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Mass mortality event of aquaculture oysters caused by high precipitation in Setiu Lagoon, Peninsular Malaysia, during the wet season

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Abstract
Mass oyster mortality occurred at an oyster farm in the Setiu Lagoon on the east coast of Peninsular Malaysia in December 2023. According to interviews with aquaculture farmers, heavy rains that occurred from 20 November to early December caused flooding in the surrounding area, leaving it exposed to low-salinity water for a long period. Mass mortality occurred at oyster farms in early December, with farmers estimating that the dead oysters had a shell length of 1–5 cm and mortality rate of over 90%, and that approximately 50,000 oysters had died. An analysis of meteorological data indicated that a monthly rainfall value of more than 1200 mm/month, which is more than double the normal amount, was observed in November in the same region. During the same period, the seawater temperature in the South China Sea was 1°C higher than normal, and the northeast monsoon caused winds from the northeast to transport moist air to the eastern coast of Peninsular Malaysia, causing heavy rain. Currently, only one waterway, approximately 200 m wide, connects the lagoon to the sea. Until approximately 2012, two waterways were connected to the sea. We concluded that by increasing the number of channels to two, the decrease in salinity in the lagoon during the rainy season could be reduced by enhancing phytoplankton occurrence.

Keywords
Mass mortality, Oyster farming, high precipitation, Setiu Lagoon, Peninsular Malaysia

Introduction

Setiu Lagoon is located in the northern part of Terengganu State on the east coast of Peninsular Malaysia. The Setiu (Caluk and Bari rivers are its tributaries) and Ular Rivers flow into the hinterland, and at their mouth, there is a wetland with an area of more than 23,000 hectares, and a shallow lagoon with a total length of approximately 14 km and water depth of less than 3.2 m (Suratman *et al.*, 2016; Norzilah *et al.*, 2016; Poh *et al.*, 2019). The sediment within the lagoon is highly variable (mean sediment size ranged between 0.06–2.52) (Yaacob and Mustapa, 2010), and the surrounding area includes mangrove forests, peat swamps, brackish waters, seaweed beds, and sandy beaches. Therefore, a unique ecosystem has formed in this region (Kassim *et al.*, 2018; Pradit *et al.*, 2016). According to previous biological surveys, edible species, such as the snail *Telescopium Telescopium* and bivalves *Meretrix meretrix*, *Polymesoda expansa*, *Marcia japonica*, *Anadara corna*, *Anadara inaequivalvis*, and *Crassostrea iredalei*, are also abundant (Omar and Kassim, 2015; Pradit *et al.*, 2016; Zakariah *et al.*, 2019;

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Ibrahim *et al.*, 2021). Moreover, Setiu Lagoon is known as a popular region for aquaculture, and in addition to grouper and sea bass aquaculture, shrimp and oyster aquaculture are also conducted (Mahmud *et al.*, 2015; Lola *et al.*, 2017; Nurul-Husna *et al.*, 2016; Nik-Nurasyikin *et al.*, 2018). *Crassostrea iredalei* is the main target of oyster farming in Setiu Lagoon (Nair *et al.*, 1993; Najiah *et al.*, 2008; Suzana *et al.*, 2011; Abidin *et al.*, 2012; Nadirah *et al.*, 2018). Young oysters are collected from natural seedlings using oyster shells, old tires, and other attachment organs (Nair *et al.*, 1993), and hanging culture is conducted using baskets. Based on statistical information from the Department of Fisheries Malaysia regarding oyster aquaculture production in each Malaysian state in 2022, the domestic production is 154.4 tons, wherein Terengganu produces 7.7 tons, and the percentage of domestic production remains at approximately 5%. The production values of oysters in Malaysia and Terengganu are 1,175.81 and 193.37 RM, respectively, and the latter accounts for approximately 16% of the domestic production; thus, the market value of oysters produced in Terengganu is high. As described above, oyster farming in Terengganu State is expected to develop in the future. However, during the rainy season of 2023, a large number of farmed oysters died in Setiu Lagoon. According to Gasim *et al.* (2007), the east coast of Peninsular Malaysia, in-cluding the state of Terengganu, is susceptible to the effects of the northeast monsoon, with the rainy season beginning in October, and flood damage gene-rally occurs from November to December. This is thought to be caused by (1) high rainfall, (2) slow ri-ver flow, (3) backwater phenomena, and (4) the ten-dency of coastal water to stagnate owing to north-eastern winds. In 2023, local newspapers began repor-ting flood damage in the area during 20 November (https://www.thestar.com.my/news/nation/2023/11/20/terengganu-now-hit-by-flooding). In the lower reaches of the Setiu River, the water level was obser-ved to be 9.08 m with a critical water level of 8.8 m at the end of December (https://www.thestar.com.my/news/nation/2023/12/27/13-rivers-in-six-districts-terengganu-exceed-danger-level), and the impact of rainfall during the rainy season was reported to be prolonged.

Therefore, in this study, we recorded the occurrence of mass mortality of farmed oysters, which was thought to be caused by heavy rains during the rainy season. We also suggested future measures to ensure the stable production of oyster farms in this region.

Materials and Methods

Interview survey

We interviewed local fish farmers regarding the damage caused by the mass mortality of oysters in December 2023 and summarised the responses. We also received photos showing the damage at the site. Topographical information on the location of farms was obtained from maps using Google Earth (https://earth.google.com) and the Sentinel-hub EO Browser (https://apps.sentinel-hub.com/) (Fig. 1).

Weather data

Weather information was obtained from the Japan Meteorological Agency website (https://www.data.jma.go.jp/cpd/monitor/index.html). The target sea

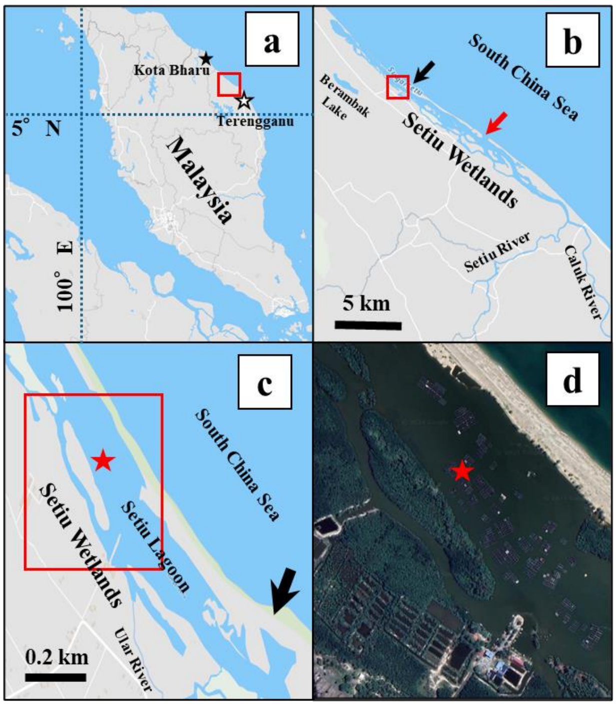

Figure 1

Location of oyster farms in Setiu Lagoon, Peninsular Malaysia. (a) Location of Setiu Lagoon in Peninsular Malaysia (red frame). (b) Location of oyster farms in Setiu Lagoon (red frame). (c) Enlarged view of the location of oyster farms (red star) in Setiu Lagoon (red frame is (d)). (d) Photo at the location of the oyster farms in Setiu Lagoon (red star). The black and white stars represent the meteorological observation points in Kota Bharu and Sultan Mahmud Airport, respectively. The red and black arrows represent the locations of the waterway leading to the sea and former waterway that is now closed, respectively. Maps in Figures a-c were obtained from Sentinel-hub EO Browser (https://apps.sentinel-hub.com/dashboard/#/collections), and Figure d was obtained from Google Earth (Retrieved from https://earth.google.com/web).

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area is located between the meteorological observation stations at Kota Bharu and Terengganu. Therefore, the data observed at a meteorological station in Kota Bharu (latitude: 6.17° N; longitude: 102.28° E; altitude: 5 m), which contain a wealth of past weather data, were used in this study. First, from the data of the average temperature and rainfall for each month from March 2023 to March 2024, we summarised the trends in the average temperature and rainfall for each month in a graph. Moreover, by displaying the average values from 1991 to 2020 in a graph, we determined the rainfall characteristics during the rainy season of 2023. Additionally, to elucidate the wind direction and speed in the target area, we used wind direction and wind speed data observed at Sultan Mahmud Airport in Terengganu (latitude: 5.38° N; longitude: 103.10° E; altitude: 6 m), which were obtained from the Ambient Weather website (https://ambientweather.net/dashboard/airport-wmkn), showing trends from May 2023 to May 2024. For long-term climate change data, we used meteorological data observed at the Kota Bharu weather station from June 1982 to March 2024 from the Japan Meteorological Agency website, and analysed long-term changes in the monthly average temperature and rainfall. In addition to summarising the results in a graph, we also summarised the annual changes in rainfall for each month from October to January, which is the rainy season, in a graph to determine the long-term fluctuation trends for each month. Moreover, we referred to a map of the global monthly mean sea surface temperature for November 2023 and a map of the sea surface temperature deviation distribution based on publicly available data from the Japan Meteorological Agency. These were then summarised as the distributions of monthly average sea surface temperature and its deviation in the sea area around Malaysia.

Satellite data

We obtained a planar distribution map of rainfall in the Malay Peninsula based on satellite data from 16-30 November 2023 from Japan's Satellite Monitoring System of Agrometeorological Information (https://jasmai.maff.go.jp/en/). Additionally, we obtained a sea surface image (true colour) at the time of damage, captured by an artificial satellite (Sentinel-2) on 4 December 2023, from the Sentinel-hub EO Browser (https://www. sentinel-hub.com/explore/eobrowser). Moreover, we plotted the flood area around the Setiu Wetlands when the river water level was 9 m using the Flood Map application (https://www.floodmap.net/?ct=MY).

Environmental data

To determine the sea surface temperature and salinity trends in the target area, the sea surface temperature and salinity data of the area around Setiu Lagoon from May 2023 to May 2024 were obtained from Umitron Pulse (https://www.pulse.umitron.com). We obtained the salinity change data for three layers (sea surface, 5 m depth, and 10 m depth). To understand the basic productivity of the target sea area, we collected data on chlorophyll-a in the same sea area from the Global Eutrophication Watch (https://eutrophicationwatch.users.earthengine.sapp/view/global-eutrophication-watch) (Maure *et al.* 2021). We obtained the chlorophyll-a concentration data and graphed the changes over time from 2003 to 2022.

Results

Interview survey

According to an interview with an oyster farmer in Setiu Lagoon, continuous rainfall from 20 November 2023 caused flooding in the surrounding area. Furthermore, flood damage subsequently occurred in early December, and the coastal areas were covered with rainwater flowing from the land; around the same time, a large number of farmed oysters died (Fig. 2).

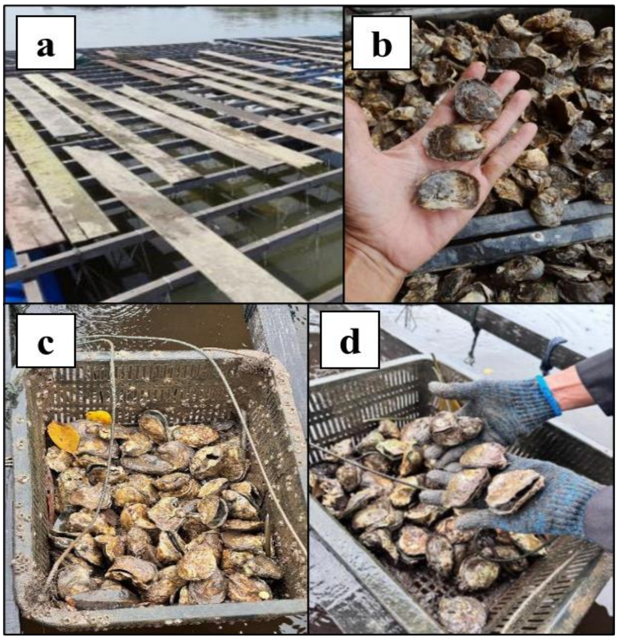

Figure 2. *Photo of oyster farming fishery in Setiu Lagoon. (a) Oyster farming raft. (b) Oysters being farmed. (c) Farmed oysters at the time of damage in December 2023. (d) Dead oysters taken from a basket. The photos were provided by an oyster farmer in Setiu Lagoon.*

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Approximately 50,000 farmed oysters with shell lengths of 1–5 cm died on the affected farms, with a morlity rate of over 90%, and the amount of damage was approximately 70,000 RM (approximately 13,700 EUR) based on fishermen's estimations. Coastal flooding was expected to end by January 2024. When confirming the location of the affected oyster farm on a map, we found that it was located deep on the left bank of Setiu Lagoon (red star in Figures 1b-d). On the right bank, where the Setiu River flows, an approximately 200 m wide channel opens into the sea at only one location (red arrow in Figure 1b).

Weather and environmental data

Trends in the monthly average temperature and rainfall recorded at meteorological stations in Kota Bharu indicated that temperatures were often approximately 0.5 °C higher than normal from April onwards in 2023, and monthly rainfall was also higher than normal from May to September in 2023. Rainfall exceeding 1200 mm/month was observed in November, which was more than double the normal amount, and remained near normal from December to January (Fig. 3).

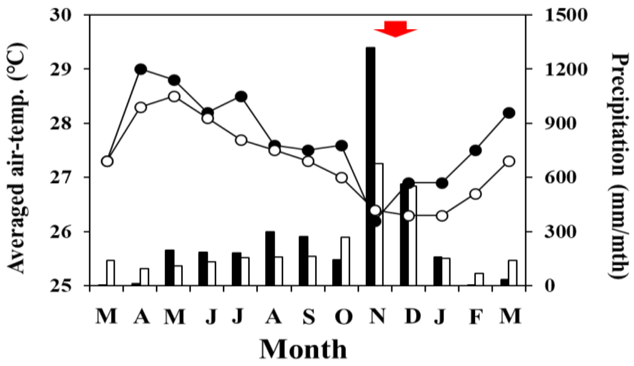

Figure 3. *Changes in the average temperature and rainfall for each month since March 2023, and changes in their statistical normal values. The black and white circles represent the average temperature and normal value of average temperature (1991-2020), respectively. The black and white bars represent the monthly rainfall and normal value of monthly rainfall (1991-2020), respectively. The red arrow indicates the period of mass mortality of oysters.*

Moreover, the wind direction and speed were usually dominated by winds from the north; however, from November to March, winds from the northeast often prevailed (Fig. 4a). Additionally, during the same period, the wind speeds increased, with average wind speeds exceeding 10 km/h; high wind speeds exceeding 20 km/h were recorded in late December (Fig. 4b).

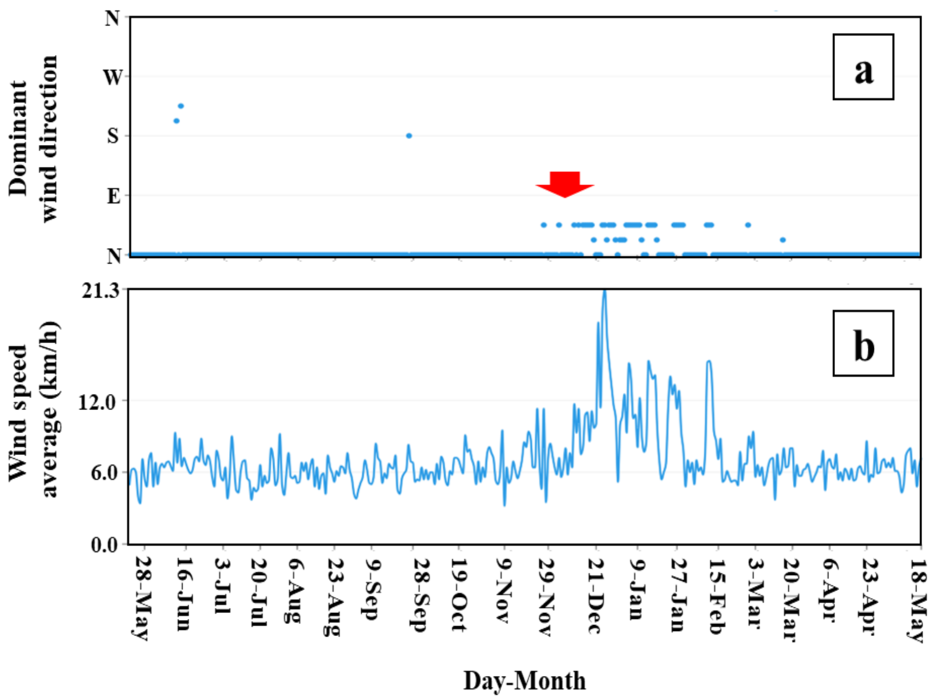

Figure 4
Trends in the predominant wind direction (a) and average wind speed (b) around the fishing ground since May 2023. N, W, S, and E represent the north, west, south, and east directions in Figure a. Data were obtained from Ambient Weather for Sultan Mahmud Airport (https://ambientweather.net/dashboard/airport-wmkn). The red arrow indicates the period of mass mortality of farmed oysters.

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Subsequently, the sea surface temperatu-re around the target area obtained from the Umitron Pulse gradually decreased in November and was below 29 °C in early December. Similar decreases in water temperature were observed from late Decem-ber to early January and February (Fig. 5a).

Salinity fluctuations in the three layers were the clearest at the sea surface, which decreased below 30 PSU in early December and subsequently showed an upward trend with fluctuations, remaining at approximately 32 PSU from April (Fig. 5b).

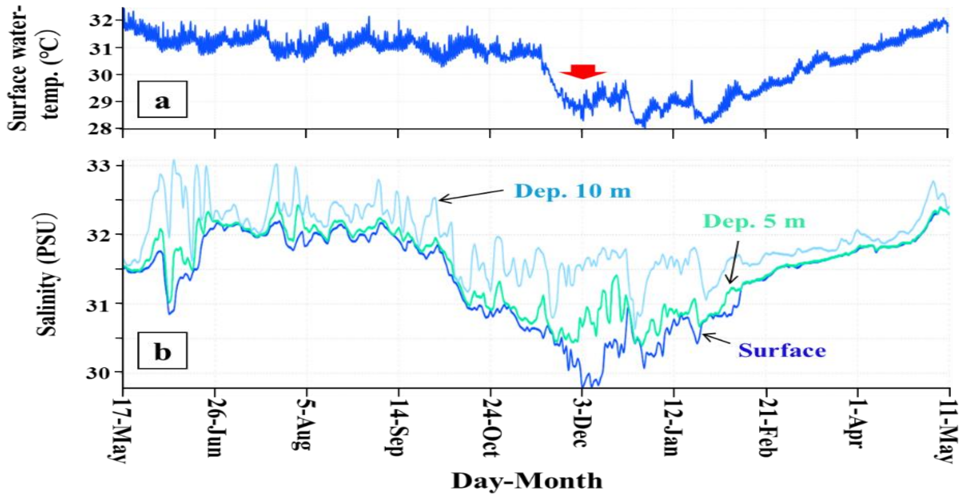

Figure 5
Changes in water temperature (a) and salinity (b) in the sea area around Setiu Lagoon. The data were obtained from Umitron Pulse (https://www.pulse.umitron.com). The red arrow indicates the period of mass mortality of farmed oysters.

Satellite data

Satellite images showed that in November, the monthly rainfall values exceeded 300 mm/month over a wide area on the east coast of Peninsular Malaysia, which was more than 200 mm/month higher than normal values (Figs. 6a and 6b). Satellite images of the coastal area captured in early). December through breaks in rain clouds showed murky water with high turbidity flowing into the sea from the channel opening (Fig. 6c). Furthermore, we simulated the flood area for a situation where the river water level reached 9 m, based on a local newspaper report at the end of December, and found that a land area extending approximately 5 km

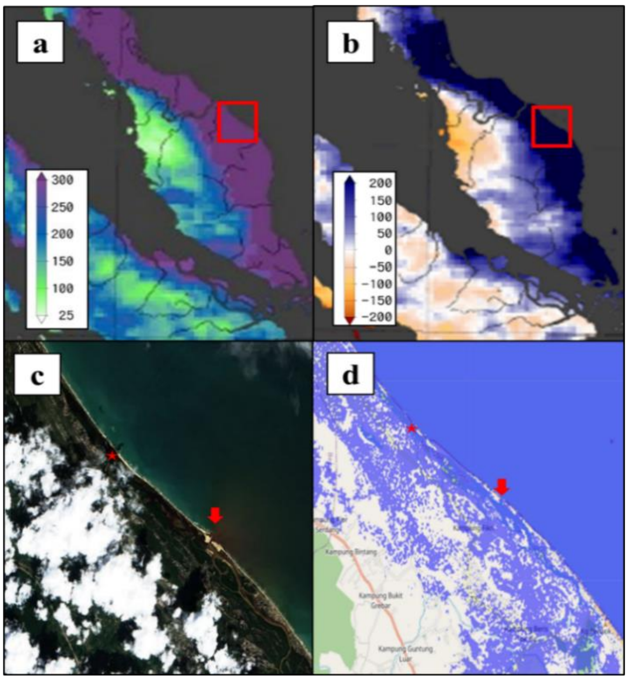

Figure 6.
Precipitation distribution (unit: mm) (a), difference in distribution compared with statistical values (unit: mm) (b) in Peninsular Malaysia from 16-30 November 2023 based on satellite data and true colour image of the Sentinel-2 satellite (c), flood map when the river water level was 9 m (d) around Setiu Lagoon in December 2023. Figures a and b were obtained from the processed data of JAXA "GSMaP precipitation product" from Japan's Satellite Monitoring System of Agrometeorological Information (https://jasmai.maff.go.jp/en/). The red frame in the figure represents the location of Setiu Lagoon. Figure c is a true colour image captured by Sentinel-2 from 0:00 to 23:59 on 4 December 2023 obtained from Sentinel-hub EO Browser (https://apps.sentinel-hub.com). Figure d was obtained from Flood Map (https://www.floodmap.net/?ct=MY). The red stars in Figures c and d indicate the location of the oyster farms, and the red arrows indicates the waterway that connects to the sea.

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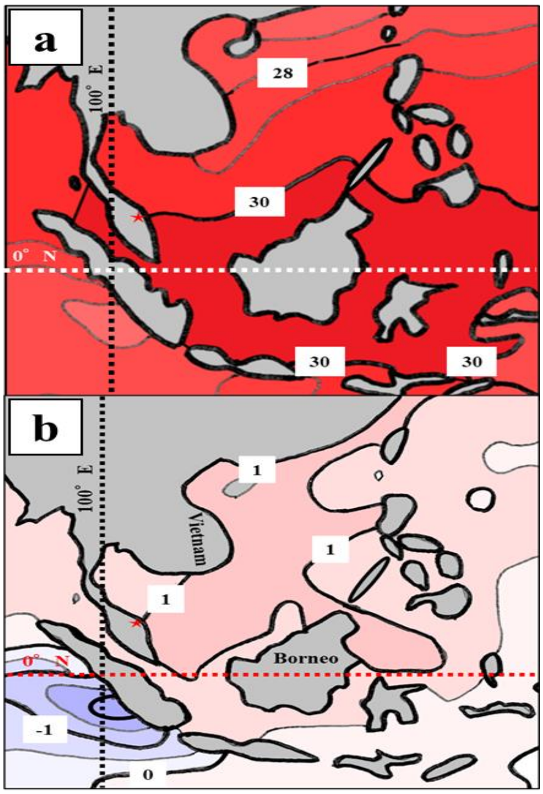

inland from the coast could fall within the flood zone (Fig. 6d). The sea surface temperature distribution in November in the South China Sea, which faces the eastern coast of Peninsular Malaysia, showed water temperatures of 30 °C or higher around Indonesia, and the area around Setiu Lagoon was located at the northern end of the area with high-temperature water (Fig. 7a). Moreover, according to the map of the deviation of sea surface temperature, the water temperature was found to be 1 °C higher than usual in a wide area of the South China Sea, from the east coast of Peninsular Malaysia to the coasts of Vietnam and China in November of that year (Fig. 7b).

Figure 7
The monthly average sea surface temperature distribution (a) and deviation distribution compared with the statistical standard values (b) in the waters around Malaysia in November 2023. Contour intervals area (a) 1.0 °C and (b) 0.5 °C. Star on map is location of the oyster farms. Data were obtained from the Japan Meteorological Agency (https://www.data.jma.go.jp/gmd/cpd/db/elnino/clmrep/sst-global.html)

Long-term changes in the weather and environment

Subsequently, to examine the characteristics of climate change around the fishing grounds, we created a time-series graph of the changes in monthly average temperature and rainfall from 1982 to 2024 (Fig. 8). Consequently, although there were repeated annual fluctuations wherein the temperatures were high and low in the dry and rainy seasons, respectively, the temperature increase estimated from the regression line was approximately 0.001 °C per year, and the temperature increase owing to secular change was almost unrecognised (Fig. 8a). Moreover, although annual fluctuations in monthly rainfall occurred between the dry and rainy seasons, the increase in rainfall estimated from the regression line was appro-

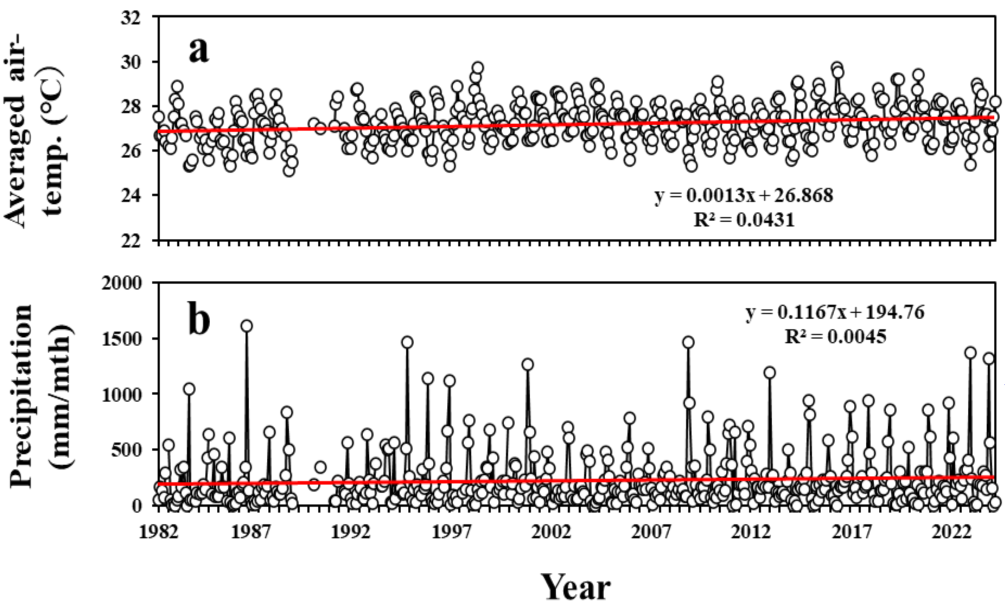

Figure 8
Long-term fluctuations in the monthly average temperature and rainfall acquired at the Kota Bharu meteorological station from June 1982 to March 2024.
The data were obtained from the Japan Meteorological Agency (https://www.data.jma.go.jp/cpd/monitor/index.html)
(a) Monthly average temperature (n=460) and
(b) monthly rainfall (n=457).

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ximately 0.1 mm per year, and almost no increase in rainfall was observed owing to secular change (Fig. 8b). Therefore, we focused on the rainy seasons of October, November, December, and January and investigated the annual changes in the amount of rainfall for each month. The regression line showed a decreasing trend at a rate of approximately 0.26 mm per year in October, an increasing trend of approximately 4.0 mm per year in November, an increasing trend of approximately 3.3 mm per year in December, and an increasing trend of approximately 4.4 mm per year in January (Fig. 9). Additionally, the chlorophyll-a concentration, namely, an indicator of the occurrence of phytoplankton that serve as food for oysters, remained at a low level, generally below 5 µg/L (Fig. 10).

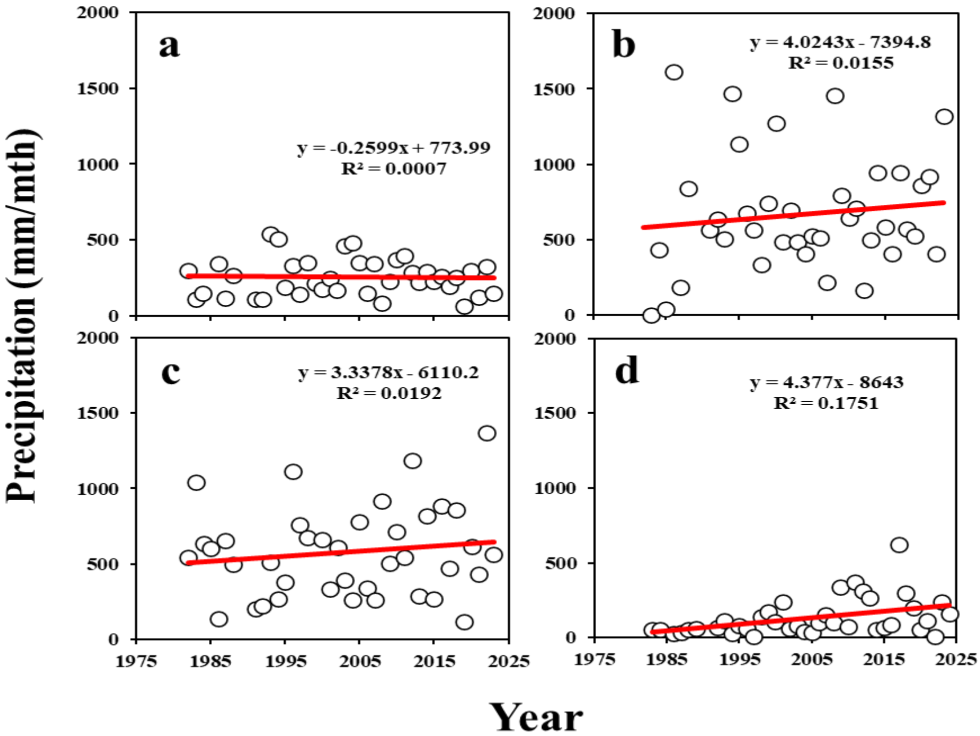

Figure 9
Annual changes in the monthly rainfall from October to January acquired from meteorological stations in Kota Bharu during the period from June 1982 to March 2024. (a) October (n=39), (b) November (n=38), (c) December (n=39), and (d) January (n=39).

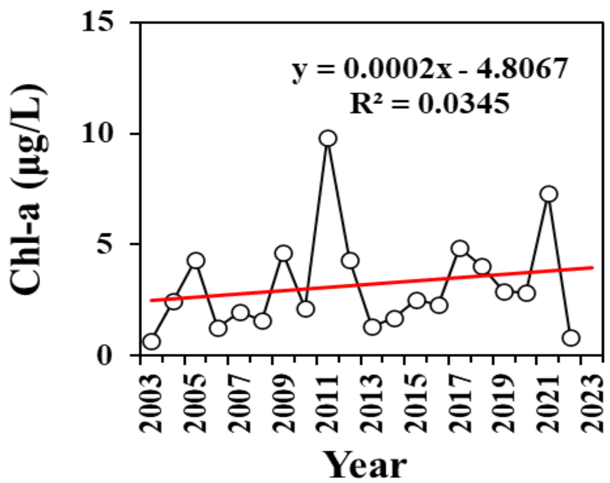

Figure 10. *Annual changes in chlorophyll-a concentration in the sea area around Setiu Lagoon. The data were obtained from the Global Eutrophication Watch (hpps://eutrophicationwatch.users.earthengine.app/view/global-eutrophication-watch).*

Discussion

Influence of salinity on oysters

Considering the influence of salinity on *Crassostrea iredalei*, the results of a diatom feeding experiment (*Chaetoceros calcitrans*) to the juvenile oyster with a shell length of approximately 2 cm at different salinities (15–45 ppt) on the water temperatures of 26–28 °C have been reported. The filtration activity was the highest at a salinity of 35 ppt and decreased at salinities of 15 and 45 ppt (Chang *et al*., 2016). Moreover, the effect of salinity on the period between the floating larval and bottom settlement stages was investigated. Type D larvae had a good survival rate at a salinity of 24–30 ppt, whereas the bottom-settlement stage had a good survival rate of 12–24 ppt. Tan and Wong (1996) reported that the optimal salinity during the settlement period was 12–18 ppt, with a survival rate of > 20%. Additionally, the water temperature and salinity of the species'

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natural fishing grounds and farms have been reported to be 18–28 °C and 17–29‰, respectively (Rosell, 1991). Furthermore, Nadirah *et al.* (2018) examined the physiological response of this species, with a shell length of approximately 10 cm, inhabiting the Setiu Wetlands after two weeks of exposure to a salinity of 7–35 ppt. In the result, the haemocyte number decreased, and superoxide dismutase activity increased, suggesting an adverse effect on immune function, and they observed histological damage in the gills and digestive gland at 7 ppt. These results indicate that if *Crassostrea iredalei* is exposed to an environment with a salinity below 7 ppt for more than two weeks, its immune, feeding, and digestive functions will be adversely affected. Long-term and/or severely low salinity may lead to its death.

Coastal environment

In this study, based on information from fishermen and reports from local newspapers, we believed that intermittent flooding occurs in coastal areas from the end of November to December. According to meteorological data, rainfall of more than 1200 mm/month was recorded in November, which is more than double the normal amount (Fig. 3). Local newspapers reported that even at the end of December, the river water level reached approximately 9 m above the dangerous water level, prolonging the peak of the rainy season. Even after this period, there was a time lag for rainwater in the upstream area to reach the river mouth; therefore, we presumed that the river remained swollen for more than a month. Considering the topography of Setiu Lagoon, there is only one open channel with a width of approximately 200 m that connects to the sea (Fig. 1b). As seawater exchange within the lagoon is low, river water is not immediately released into the sea. Thus, we believed that a long-term low-salinity environment was created in the lagoon. To determine the salinity inside a lagoon, as no actual measurement data were available, we obtained calculated data from the Umitron Pulse based on satellite data. These data captured a decrease in sea surface temperature below 29 °C from late November to early February (Fig. 5a). Moreover, the surface salinity decreased slightly but fell below 30 PSU in early December, and subsequently recovered for approximately one week. However, from the end of December to the beginning of January, salinity repeatedly decreased and reached 30 PSU (Fig. 5b). The SAC-D sensor moun-ted on the Aquarius satellite is famous for salinity measurements using an artificial satellite; however, it is mainly suitable for measurements in the salinity range of 32-37 PSU (accuracy of 0.2 PSU) (Aslebagh *et al.*, 2013; Kao *et al.*, 2018; Le Vine *et al.*, 2018). The detection sensitivity was low for low-salinity areas caused by rainwater, as in this study, and the salinity values were thought to be overestimated. We observed changes in sea surface temperature and salinity at a depth of 1 m where oysters were cultivated at an oyster farm in the Merbok Estuary, located on the west coast of Peninsular Malaysia, from the end of October to the beginning of November during the rainy season of 2023. When the river water level increased owing to rainfall, a temporary decreased in sea surface temperature (below 28 °C). Also, during the same period, the salinity remained below 10 PSU for approximately one week, although it fluctuated owing to tidal fluctuations. However, the mass mortality of *Crassostrea iredalei* reared on the farm was not observed on the time (unpublished data). Conversely, considering the water quality observation data from a station (S8) relatively close to the Setiu Lagoon oyster farm and salinity data during the rainy season, a salinity of 11.84 PSU was observed in late December in the past (Zainol *et al.*, 2021). Moreover, the low salinity to below 10 PSU around oyster farms during the rainy seasons of 2003-2010 and 2014-2015 were recorded (Poh *et al.*, 2019). Moreover, in the exposure experiment, Nadirah et al. (2018) showed an exposure experiment result at 7 ppt for 2 weeks; thus, in the case of oyster farms where mass mortality occurred more than 90%, low salinity of less than 7 ppt was considered to have lasted for more than two weeks.

Causes and countermeasures for heavy rain

High rainfall was recorded over a wide area along the eastern coast of Peninsular Malaysia during the rainy season in 2023 (Figures 6a and b). This is thought to be related to sea surface temperature in the South China Sea. Considering the sea surface temperature in November, a wide area of the South China Sea had a high range of water temperature of over 29 °C, which was 1 °C higher than the statistical average value in November (Fig. 7). In such a situation, the northeast monsoon hit the east coast of Peninsular Malaysia in mid-November (Fig. 4). We believed that high water temperatures caused seawater to evaporate, and moist air was blown to the east coast by the northeast winds, causing heavy rain.

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However, considering the long-term changes observed in meteorological data, no clear increasing trend was observed in either average temperature or monthly rainfall (Fig. 8), and we presumed that the effects of global climate change were not significant in the area surrounding Setiu Lagoon. Furthermore, the rate of temperature increase was approximately half that in the west coast of Peninsular Malaysia, where the rate of temperature increase was confirmed through a similar analysis of meteorological data (Yurimoto, 2020). Additionally, the annual change in monthly rainfall showed an increasing trend, which differed from the findings of Penang and Malacca, who showed a decreasing trend in rainfall in a similar analysis (Yurimoto, 2020). Therefore, we investigated the long-term changes in rainfall for each month from October to January, which is the rainy season in the region, and found that although rainfall decreased in October, it increased slightly from November to January (Fig. 9). Notably, the increase in rainfall in January and these results are more noticeable in recent years than in 1980, suggesting that the end of the rainy season is likely to be delayed in January and that the rainy season has become longer (Fig. 9d). Conversely, long-term chlorophyll-a data in Setiu Lagoon showed a slight increasing trend but generally remained at a low level of less than 5 μg/L (Fig. 10). Nutrient-rich freshwater flows from rivers; however, turbid water from land blocks light and inhibits phytoplankton growth. When mixed with highly transparent open ocean water, the amount of light increases and phytoplankton grow easily (Htoo-Thaw *et al.*, 2017). In areas near oyster farms, water quality surveys have reported total suspended solids (TSS) concentrations exceeding 100 mg/L, primarily during the dry season (Suratman *et al.*, 2016). Currently, only one waterway connects Setiu Lagoon to the sea, and another waterway that existed in the past was open until 2012 but closed in 2015 owing to natural topographical changes caused by the northeast monsoon. (Zainol and Akhir, 2019; Poh *et al.*, 2019). Normally, the inflow of river water from the Setiu River is small; therefore, the exchange of seawater within the lagoon is small and vertical mixing of the water column is difficult, which is known to explain the low phytoplankton production (Zainol *et al.*, 2020). To create an environment where phytoplankton can easily proliferate, waterways that existed in the past can be reopened and seawater can flow in from the outside, increasing the vertical mixing of the water column in the area around the oyster farms in the lagoon. The mixing of seawater and water in the lagoon can facilitate the proliferation of phytoplan-kton and improve the food environment for the oysters. Additionally, when flooding occurs owing to heavy rains, such as in this case, more of the inflowing river water can be drained by having two channels connecting the lagoon and sea, mitigating the reduction in the salinity level in the lagoon. Currently, seawater exchange in Setiu Lagoon is limited; therefore, the same water tends to remain inside the lagoon for a long time (Norzilah *et al.*, 2016; Zainol *et al.*, 2022). If freshwater flowing into the lagoon during the rainy season is released into the sea as soon as possible, it will mitigate the decrease in salinity and help prevent the mass death of farmed oysters.

Conclusions

The analysis of meteorological data indicated that the mass mortality of oysters at the Setiu Lagoon oyster farm was related to a monthly rainfall value of more than 1200 mm/month in November, which is more than double the normal amount. At that time, the seawater temperature in the South China Sea was 1 °C higher than normal, and winds from the northeast monsoon supplied humid air to the eastern coast of Peninsular Malaysia. Currently, only one waterway connects the Setiu Lagoon, where the oyster farm is located, to the sea. Until 2012, two waterways connected the lagoon to the sea. Therefore, increasing the number of waterways to two can increase seawater exchange within the lagoon, making it easier for the proliferation of phytoplankton, which are food sources for oysters. Furthermore, we assumed that the decrease in salinity during the rainy season could also be reduced by this method.

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