International Journal of Fisheries and Aquatic Research
www.fishjournals.com
ISSN: 2456-7248
Received: 01-06-2025, Accepted: 01-07-2025, Published: 16-07-2025
Volume 10, Issue 2, 2025, Page No. 1-7

Seasonal variability of sea surface temperature in surabaya, Gresik and Bangkalan waters in neutral phase

Supriyatno Widagdo, Bambang Semedi, dan Muhammad Firdaus
Faculty of Fisheries and Marine Science, Universitas Brawijaya Malang, Indonesia

Abstract
The study was conducted with the aim of analysing the seasonal sea surface temperature (SST) characteristics in SGB waters during the neutral phase, when El Niño and La Niña are not occurring. Data were processed using Ocean Data View and analysed through descriptive statistics and cluster analysis. The results showed that the Madura Strait has seasonal sea surface temperature variability that is strongly influenced by the monsoon system. Sea surface temperature fluctuations form a bimodal pattern, with the narrow and shallow western side relatively warm throughout the season compared to the eastern side of the sea waters which are relatively wide, deep and open to the ocean. The eastern season is a cold period in the waters of all three loci with SSTs of ~30.05 oC. The SST distribution pattern shows that the deep areas of the strait are relatively warmer compared to the waters of the northern side of the strait. The western season with an average SST of 31.17°C has a strong seasonal segregation from Bangkalan to Surabaya waters with SST values of 31.60°C, 31.20°C and 30.70°C respectively. The western season is also characterised by the largest SST range difference of 0.90 oC. SST segregation still occurs in the early spring with a decreasing gradient of 0.20 oC from Bangkalan to Surabaya with an average SST of 31.40 oC. The eastern season which has an average SST of 30.90 oC with a range of 30.90-31.00 oC marks the coldest period of the season. The late transitional period is characterised by the highest average SST throughout the season at 31.57 oC in addition to being characterised by the smallest SST range at 0.10 oC. Spatially, Surabaya SST has similar characteristics with Gresik SST compared to Bangkalan SST.

Keywords: Fisheries, seasonality, temperature, madura strait, neutral phase

Introduction

The waters of East Java, of which Surabaya, Gresik and Bangkalan are part, have the highest fisheries production in Indonesia as of 2021. This condition is supported by the presence of fishermen, fishing boats and fishing ports to the production of captured fisheries in this province (Aida *et al*., 2023). Fisheries in the waters of Surabaya, Gresik and Bangkalan (hereafter SGB) themselves present complex interactions involving ecological factors, in addition to economic and health factors. Ecologically, research by Mahmudiono *et al*. (2020) [17] showed the presence of significant levels of mercury in fish from Kenjeran beach in Surabaya. In line with that, the results of water quality research using temperature and COD parameters as indicators conducted by Maulana & Kuntjoro (2023) [18] in Kali Surabaya, Wringinanom, Gresik as one of the rivers that empties into SGB waters, showed the effect of pollution on macrobenthos biodiversity which was at a moderate index.

Temperature influences biological and chemical processes and thus significantly affects the growth and survival of contaminants in various environments (Bhatt *et al*., 2024; Garzón, 2004; Raths *et al*., 2022) [4, 8, 21]. Temperature effects on marine ecosystems are profound and diverse, affecting metabolic rates, community structure, and overall ecosystem health. The results of Archibald *et al*. (2022) [2], for example, showed that increasing ocean temperatures directly affect marine ecosystems by increasing metabolic rates, leading to higher productivity followed by lower biomass stocks. Correspondingly, Venegas *et al*. (2023) [23] stated that ocean warming affects marine ecosystems by altering the physiology, abundance and distribution of species, while reducing oxygen availability which in turn impacts trophic interactions. Chabrerie & Arenas (2024) [5], added that increasing temperatures in marine ecosystems especially in coastal areas, as stated by Chabrerie & Arenas (2024) [5], significantly increase respiration rates and decrease productivity, especially in canopy-forming species such as seaweeds. This leads to compositional shifts and a potential decline in overall ecosystem health and services.

Overfishing is also an important fisheries management issue in the region. Overfishing in the waters of the SGB and the Madura Strait in general has reached critical levels, thus significantly impacting local fish populations and the livelihoods of fishing communities. Research shows that overfishing with various fish species exploited beyond sustainable limits has been a persistent problem since at least 1997 (Muhsonim & Nuraini, 2006; Hidayah *et al*., 2020) [11, 19].

This condition is also exacerbated by the increase in global temperature caused by climate change which is intensifying with impacts that are increasingly widespread and penetrating various regions, especially in coastal waters that are directly adjacent to the sea. The increase in global temperature, which is currently about 1 oC above pre-industrial levels, has posed a significant threat to ecosystems ('Interactions between Climate Change and Contaminants', 2022; Gagnon, 2022; MacCracken, 2009) [7, 16]. Li & Convertino's (2021) research in Maizuru Bay, Japan confirms this. Their results showed a 25% decrease in fish diversity due to a 20% increase in local temperature. In addition, changes in species interactions due to temperature fluctuations can disrupt fish communities, leading to critical slowdowns and decreased ecosystem resilience. Liu (2024) [15] stated that rising ocean temperatures due to global warming affect physical, chemical and biological processes in marine ecosystems, leading to significant changes such as ocean acidification, which impacts marine life and fish catches.

The above review emphasises the importance of understanding the characteristics of sea surface temperature in SGB waters, not only because it is related to its existence as one of the main supporters of high fisheries production in Indonesia (East Java) which is experiencing overfishing practices; but also the threat of degradative environmental aspects that are increasingly worrying along with the ongoing impacts of global warming due to climate change that are increasingly threatening and diverse. The objective to be achieved in this study is to analyse the seasonal sea surface temperature variability in the Madura Strait as well as the waters of Surabaya, Gresik and Bangkalan as a narrow and shallow part of the Madura Strait during the Neutral phase, when ENSO is not occurring.

Research Methods

This research was conducted in two research areas. The first area is located on the coast of the Madura Strait, which stretches from the narrow and shallow west side to the wide and deep east side with a geographic coverage between 6.40°-7.55° N and 112.30°-114.20° East. This division considers significant spatial heterogeneity, both in terms of seabed topography and the influence of regional oceanographic dynamics. The location of the study is shown in Figure 1A. The second area is on the north-west side of the ‘swan neck’ of the strait, which includes the waters of Surabaya, Gresik and Bangkalan. Geographically, the second study site covers an area with boundaries: 7.55°-7.75°N; 112.50°-112.60°E. The study sites represent a semi-enclosed area on the western side of the narrow strait; while on the eastern side lies the wide strait mouth facing the oceanic region of the Java Sea to the east of the Madura Strait (Figure 1B). The study locus includes three waters at the entrance to the northern side of the Madura Strait, namely the waters of Surabaya, Gresik and Bangkalan with each having geographic coordinates: 7.25°N, 112.833°E; 7.155°N, 112.677°E and 6.917°N, 112.75°E.

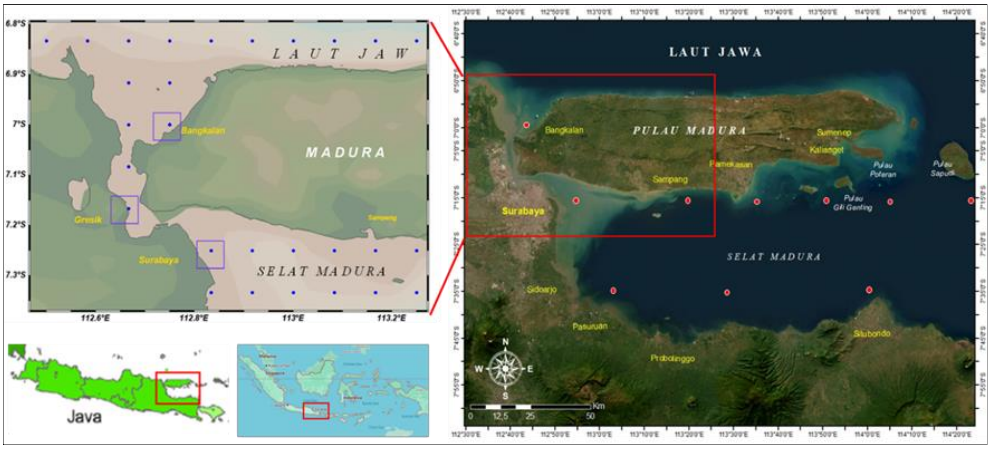

Fig 1: The research location covers the waters of the Madura Strait in general from the relatively closed and shallow western side to the wide and open eastern side (A), as well as the narrow and shallow waters of the western side of the strait with the study locus in the coastal waters of Surabaya, Gresik and Bangkalan (B).

The data used in this study are sourced from the Copernicus Marine Environment Monitoring Service (CMEMS) and are secondary. The data consists of sea surface temperature in two periods of neutral phase which is continuous, that is, in one seasonal cycle in a year not interrupted by global climatic phenomena such as ENSO, either El Niño or La Niña or Indian Ocean Dipole (IOD), both positive and negative. The Neutral phase used has an Oceanic Niño Index (NOI) value of 0.2-0.5. The two Neutral phases include:

- The Neutral Phase from June 2019 to May 2020 is used as data to describe the overall surface temperature distribution of the Madura Strait,
- the Neutral Phase from December 2015 to November 2016 which is used as a comparison to strengthen and/or weaken the surface temperature distribution at the same location as part of the overall Madura Strait and a different Neutral period.

The year-long data were further grouped quarterly to represent the seasonal period. The western season has a temporal span of December, January and February (DJF), the Early transition spans March, April, May (MAM), and so on. Data collection is emphasised during this period to eliminate global climatic effects caused by ENSO and IOD. Thus, a relatively ‘natural and clean’ picture of sea surface temperature fluctuations will be obtained from neighbouring global climatic influences. The data were processed with Ocean Data View (ODV) to obtain seasonal SST distribution maps supplemented with descriptive statistical analyses. In addition, to understand the similarity of seasonal SSTs between the three loci, the data were also multivariate analysed using hierachical cluster analysis displayed through heat maps with dendrograms.

Results and Discussion

Madura Strait Waters

In general, sea surface temperature (hereinafter abbreviated as SST) in the Madura Strait waters in the neutral phase, as shown in Figure 2, has a range of about 30 oC to 32 oC. The west season is the season with the hottest SST distribution, while the coldest SST distribution is found in the east season although with relatively small inter-seasonal SST differences. In the western season, SST ranges from about 30.5-32.5 oC (Figure 2A). The hottest area is centred on the western side of the strait, particularly in the Bangkalan-Surabaya-Sidoarjo region, and it extends upwards to the northern coast of the strait. Lower SSTs are generally found on the southern side of the strait and the eastern areas that are relatively open to the open sea.

The following season in the early transitional season, the SST pattern of the western season experienced a strengthening of zonation segregation. The Bangkalan-Surabaya-Sidoarjo area up to the north coast of the strait is more prominent than the south-east side. A different pattern is found in the eastern season. As shown in Figure 2B, in contrast to the previous two seasons, this season's SST shows a high-temperature area (~31.5 oC) on the southern side of the strait (Sidoarjo to Situbondo). In the eastern area, especially in the area of Sapudi Island and its surroundings, SST experienced its nadir value throughout the season with ~30 oC. This decrease in SST is thought to be caused by the influx of cold-water masses from cold Australian waters carried by the east monsoon current.

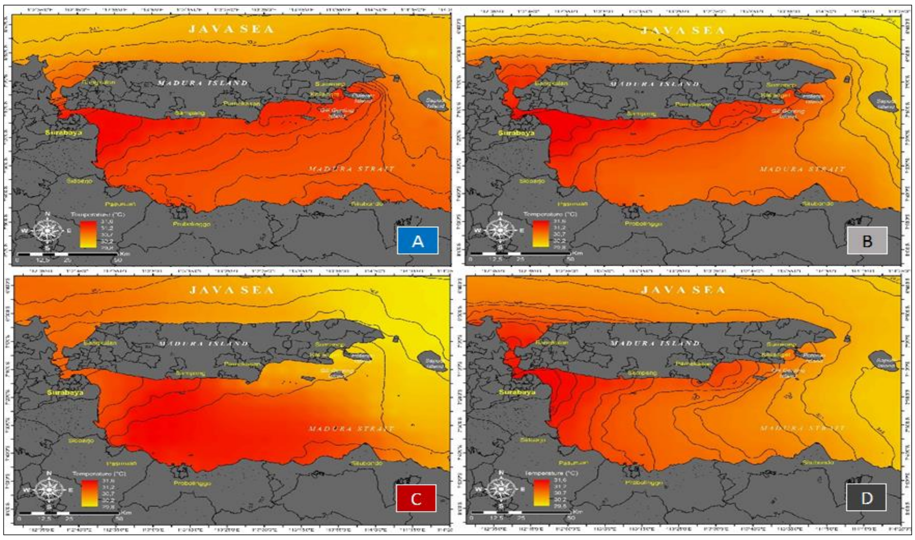

Fig 2: Surface temperature distribution in Madura Strait waters during the neutral phase: west monsoon (A), Early transition (B), east monsoon (C) and Late transition (D).

After cooling during the eastern season, the strain isotherm in the Madura Strait water body began to spread evenly with a high SST zoning pattern that began to form on the west side of the strait and gradually decreased SST on the east side (Figure 5.2D). The cold area indicates that there is still an influx of cold-water masses that are now weakening during the Late transition. A prelude to the maturation of the isotherm distribution as it will occur in the western season. It can thus be stated that the SST distribution during the neutral phase of the Madura Strait characterises a relatively strong monsoonal zonation with relatively small inter-seasonal variations (1.00-2.00 oC) typical of tropical temperature variations.

The monsoon system, characterised by seasonal wind reversals, plays an important role in the Java Sea and Madura Strait. In the Java Sea, the monsoon significantly affects SST. The southeast monsoon is associated with cooler SSTs due to increased mixing and wind-induced upwelling, while the northwest monsoon leads to warmer SSTs. This seasonal SST variability is a direct result of the influence of the monsoon on wind patterns and ocean currents (Haryanto *et al*., 2019; Hafiz *et al*., 2024) [9, 10].

In the Madura Strait, significant seasonal SST variations are mainly due to the influence of the monsoon cycle. During the western monsoon SST tends to increase and decrease during the eastern monsoon (Yuliardi *et al*., 2024) [25]. Meanwhile, during the southeast monsoon (May to September), the region experiences strong winds from the southeast, leading to increased salinity and decreased SST compared to the northwest monsoon period (Siregar *et al*., 2017; Haryanto *et al*., 2019) [9, 22].

Furthermore, although not specifically mentioning the Madura Strait, the results of Siregar *et al*. (2017) [22] and Kok *et al*. (2021) [13] mentioned that the rainy season affects the exchange of water masses in the Java Sea. During the southeast monsoon, the Indonesian Throughflow (ITF) is strengthened, bringing water masses from the Makassar Strait to the Java Sea. This results in higher salinity levels and cooler temperatures. In contrast, during the northwest monsoon, water masses from the South China Sea dominate, causing different oceanographic conditions. In addition to the monsoon system, the oceanographic conditions of the Madura Strait including its surface temperature are influenced by regional climatic phenomena. The influence of the monsoon is interconnected with other climatic phenomena such as the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). These interactions can strengthen or reduce the monsoon effect in the Java Sea and Madura Strait, further affecting regional climate variability (Hafiz *et al*., 2024; Xu & Xu, 2014) [10, 24].

The western side of the Madura Strait, which is more exposed to the open Java Sea, may experience different temperature dynamics compared to the more enclosed eastern side. The western side is likely to be influenced by the wider oceanic conditions in the Java Sea, which can lead to higher temperatures during certain seasons (Yuliardi *et al*., 2024) [25].

Surabaya-Gresik-Bangkalan Waters

The seasonal distribution of sea surface temperature (hereafter abbreviated as SST) in the waters of Surabaya, Gresik and Bangkalan (hereafter abbreviated as SGB) during the neutral phase shows quite distinct distribution patterns. As shown in Figure 3, the eastern season marks the seasonal cold period when SGB waters are dominated by SSTs of ~30.05 oC. The colder region during this season is found on the inner side of the strait, i.e. on the eastern side of Surabaya.

In other seasons, in general, the SST horizoantal distribution pattern can be said to be divided into two general zones, namely a warm zone that dominates the southeastern waters of the swan-necked strait, namely the coastal waters of Surabaya and Gresik; while a relatively higher zone is found in the coastal waters and Bangkalan to the north-northwest which is an open area in the southern Java Sea. The segregation of these two zones is more clearly recorded in the west season with the warm zone having temperatures in the range of about 31.00-31.60 oC in the Surabaya-Gresik waters, while the coastal waters of Bangkalan to the north-northwest have a relatively cooler and narrower range of SST in the range of about 30.50-30.30 oC. During the Early transition, the waters in the three loci became warmer with the spread of warm SST to the mouth of the strait on the north-northwest side. The peak warming of the Madura Strait in the SGB water area occurred during the Late transition with higher TLP values (~31.50 oC).

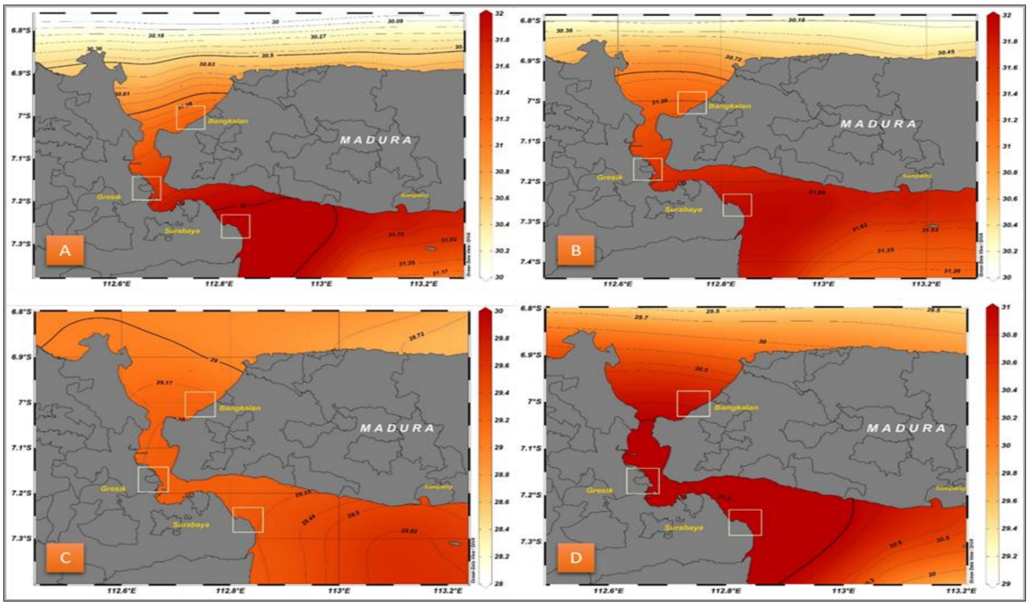

Fig 3: Seasonal SST distribution in Surabaya-Gresik-Bangkalan waters during the western season (A), early spring (B), eastern season (C) and late spring (D). The eastern season marks the cold period throughout the locus area.

Seasonal fluctuations at each locus as shown in Figure 4 show a sharp decrease in SST from the southern waters of the locus (Surabaya) to the northern side (Bangkalan) with a degree of decrease reaching 4.1997 in the first degree of the polynomial. Respectively, SST in SGB waters was recorded at 31.60°C, 31.20°C and 30.70°C with an average seasonal SST of 31.17°C. These fluctuations in SST values reaffirm the horizontal distribution of SST as shown in Figure 2A. A decrease in SST in the south-north direction was also found two seasons later (Early transition and eastern season) with a smaller third-degree polynomial (-0.3519). The mean SST of the eastern season only reached 30.90°C which was the smallest mean throughout the season. In this season SST in SGB waters only reached 31.00 oC, 30.80 oC and 30.90 oC respectively.

Seasonal fluctuations at each locus as shown in Figure 4 show a sharp decrease in SST from the southern waters of the locus (Surabaya) to the northern side (Bangkalan) with a degree of decrease reaching 4.1997 in the first degree of the polynomial. Respectively, SST in SGB waters was recorded at 31.60°C, 31.20°C and 30.70°C with an average seasonal SST of 31.17°C. These fluctuations in SST values reaffirm the horizontal distribution of SST as shown in Figure 2A. A decrease in SST in the south-north direction was also found two seasons later (Early transition and eastern season) with a smaller third-degree polynomial (-0.3519). The mean SST of the eastern season only reached 30.90°C which was the smallest mean throughout the season. In this season SST in SGB waters only reached 31.00 oC, 30.80 oC and 30.90 oC respectively.

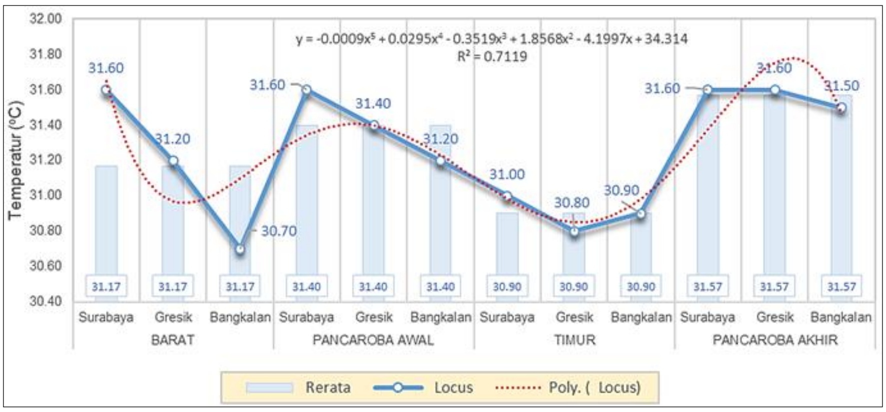

Fig 4: SST fluctuations in the coastal waters of Surabaya, Gresik and Bangkalan which generally show relatively high SST in Surabaya waters and relatively low SST during the eastern season in all three loci.

Furthermore, the trend of SST increased from the early east-mid-year season to the late-year season (+0.0295 in the fourth degree). During the end of the year SST in the south - north direction of SGB waters showed a slight decrease with SST values of 31.60°C, 31.60°C and 31.50°C respectively with an average SST of 31.60°C. The mean SST was the highest mean throughout the season. This condition also confirms the peak of the warm period of SGB waters that occurred at the end of the year. Seasonal fluctuations in SST also confirm the relatively high SST of Surabaya coastal waters throughout the season at 31.60 oC. An exception occurs in the eastern season which marks the coldest period of SGB waters. During this period of seasonal SST decline Surabaya coastal waters reached 31.00 oC. Although this SST value is relatively lower by 0.60 oC than other seasons, in the eastern season the SST is 0.01-0.02 higher compared to Bangkalan and Gresik waters.

The seasonal range of SST in SGB waters also shows a specific pattern. During the western season the SST range reached 0.90°C with a maximum mean SST range of 31.60 and a minimum mean SST range of 30.70°C. This value was the highest SST range throughout the season (Figure 5). Uniquely, this SST range narrows to its lowest value during the early transitional period when the SST range reaches only 0.1 oC (31.60 oC - 31.50 oC). This range is smaller when compared to the SST range of the eastern season (0.20 oC) and Early transition (0.40 oC).

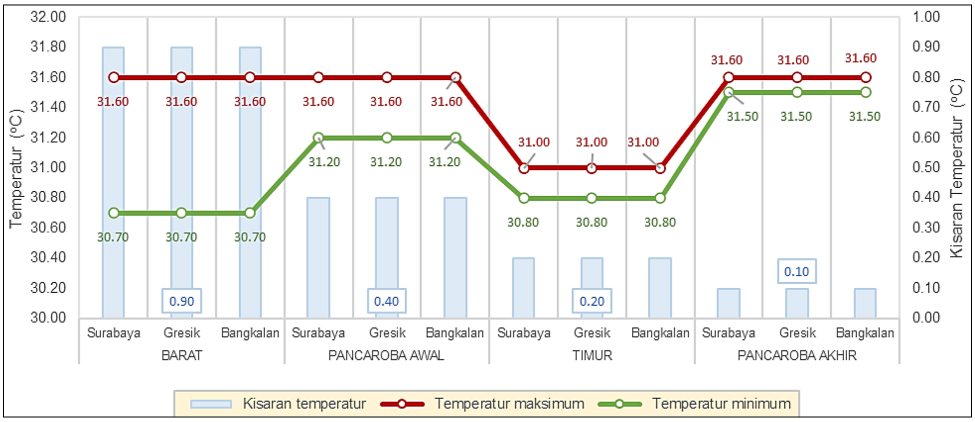

Fig 5: Inter-seasonal comparison of maximum and minimum SSTs at the three aquatic loci generally confirms the relatively high range of SSTs during the western and early transitional seasons and the low range of SSTs during the early transitional and eastern seasons.

The high range of SSTs, characterised by higher maximum and minimum SSTs, indicates a dynamic process of ocean-atmosphere interaction resulting in intensive warming. The boreal winds due to the barometric difference from Asia to Australia that mark the dry period are thought to play a major role (discuss). As the monsoonal wind system weakens, entering the Early transition that marks the end of the west monsoon, the SST warming trigger also weakens with the maximum and minimum SST differences also shrinking.

The high range of SSTs, characterised by higher maximum and minimum SSTs, indicates a dynamic process of ocean-atmosphere interaction resulting in intensive warming. The boreal winds due to the barometric difference from Asia to Australia that mark the dry period are thought to play a major role (discuss). As the monsoonal wind system weakens, entering the Early transition that marks the end of the west monsoon, the SST warming trigger also weakens with the maximum and minimum SST differences also shrinking.

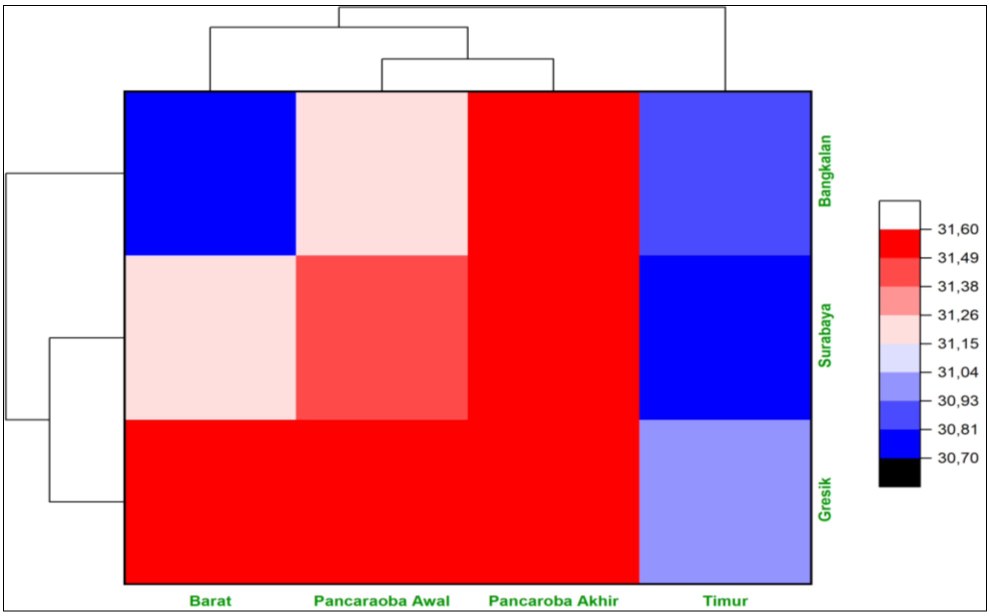

Fig 6: Heatmap of SSTs in SGB waters showing temporal cluster proximity of inter-transitional SSTs and spatial cluster proximity of Surabaya-Gresik SSTs.

Spatially based on the level of difference in the SST range, Surabaya waters with a SST range of 30.70-30.81 oC actually have more in common with Bangkalan waters which have a SST range of 30.81-30.93 oC than with Gresik waters whose SST range is 30.93-31.04 oC. However, the cluster analysis results show that the Surabaya-Gresik SST spatial cluster is closer than the Surabaya-Bangkalan SST spatial cluster. This is accompanied by consideration of all spatial and temporal axes that unequivocally show the prominence of relatively cold SSTs in Bangkalan waters in the west monsoon, while warmer SST conditions are closer together in Surabaya-Gresik waters. The relatively close SST range of Surabaya-Gresik compared to Surabaya-Bangkalan also occurred during the Early transition. During the late transitional period warm SSTs with a range of 31.49-31.60 oC occurred in the waters of the three loci. Therefore, spatially the SSTs of Surabaya and Gresik waters are closer in forming a cluster. The Surabaya-Gresik SST cluster further completes the overall spatial cluster by building a new SST cluster with Bangkalan waters. SST cluster analysis through heapmaps also reaffirmed the relatively cold SST of the eastern season with a long range of 30.70-31.04 oC; while the late spring marked the warmest period of the season at all loci with SSTs that had a short range of 31.49-31.60.

Spatially based on the level of difference in the TPL range, Surabaya waters with a TPL range of 30.70–30.81 oC actually have a closer proximity to Bangkalan waters which have a TPL range of 30.81–30.93 oC than to Gresik waters which have a TPL range of 30.93–31.04 oC. However, the results of the cluster analysis show that the Surabaya–Gresik TPL spatial cluster is closer than the Surabaya–Bangkalan TPL spatial cluster. This is accompanied by consideration of all spatial and temporal axes which clearly show the relatively cold TPL in Bangkalan waters during the west season, while warmer TPL conditions occur in Surabaya–Gresik waters. The relatively close range of Surabaya–Gresik TPL compared to Surabaya–Bangkalan also occurs in the early transition season. During the late transition season, warm TPL with a range of 31.49–31.60 oC occurs in the waters of the three loci. Therefore, spatially, the TPL of Surabaya and Gresik waters are closer in forming one cluster. The Surabaya-Gresik TPL cluster then completes the entire spatial cluster by building a new TPL cluster with Bangkalan waters.

TPL cluster analysis through heapmap also reaffirms the relatively cold TPL of the east season with a long range of 30.70–31.04 oC; while the final transition period marks the warmest period throughout the season at all loci with TPL that has a short range of 31.49–31.60 oC. Meanwhile, the west season clearly shows a very strong segregation through the increasingly warm TPL gradient from the northern waters (Bangkalan) which is the entry point for water masses from the Java Sea in the north to the Surabaya waters which are part of the "deep waters" of the Madura Strait on the southeast side.

The results of the above study are in accordance with the results of research by Yuliardi *et al*. (2024) [25] and Ayu (2015) [3] who found that TPL in the Madura Strait increased during the west season. This is associated with the position of the sun in the southern hemisphere, which results in higher solar radiation and warmer temperatures in the region. Complementing this, Yuliardi *et al*. (2024) [25] also highlighted that TPL increased during the west season, influenced by the monsoon cycle and river discharge, which also affected salinity levels. The west season is characterized by higher SST values, with temperatures reaching up to 30.17° C during the early transition period, as noted in research in the Madura Strait ("Salinity and Surface Temperature Distribution Based on Wind and Currents in the Madura Strait", 2023). East Season or Southeast Monsoon TPL decreased. This is due to reduced solar radiation as the sun moves north, which causes cooler temperatures in the region. The east monsoon is characterized by lower TPL values, with the lowest average temperature recorded at around 28.38°C ("Salinity and Surface Temperature Distribution Based on Wind and Current in Madura Strait", 2023). The influence of the southeast monsoon results in a cooler TPL, as observed in various studies focusing on the Madura Strait and its surrounding areas (Raihan *et al*., 2024) [20].

Conclusion

The Madura Strait has seasonal sea surface temperature variability that is strongly influenced by the monsoon system. Sea surface temperature fluctuations form a bimodal pattern, with the narrow and shallow western side relatively warm throughout the season compared to the relatively wide, deep and open eastern side of the sea waters to the ocean.

The TPL of the SGB waters has characteristics that are responsive to the season. The east season marks the cold period in the waters of the three loci with a TPL of ~30.05 oC. The seasonal TPL distribution of these waters is also marked by the inner area of the strait, namely the waters on the east-southeast side of Surabaya, which are relatively warmer compared to the waters on the north side of the strait.

The west season which has an average TPL of 31.17 oC is marked by a clear TPL segregation. A wider TPL gradient is formed from the waters of Bangkalan to Surabaya with TPL values of 31.60 oC, 31.20 oC and 30.70 oC respectively. The west season is marked by the largest difference in TPL range throughout the season of 0.90 oC (30.70–31.60 oC). A season later, TPL segregation still occurs with a decreasing gradient of 0.20 oC from Bangkalan to Surabaya. The average TPL in this early transition season reaches 31.40 oC. TPL occurs in the east season with a TPL range of 30.90–31.00 oC with an average of 30.90 oC. This is thought to be due to the entry of water masses from the cold waters around Australia which are carried to the Madura Strait along with the monsoon winds. The final transition season is marked by the highest average TPL throughout the season of 31.57 oC. In addition, with a TPL of 0.10 oC, the final transition season also marks the season with the smallest TPL range (31.50–31.60 oC) that has ever occurred season after season. Spatially, Surabaya TPL has similar characteristics with Gresik TPL which is located closer, compared to Bangkalan TPL. Meanwhile, temporally, TPL between transition seasons has strong similarity in TPL characteristics. The cluster with the early and late transition seasons then forms a new, larger cluster with the west season. The hierarchy of these three seasons then completes the cluster hierarchy by forming a new cluster with the east season. The cold period of the east season with the lowest TPL throughout the season in all three loci makes the east season the most different season and at the same time becomes the final component of the cluster that complements the temporal hierarchy.

Reference

1. Aida GR, Illahi RW, Pramesthy TD. Analisys of The Effect of Fisherman, Fishing Boat, and Fishery Ports on Catching Fisheries Production in East Java Province. Barakuda,2023:5(1):35–44. https://doi.org/10.47685/barakuda45.v5i1.338
2. Archibald KM, Dutkiewicz S, Laufkötter C, Moeller HV. Thermal responses in global marine planktonic food webs are mediated by temperature effects on metabolism. Journal of Geophysical Research: Oceans, 2022, 127(12). https://doi.org/10.1029/2022jc018932
3. Ayu W. Study of Sea Surface Temperature Using Aqua MODIS Satellite Imagery and Landed Fish Catch at Palabuhan Ratu Archipelago Fisheries Port, 2015. https://repository.ipb.ac.id/handle/123456789/74672
4. Bhatt P, Kumar V, Singh S, Kanojia K. *Climatic/Meteorological Conditions and Their Role in Biological Contamination*, 2024, 56–88. https://doi.org/10.1002/9781394178964.ch4
5. Chabrerie A, Arenas F. What if the upwelling weakens Effects of rising temperature and nutrient depletion on coastal assemblages, 2024. Oecologia. https://doi.org/10.1007/s00442-024-05571-6
6. Distribution of Salinity and Surface Temperature Based on Wind and Current in Madura Strait. Journal of Tropical Marine Research J-Tropimar,2023:4(1):1–15. https://doi.org/10.30649/jrkt.v4i1.64
7. Gagnon JS. Significance of a 1 °C increase in global temperature. *European Journal of Physics*,2022:43(6):065101. https://doi.org/10.1088/1361-6404/ac812a
8. Garzón L. Microbial life and temperature: a semi empirical approach. Origins of Life and Evolution of

Biospheres,2004:34(4):421–438. https://doi.org/10.1023/B:ORIG.0000029885.80109.8D

9. Haryanto YD, Agdialta R, Hartoko A, Anggoro S, Zainuri M. Effect of The Monsoon to Sea Surface Temperature in The Java Sea, 2019, 86–89. https://doi.org/10.2991/ICOMA-18.2019.19
10. Hafiz M, Widagdo S, Prasita VD. Upwelling intensity during the El Niño–Southern Oscillation ENSO period in the southern waters of Java. Journal of Tropical Marine Research J-Tropimar,2024:6(1):1–10. https://doi.org/10.30649/jrkt.v6i1.77
11. Hidayah Z, Nuzula NI, Wiyanto DB. Analysis of Sustainability of Fisheries Resources Management in the Madura Strait Waters of East Java,2020:22(2):101–111. https://doi.org/10.22146/JFS.53099
12. Interactions between Climate Change and Contaminants. CRC Press eBooks, 2022, 157–180. https://doi.org/10.1201/9781003149774-8
13. Kok PH, Wijeratne S, Akhir MF, Pattiaratchi C, Roseli NH, Ali FS *et al*. Interconnection between the Southern South China Sea and the Java Sea through the Karimata Strait. Journal of Marine Science and Engineering,2021:9(10):1040. https://doi.org/10.3390/JMSE9101040
14. Li J, Convertino M. Temperature increase drives critical slowing down of fish ecosystems. *PLOS ONE*, 2021, 16(10). https://doi.org/10.1371/JOURNAL.PONE.0246222
15. Liu Z. Impacts of Global Warming on Marine Ecosystems: Ocean Acidification and Fish Catches. Applied and Computational Engineering,2024:56(1):12–17. https://doi.org/10.54254/2755-2721/56/20240051
16. MacCracken MC. The Increasing Pace of Climate Change. *Strategic Planning for Energy and the Environment*,2009:28(3):8–25. https://doi.org/10.1080/10485230909509197
17. Mahmudiono T, Nasikhah AD, Wishesa CC, Indriani D, Setyaningtyas SW. Mercury exposure from fish in the kenjeran beach area, surabaya: research protocol. Systematic Reviews in Pharmacy,2020:11(8):414–417. https://doi.org/10.31838/SRP.2020.8.60
18. Maulana MA, Kuntjoro S. Relationship of Macrozoobenthos Diversity Index with Water Quality of Surabaya River, Wringinanom, Gresik. LenteraBio,2023:12(2):219–228. https://doi.org/10.26740/lenterabio.v12n2.p219-228
19. Muhsonim FF, Nuraini C. Study of the Level of Utilization of Fish Resources in the Madura Strait Waters Using Holistic Methods and Its Economic Analysis, 2006, 13(1). http://ejournal.umm.ac.id/index.php/protein/article/view/22/
20. Raihan AS, Atmadipoera AS, Naulita Y, Balbeid N, Noviyanti R. Assessment of Oceanographic Trend and Ocean Health Index in The Gulf of Madura. E3S Web of Conferences,2024:483:01012. https://doi.org/10.1051/e3sconf/202448301012
21. Raths J, Švara V, Lauper BB, Fu Q, Hollender J. Speed it up. How temperature drives toxicokinetics of organic contaminants in freshwater amphipods. *Global Change Biology*,2022:29(5):1390–1406. https://doi.org/10.1111/gcb.16542
22. Siregar SN, Sari LP, Purba NP, Pranowo WS, Syamsuddin ML. Water mass exchange in the Java Sea against monsoon and Arlindo periodicity in 2015,2017:6(1):44–59. https://doi.org/10.13170/DEPIK.6.1.5523
23. Venegas RM, Acevedo J, Treml EA. Three decades of ocean warming impacts on marine ecosystems. A review and perspective. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 2023. https://doi.org/10.1016/j.dsr2.2023.105318
24. Xu J. Change of Indonesian Throughflow outflow in response to East Asian monsoon and ENSO activities since the Last Glacial. Science China-Earth Sciences,2014:57(4):791–801. https://doi.org/10.1007/S11430-014-4845-0
25. Yuliardi AY, Rahman HA, Sari RJ, Rahmalia DA, Nugroho AT, Prayogo LM. Analysis of Seasonal Variations of Temperature, Salinity, and Surface Currents in Madura Waters. Indonesian Journal of Oceanography,2024:6(4):292–305. https://doi.org/10.14710/ijoce.v6i4.24477