take tourists to the dolphin sighting spots may interfere with the dolphin's behavior, travel path, and foraging time (Christiansen et al., 2010, 2013; Constantine et al., 2004; Lusseau, 2006; Schaffar et al., 2013). The presence of tour boats in large numbers can also displace the dolphin population from its key habitats (Bejder et al., 2006). In Sanniang Bay, China, the interaction between boats and Indo-Pacific humpback dolphins often disrupts their natural habitat, highlighting the long-term impact of tourism activities on dolphin behavior and habitat use (Wu et al., 2020). Similarly, in Bocas del Toro, Panama, intense dolphin-watching activities have led to negative impacts on local bottlenose dolphin populations, prompting calls for better management strategies that align with tourist preferences and conservation goals (Sitar et al., 2017). Furthermore, in Fiordland, New Zealand, ongoing interactions with tour boats are affecting the viability of local dolphin populations, necessitating the creation of marine mammal sanctuaries to manage tourism impacts sustainably (Lusseau et al., 2006).

Dolphin watching activities in Lovina have also been facing similar problems. On average, there are approximately 35 tour boats per day operated for around 3 h each morning by four local dolphin watching tourism associations (Mustika, 2011). During the peak season in June–October, the number of tour boats increased to nearly 100 tour boats per

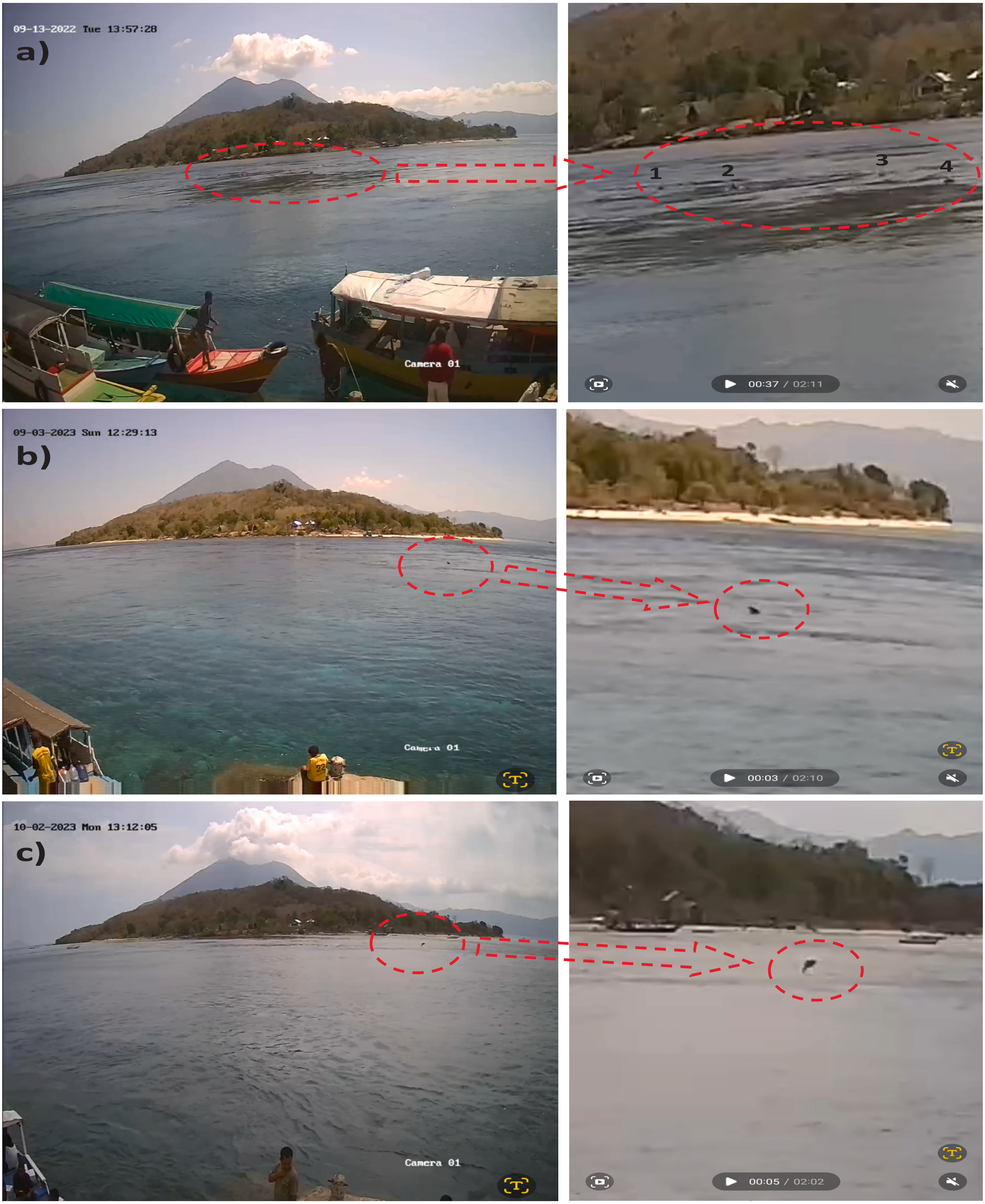

Fig. 4. Dolphin occurrences captured by CCTV on a) September 13, 2022, at 01:57 PM; b) September 3, 2023, at 12:29 PM; and c) October 2, 2023, at 01:12 PM.

Fig. 5. A drone photo at the similar location of Fig. 4b shows a different point of view of dolphin occurrence. The yellow circle denotes the dolphin sighting that was also captured by CCTV (Fig. 4b), while the red circle shows six individual dolphins that were not able to be captured by CCTV. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 6. Dolphin sighting at the southwestern tip of the Mulut Kumbang Strait on May 22, 2022, at 06.22 AM, captured by a DSLR camera.

day (Mustika, 2011). Mustika et al. (2015b) also observed that the boat's behaviors in Lovina did not follow the code of conduct for dolphin watching tourism that has been implemented in other countries that have already put such protocols into practice, such as Australia (Department of the Environment and Heritage, 2005). This unsatisfactory practice may harm and cause adverse impacts on the dolphins in Lovina. To ensure sustainable dolphin watching tourism, management practices need to accommodate ecological considerations, tourist satisfaction, and economic viability, integrating community-based strategies that respect both marine ecosystems and the livelihood of local populations (Wu et al., 2024). Therefore, there is a need to develop a more responsible and nonharmful dolphin watching tourism as an alternative to the current tourism activities.

Within the Lesser Sunda ecoregion, the Mulut Kumbang Strait of the seas of Alor Kecil, located in Pantar Strait (Fig. 1), is one of the potential sites to be investigated for the development of nonharmful dolphin watching tourism since people can easily watch dolphins from the strait fringe without necessarily taking a boat. In this area, dolphins are

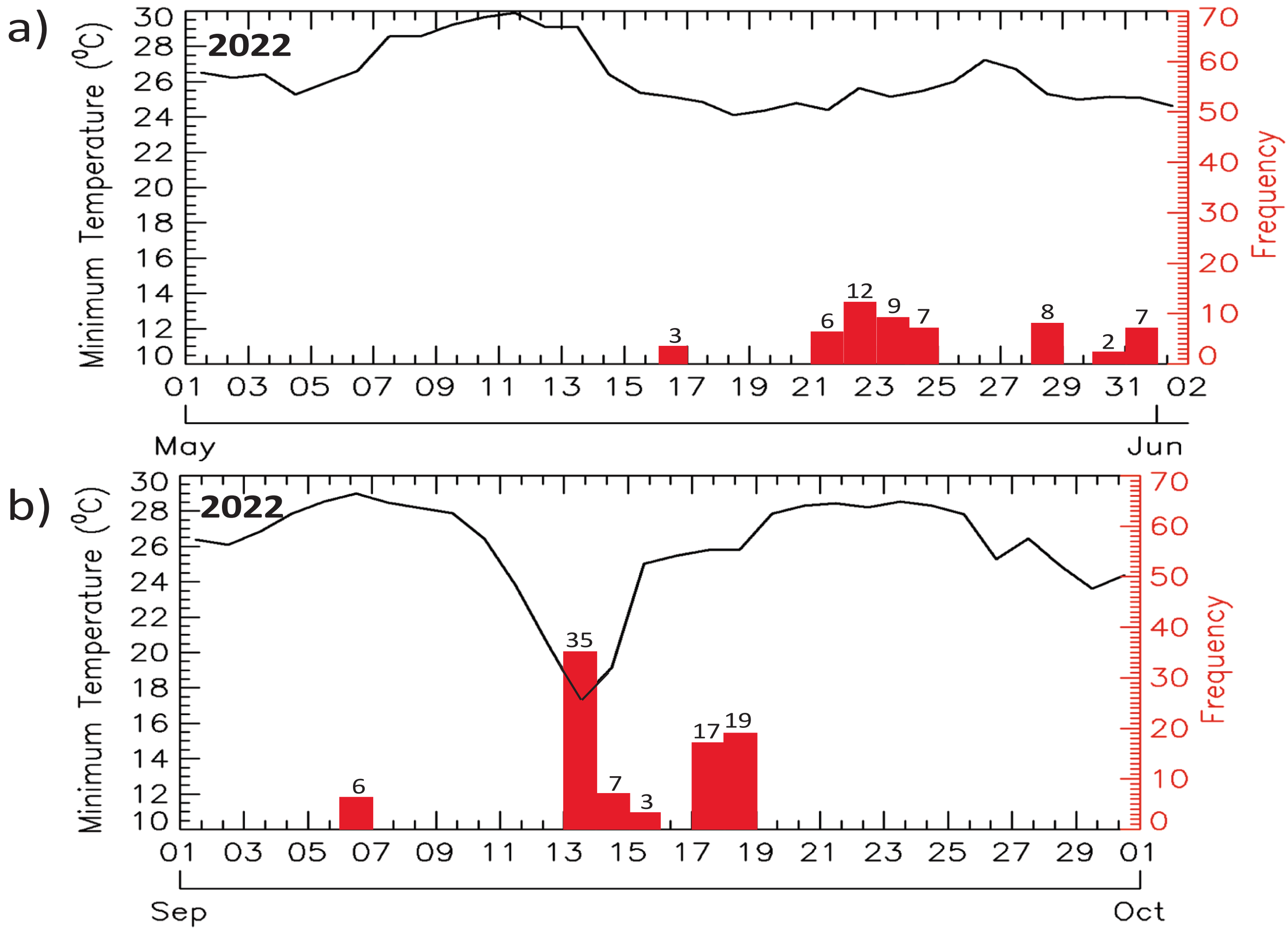

Fig. 7. Daytime minimum temperature and frequency of dolphin occurrence in a) May 2022 and b) September 2022.

reported to aggregate in certain months of the year (Maro et al., 2021a, b); however, the area has not been developed as a marine wildlife tourism spot. In addition, in the Mulut Kumbang Strait, there is a unique and probably the only one oceanographic phenomenon in the world called Extreme Upwelling Event (EUE), as there is no report of such a phenomenon in other tropical seas. Wirasatriya et al. (2023) define EUE as a dramatic drop of near-surface temperature (NST) to less than 15 °C within an hour that last at least one day and occur twice a day, along with the increasing salinity from ~ 30 PSU into 34–36 PSU. The strong flood current during the spring tide may bring the cold water mass from the deep basin at the south to the Mulut Kumbang Strait through a narrow channel. The sudden and dramatic temperature drop during EUE makes the small fish unconscious and then attracts dolphins to come and feed (Wirasatriya et al., 2023). Unfortunately, Wirasatriya et al. (2023) did not quantify the increasing dolphin occurrence during EUE. Using closed-circuit television (CCTV) and visual observation, the present study provided the first evidence of the increasing dolphin occurrences during EUE and discussed the potential nonharmful marine wildlife tourism in Alor Kecil Village.

2. Materials and Methods

2.1. Study area

The study was conducted at the seas of Alor Kecil Village which refers to a narrow strait called the Mulut Kumbang Strait, located in the middle Pantar Strait. The Mulut Kumbang Strait separates Kepa Island and Alor Kecil Village (Fig. 1a, top panel). The Pantar Strait is a wider strait that connects the Savu Sea and Flores Sea and separates Alor Island to the eastern part and Pantar Island to the western part (Fig. 1a, middle panel).

2.2. Equipment

The main tool for observing dolphin occurrences at the Mulut Kumbang Strait was a set of HiLook CCTV, which consisted of a digital video recorder (DVR) and one outdoor camera (2MP THC-B120-PC). The specifications of the camera are listed in Table S1 in the Supplementary Materials. The outdoor camera was installed at a harbor pier in Alor Kecil Village with a height of 4 m above the pier floor (Fig. 1a, middle panel). The DVR was placed in the control room 15 m from the pier (Fig. 1a). Since the position of the camera was located at the northern tip-end of the Mulut Kumbang Strait, we set the angle of camera view to the west and south directions to cover the whole strait area and the north part of Kepa Island (white arrows in Fig. 1a, top panel). The camera was not able to capture the southeast portion of the strait with this setting. We made this arrangement to cover the maximum area with a high probability of recording dolphin occurrences. Fig. 1b shows the example image captured by CCTV of the Kepa Island in front of the Alor Kecil Village.

Digital single-lens reflex (DSLR) Fujifilm camera FINEPIX HS50EXR and drone DJI Mavic 2 Enterprise Advanced were also used for occasionally capturing dolphin occurrences. A temperature logger the HOBO Pendant MX 2201, was deployed at the Alor Kecil harbor pier (Fig. 1b) at

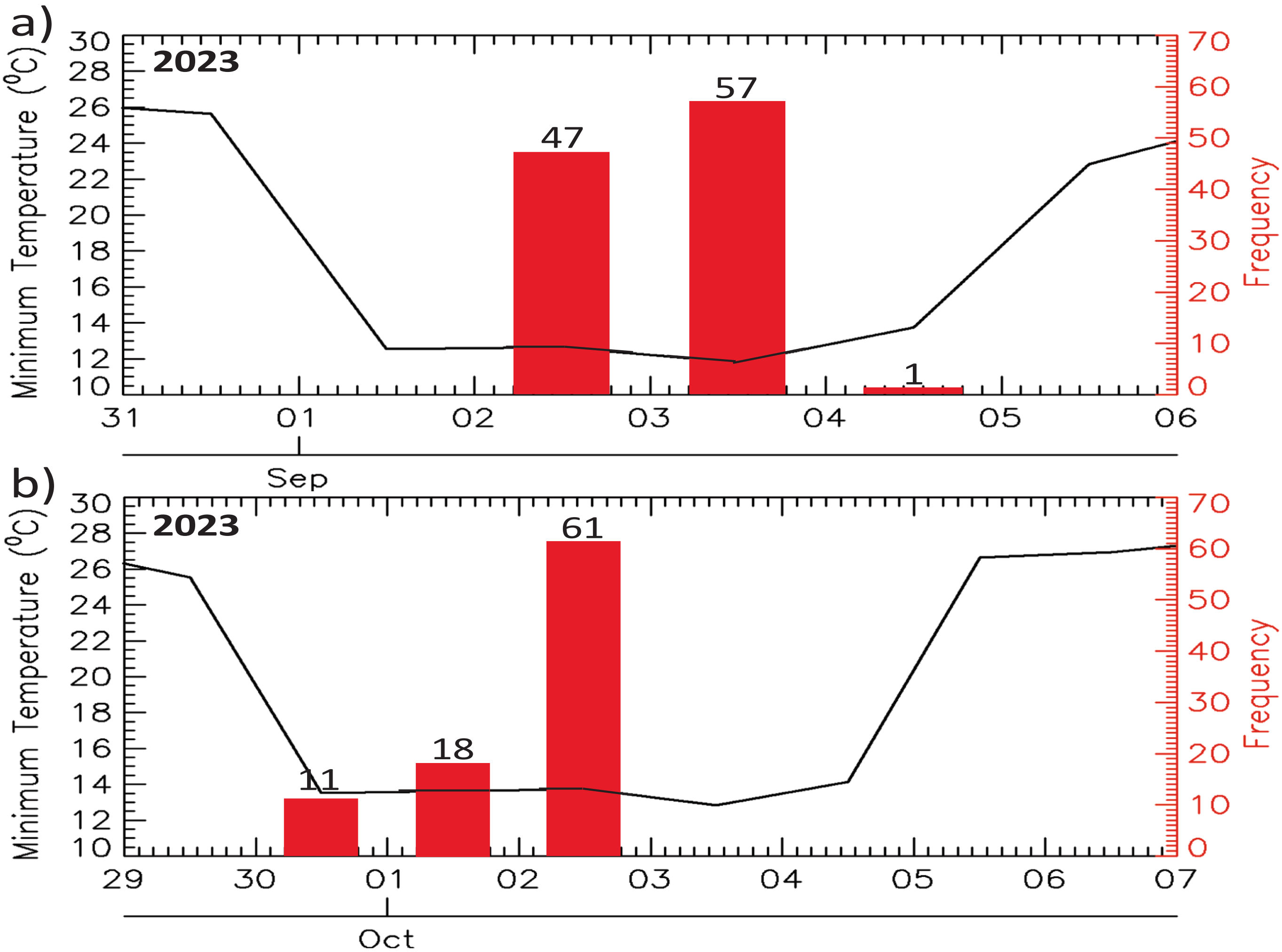

Fig. 8. Daytime minimum temperature and frequency of dolphin occurrence during EUEs on a) September 1– 4, 2023; and b) September 30 – 4 October 2023.

1 m below the lowest water level to record seawater temperature during the observation periods. The time interval measurement of the HOBO temperature logger was set to 10 min.

2.3. Observation

Despite being equipped with an infrared sensor, the infrared range of the camera is only 20 m. Thus, we focused the observation only during the daytime from 06:00 to 18:00 local time. The initial observations were conducted in May and September 2022 to represent a month without and with EUE occurrences, respectively. Fig. 2a shows that the temporal variation in water temperature in the seas of Alor Kecil in May 2022 was higher than 20 °C, indicating no EUE was detected. Conversely, in September 2022, sea water temperature dropped to 14.2 °C, which indicates the occurrence of EUE. However, it is worth noting that the temperature drop on September 12–15, 2022, which was below 15 °C, only occurred at night. During the daytime, the minimum temperature only ranged from 17 °C to 19 °C (Fig. 2b), meaning that the EUE in September 2022 was weak. Therefore, we conducted additional observations in 2023, which had strong EUE occurrences. We focused our dolphin observations on 1– 4 September (period 1) and 30 September – 4 October 2023 (period 2) during noon time (12:00 PM–02:00 PM), which had daytime minimum temperatures less than 15 °C (Fig. 3).

The data captured by CCTV was in video format. We carefully checked the record and counted the dolphin appearance. It is important to note that we did not count the exact number of dolphin individuals by excluding the similar individuals recorded by CCTV. Thus, the occurrences of dolphins may come from one dolphin that has been recorded several times. We were aware that it can introduce a bias in counting dolphin occurrences, and a method using baited remote underwater video surveys (BRUVs) has been used recently in other studies (e.g., Grimmel et al., 2020) to minimize the bias. However, our focus was only to quantify the frequency of dolphin occurrences, regardless of the same or different individuals, both during and outside the EUEs, not to investigate dolphin demography, such as estimating the dolphin density. The camera setting in our study made it impossible for us to apply the BRUV method. To relate the dolphin occurrence with EUE, we analyzed the daytime minimum temperature from the HOBO temperature logger. The dolphin occurrence and daily minimum temperature during the day were descriptively analyzed in the time series and scatter diagrams. We also performed a Pearson correlation analysis to quantify the correlation between these parameters.

3. Result

3.1. Dolphin occurrences captured by CCTV

The dolphin occurrences in the seas of Alor Kecil were successfully recorded through CCTV during our observations. Fig. 4 shows examples of dolphin occurrences captured by the CCTV. On September 13, 2022, at 01:57 PM, the CCTV recorded the occurrence of a group of four dolphin individuals traveling along the Mulut Kumbang Strait (Fig. 4a). On September 3, 2023 a traveling activity of an individual dolphin was

Fig. 9. Local people of the Alor Kecil Village caught fainted fish during EUE on September 2, 2023.

recorded at 12:29 PM. An above water body appearance of an individual dolphin was captured on October 2, 2023, at 01:12 PM. It jumped out of the water. We also provide the video sample of CCTV capturing dolphin occurrence in the Supplementary Material (S2).

However, since CCTV can only capture dolphin occurrences above the sea surface, dolphins that swim below the sea surface were not recorded by CCTV. Fig. 5 is the drone image at the same location as Fig. 4b, which shows the six individual dolphins swimming below the sea surface. CCTV also could not identify dolphin occurrences at the southwestern tip of the Mulut Kumbang Strait due to the far distance (more than 800 m). Fig. 6. shows the aerial behavior of an individual dolphin at the southwestern tip of the strait, captured by a DSLR camera on May 22, 2022, at 06:22 AM. From the morphological characteristics of the dolphin captured by the DSLR camera, we positively identified the dolphin species as the common bottlenose dolphin (*Tursiop truncantus*).

3.2. Frequency of dolphin occurrence

In our initial observation, we compared the frequency of dolphin occurrences in May and September 2022, which represented a month without and with EUE (Fig. 7). In May 2022, the daytime minimum temperature was more than 24 °C for the whole month (Fig. 7a). The dolphin occurrence was identified on 17, 21–24, 28, 30, and 31 May, with a total frequency of 54 occasions. The highest frequency of dolphin occurrences was recorded on 12 occasions recorded on May 2022. All dolphins were sighted in the morning between 06:00 AM–08:00 AM. In September 2022, the total frequency of dolphin occurrences was 87. The highest frequency was recorded 35 occasions on September 13, 2022, when EUE occurred, as denoted by the daytime minimum temperature of 17.34 °C (Fig. 7b). It is also important to state that the highest frequency of dolphin occurrences on September 13, 2022, occurred at noon time between 12:00 PM and 02:00 PM, while 75 % of the other dolphin occurrences in May and September 2022 were observed in the morning.

During the additional observations in 2023, two strong EUEs were observed. The first EUE (period 1) occurred on September 1–4, 2023, with the daytime minimum temperature ranging from 12.5 °C to 13.9 °C, and the second EUE (period 2) occurred on September 30 – October 4, 2023, with the daytime minimum temperature ranging from 13.1 °C to 14.4 °C (Fig. 8ab). No dolphin was identified on the first day of EUE on September 1, 2023. On September 2 and 3, 2023, the frequencies of dolphin occurrences were observed on 47 and 57 occasions, respectively. These 2023 frequencies were much higher than the frequency of dolphin occurrences recorded from the initial observation on September 13, 2022. We also observed abundantly fainted fish on September 2 and 3, 2023 which attracted local people to catch the fish (Fig. 9). On September 4, 2023, there was only one dolphin occurrence, and the daytime minimum temperature slightly increased, indicating the end of EUE. The total dolphin occurrences on the first EUE (period 1) in 2023 were 105.

On the second EUE (period 2), from September 30 to 2 October 2023, the frequency of dolphin occurrences increased from 11, 18, and 61 occasions, respectively. In total, dolphin occurrences ware recorded 90 occasions, slightly lower than that of period 1 EUE, although still higher than that of the initial observation in 2022. Afterwards, no dolphin was detected in the rest two days of period 2 EUE.

Next, we summarize the timing of dolphin occurrences during EUE and non-EUE periods (Fig. 10). During non-EUE period, dolphin occurrences were mainly observed in the early morning between 05:00 AM and 08:59 AM. The dolphins that were sighted in the morning were usually observed to travel through the Mulut Kumbang Strait (Basana's Personal Observation). During EUE period, the timing of dolphin occurrences was shifted to between 11:00 AM and 01:59 PM, matching with the peak time of EUE. However, ten dolphins transited in the Mulut Kumbang Strait were still observed in the morning.

The scatter plot in Fig. 11 shows the tendency that the lower the daily minimum temperature, the more dolphin occurrences. Furthermore, the daily minimum temperature has a negative correlation with dolphin occurrences ($r = -0.64^{**}$), meaning that EUE significantly increases dolphin occurrences.

4. Discussion

The use of CCTV for marine animal observation has proven to be an effective tool in enhancing conservation efforts by providing reliable and accurate data. Previously, Kim et al. (2025) used CCTV, hydrophone monitoring, and drone observations at a sea–pen–rehabilitation site. The CCTV was used to visually document interactions between rehabilitating (captive) dolphins and wild dolphins. Hentati-Sundberg et al. (2023) also used CCTV with artificial intelligence for auto detection of seabird presence and activity. Our observations using CCTV successfully recorded dolphin occurrences in the Mulut Kumbang Strait in the seas of Alor Kecil during Extreme Upwelling Events (EUEs). The present study also showed that the occurrence of dolphins increased notably during EUE compared to non-EUE (Fig. 11). We first described the reasons for increasing dolphin occurrence during EUE from both oceanographical and animal behavioral perspectives, then elaborated on the potential of dolphin occurrence for more responsible and nonharmful marine wild tourism as an alternative to the current tourism practice in Indonesia. Lastly, we discussed the limitations and caveats of our study and concluded by confirming the application of CCTV in dolphin observations to support dolphin conservation management.

The EUE in the Mulut Kumbang Strait is a unique oceanographic phenomenon that possibly becomes the only one in the world since there is no report from other tropical seas that sea surface temperature drops to less than 15 °C. Wirasatriya et al. (2023) indicated that the EUE in the Mulut Kumbang Strait is generated by tidal force. The existence of a channel that connects the deep basin and the Mulut Kumbang Strait

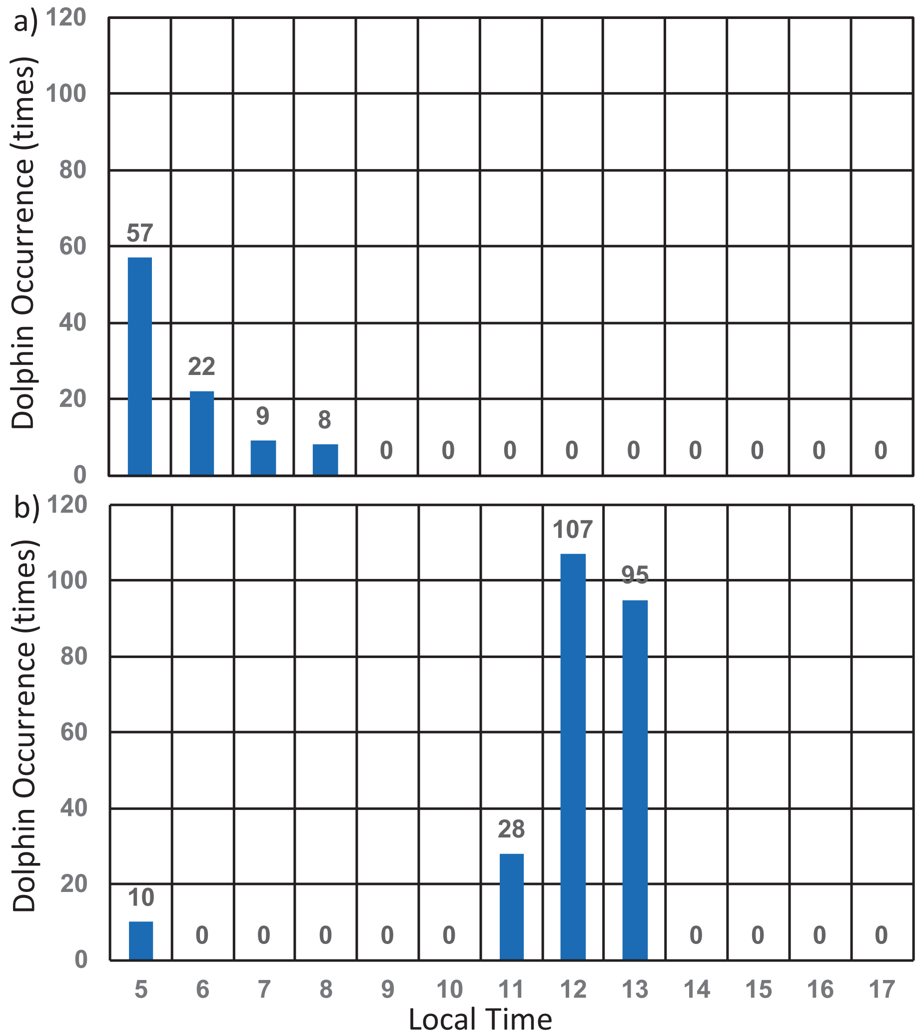

Fig. 10. Timing of dolphin occurrences during a) non EUE and b) EUE periods.

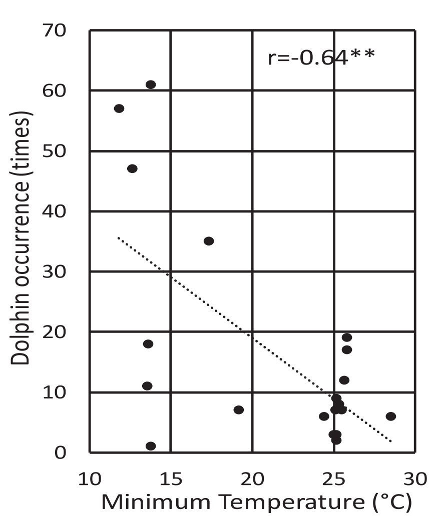

Fig. 11. Scatter plot of daily minimum temperature during daytime vs. dolphin occurrence.

plays an irreplaceable role as a path for tidal sloshing to bring in (out) the cold water to (from) the strait. Furthermore, according to Wirasatriya et al. (2025), the interaction between tidal currents and the background current, potentially linked to the Indonesian Throughflow (ITF), plays a role in the formation and dissipation of EUE. A northward flood current transports cold water from the deeper layers at the strait's entrance into the strait, where it encounters the southward-flowing ITF current. When EUE dissipates, the combined ebb and background currents create a strong, warm southerly current that pushes the cold water back to the deep layers at the strait's entrance.

Dolphin occurrence increased during EUE because small fish were shocked by the temperature drop (eg., Schoenfuss et al., 2023) that made the schooling fish unconscious and available in an abundant amount, thus finally attracted the dolphins to feed. Dolphins have been reported to aggregate in areas where their main prey occurs to increase their feeding success rate (López et al., 2004). As a larger marine mammal, dolphins may adapt to the temperature drop compared to the smaller fish. Yeates and Houser (2008) investigated that water temperature had a minimal synergistic effect on small dolphin thermoregulation, such as bottlenose dolphins. Coastal bottlenose dolphins generally tolerate the temperature drop with changes in integument thickness and whole-body conductance (Carmichael et al., 2012). According to Silva (2004), bottlenose dolphins are able to adapt to relatively cold temperatures by retaining heat in the fat that covers most of their body. For example, a dolphin with 2 cm of fat can maintain a body temperature up to 39 °C higher than the ambient temperature. As endothermic animals, dolphins depend on blubber and internal metabolic processes to maintain a stable body temperature (Mintzer and Fazioli, 2021), although Favilla et al. (2022) stated that unlike the skin surface, blubber is not directly affected by external influences, such as

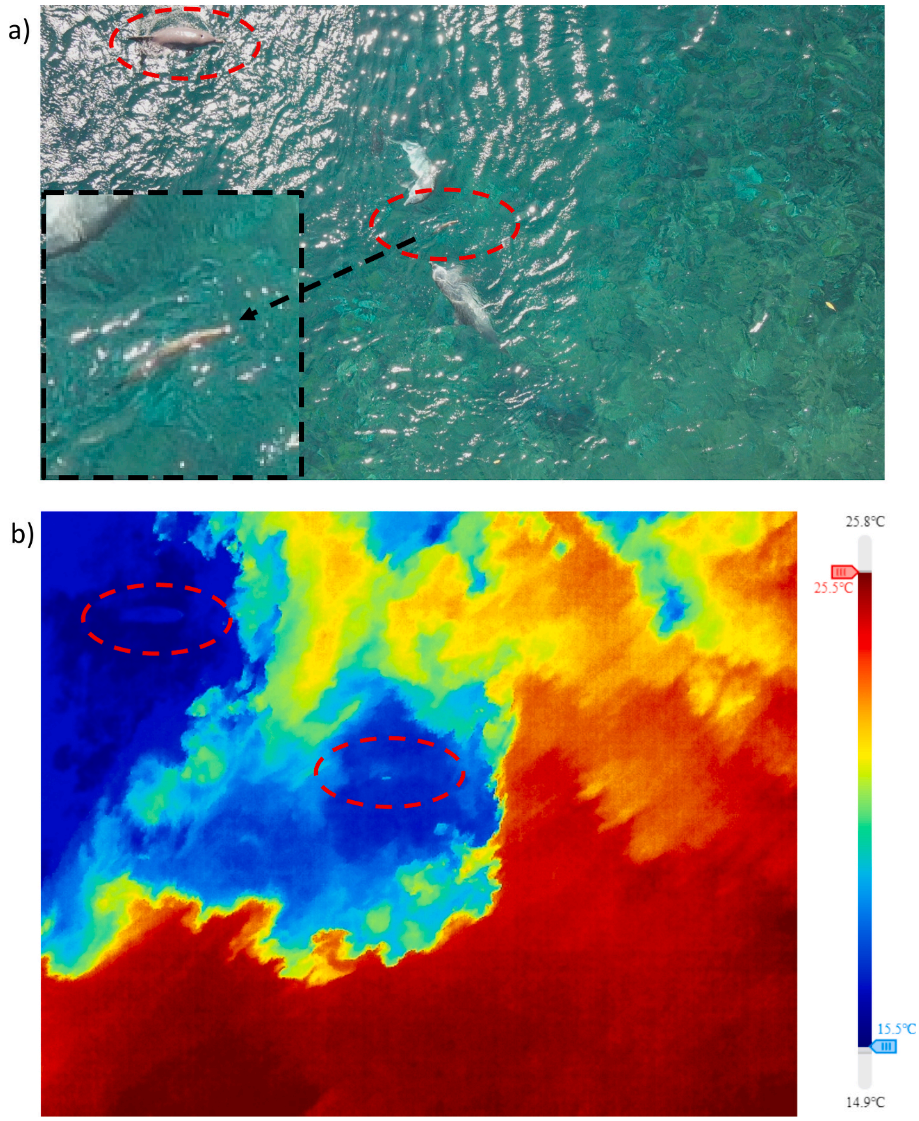

Fig. 12. Dolphins prey on a fainted fish captured by drone DJI Mavic 2 Enterprise Advanced on 23 August 2024 at 02:00 PM for a) true color image, b) thermal infrared image. The red dashed circles denote a dolphin and fainted fish detected by thermal infrared sensor as indicated by the higher temperature than their surroundings. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

convective heat loss from water flow. Instead, blubber temperatures reflect internal processes that serve to maintain homeostasis.

The highest frequency of dolphin occurrence was found in the noon time between 11:00 AM and 01:59 PM when the EUE occurred (Fig. 10). This indicates that during EUE, dolphins aggregate in the Mulut Kumbang Strait not only for transiting (as commonly observed in the morning), but also for feeding the unconscious fish as the EUE impact. Spinner dolphins in Hawaii were reported to rest during the day and move offshore during the night, likely following their prey (Thorne et al., 2012). Furthermore, Vermeulen et al. (2015) reported that a small population of bottlenose dolphins were showed not only seasonal but also diurnal behavior patterns such as rest, travel, and forage. During the early morning, most dolphin groups were resting, while towards the afternoon and evening, surface feeding and social activities peaked. Here in Alor Kecil, we reported unusual behavior since the dolphins were feeding on the unconscious fish at noon. This finding indicates that the dolphin is possibly also a cosmopolitan feeder, feeding whenever prey is available regardless of the time of day. This strategy is similar to what has been reported for other marine mammals, such as blue whales, as the animals require energy for their activity, including during the noon and migration seasons (Goldbogen et al., 2013). Likewise in Wakatobi, South Sulawesi, however, the information on dolphin detailed feeding behavior in Alor Kecil is also still lacking (Sahri et al., 2020b). It is also possible that the dolphins recorded by CCTV are a mixed group that consists of other cetacean species that may have different feeding habits. A CCTV with higher resolution may confirm this question in the future.

The dolphins were also not sighted in the Mulut Kumbang Strait at the end stage of Period 2 EUE in 2023. The absence of fainted fish, indeed, did not attract dolphins to come and prey. Therefore, the association between EUE and dolphin occurrences cannot be solely explained by the temperature drop. The availability of the fainted fish due to the low temperature shock may have contributed to the association with the dolphin occurrence. Bottlenose dolphin is known to feed mainly on octopush (*Octopodidae*), cuttlefish (*Sepiidae*), squid (*Loliginidae*), some crustaceans, and a range of different fish species including jacks (*Pseudocaranx sp.*), trevallies (*Trachurus sp.*), sardines (*Sardinops sagax*) and silver bellies (*Parequula melbournensis*) (Gibbs et al., 2011; Bilgmann et al., 2019). Unfortunately, we did not quantify the fainted fish during EUEs in our study, and this could be the focus of future investigations.

The evidence of dolphin prey on the fainted fish was captured on 23

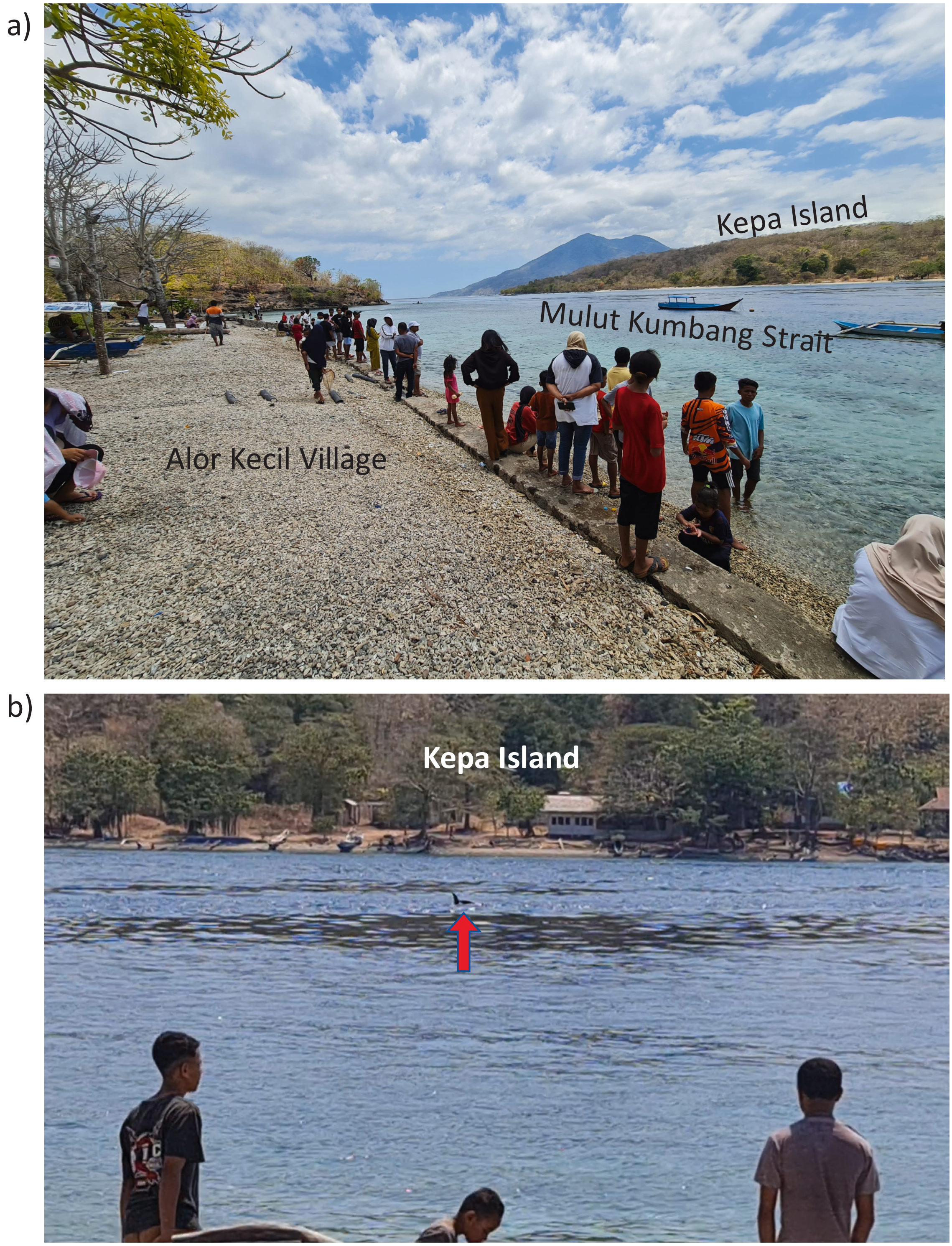

Fig. 13. a) Local people gather along the strait fringe, waiting for the dolphin occurrence during EUE on October 1, 2023. b) Locals can easily observe the dolphin sighting (red arrow) along the strait's edge. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

August 2024 at 02:00 PM using drone DJI Mavic 2 Enterprise Advanced equipped with thermal infrared sensor (Fig. 12.). A fainted coral fish lied among three dolphins (Fig. 12a). EUE created strong thermal front in the Mulut Kumbang Strait with the minimum (maximum) temperature is 15.5 °C (25.5 °C) as also detected by Wirasatriya et al. (2025). One dolphin is located at the area with high temperature while two dolphin and the fainted fish are in the cold-water area (Fig. 12b). video at the Supplementary Material (S3) reveals how the dolphins firstly play with the fainted fish and finally prey on it. The behavior on how dolphins play and prey on the fainted fish may be explored more for the future study.

The known dolphin occurrence in the Alor Kecil Village has potential for marine wildlife tourism. However, it is necessary to state that the high frequency of dolphin occurrence during EUEs occurs only within 2 h. Thus, with the relatively limited time yet abundant dolphin occurrence, local people as well as tourists can visit the Mulut Kumbang Strait to experience dolphin watching as long as the animals are present during

EUEs. In addition, local people and tourists can also feel the sensation of icy water in the tropics and catch unconscious fish. The latter, however, can lead to a food competition between humans and dolphins that further can causes the prey depletion for the dolphins (Gore et al., 2012; Sahri et al., 2020b).

Different from the dolphin watching tourism in Lovina, where people need to take a boat to see the animals (eg., Mustika, 2011; Mustika et al., 2015a), dolphin watching in the seas of Alor Kecil is more convenient for the people and more friendly and safer for the dolphins (Fig. 13). Fig. 13a shows that local people along the Mulut Kumbang Strait were waiting for the dolphin occurrence during EUE on October 1, 2023. With the width of the strait being less than 300 m, people can easily watch the dolphin occurrence from the beach or strait fringe without taking a boat (Fig. 13b). Thus, this dolphin watching tourism during EUE will not only provide economic benefits for the local people of Alor Island but will be also environmentally friendly and sustainable for the dolphins because it will take animal welfare into account as well. This prospective activity is important in promoting more responsible and nonharmful marine wild tourism as an alternative to the current tourism practices in Indonesia. It is crucial since no regulation or standard protocol for dolphin watching tourism is currently in force in the country (Sahri et al., 2020a).

To support the development of dolphin occurrence during EUE in Alor Kecil as a tourist destination, the prediction of EUE occurrence is crucial. The accurate prediction of EUE will ensure that incoming tourists enjoy dolphin watching during EUE. Since tide is predictable and tidal force is what generates EUE (Wirasatriya et al. 2023), the occurrence of EUE is theoretically also predictable. Wirasatriya et al. (2023) reported that EUE in Alor Kecil occurs four months in a year, i.e., from August to November. Since tidal force is what causes EUE, it happens twice daily for one to five days during the highest flood tide of the spring tide period.

Currently, EUE is limited to the residents of Alor Kecil Village and its surroundings. Consequently, local residents are the ones who enjoy EUE. Going forward, this paradigm must change; EUE should be enjoyed by both domestic and international tourists. The local government should see the dolphin watching tourism in Mulut Kumbang Strait as new potential economic sources both for local people and government. As this event is just recently revealed, the government also need support from other stakeholders (entrepreneurs, universities, tourism activists, tourism consultants, banks etc.) to develop and drive the tourism to right direction to avoid harmful and mass tourism that can disturb the natural behavior of dolphins.

Our study comes with some limitations that need to be considered for future research. In counting the dolphin occurrences captured by CCTV, we could not count the exact number of individual dolphins, but only the frequency of the dolphin occurrence during the EUEs. Very high-resolution CCTV that can capture the external appearance or morphological characteristics of dolphins may be used in the future to refine dolphin estimation and support the initiation of a dorsal fin catalog for species or individual identification.

In addition, since CCTV can only capture dolphin occurrences above the sea surface, dolphins that swim below the sea surface were not recorded by CCTV. In this case, a drone photo is beneficial to record the dolphin occurrences (as shown in Fig. 5). It is the weakness of using CCTV for observation of animals that spend most of their time underwater, such as dolphins. Furthermore, as mentioned earlier regarding the CCTV angles, CCTV also could not identify dolphin occurrences at the southwestern tip of the Mulut Kumbang Strait due to the far distance, which was more than 800 m and out of the CCTV coverage. As a complementary method, a DSLR camera was used to capture the aerial behavior of an individual dolphin at such a hard-to-observe location (Fig. 6). Thus, distance to the targeted object is also another weakness of CCTV for dolphin observation.

5. Conclusion

We have quantified the dolphin occurrence using CCTV observation in the month with and without EUEs and revealed the increasing dolphin occurrence during EUE. We argue that the impact of the temperature drop during EUE on the frequency of dolphin occurrence is not a direct association since the dolphin appearance may be more influenced by the availability of fainted fish during EUE for their prey. The notable increase in dolphin occurrence during EUE has the potential to be developed as sustainable and nonharmful marine wildlife tourism since people can experience dolphin watching only from the seashore along the Alor Kecil Village without taking a boat that can interfere with dolphin behavior. Our study demonstrates the benefits of using CCTV as a tool for dolphin observation, the animal behavioral investigation, and finally, inform conservation management for cetaceans.

CRediT authorship contribution statement

Anindya Wirasatriya: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Funding acquisition, Conceptualization. **Arthur Mattews Basana:** Visualization, Validation, Investigation, Formal analysis, Data curation. **Elis Indrayanti:** Writing – review & editing, Visualization, Resources, Investigation. **Agus Anugroho Dwi Suryoputro:** Writing – original draft, Project administration, Investigation. **R. Dwi Susanto:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Retno Hartati:** Writing – review & editing, Supervision, Investigation. **Nur Taufiq-SPJ:** Writing – review & editing, Supervision. **Jahved Ferianto Maro:** Visualization, Formal analysis, Data curation. **Parichat Wetchayont:** Writing – review & editing, Supervision. **Mochamad Iqbal Herwata Putra:** Writing – review & editing, Supervision. **Achmad Sahri:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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