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RESEARCH

Environmental Conditions Associated with a Mass Beach Stranding Event of *Porpita porpita* along the Gopalpur Coast, North-Western Bay of Bengal

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Abstract

A mass beach stranding of the blue button jellyfish (*Porpita porpita*) was observed on 17 April 2025 along the Gopalpur Coast, north-western Bay of Bengal. This descriptive case study documents the event and the environmental conditions associated with it. Semi-quantitative field estimates indicated patchy deposits along about 1 km of shoreline, with a mean density of about 5 colonies m^{-2}. Satellite-derived datasets on sea surface temperature (SST), chlorophyll-*a* (chl-*a*), wind, currents, and salinity were examined for 1–17 April 2025. Persistent southwesterly to southerly winds (4–10 m s^{-1}) weakened in the second week and strengthened again before the event. A northward coastal current (0.3–1.4 m s^{-1}) prevailed over the shelf. Relative to the local coastline, these fields combined a dominant alongshore component with a weaker onshore component, consistent with the passive drift of *P. porpita* colonies towards the coast. SST near Gopalpur rose from 28.6 to 29.2 °C, within the 28–30 °C range reported for earlier strandings. SST was 0.1–1.3 °C above the decadal climatology of 2015–2024, with the largest anomaly in early April and near-climatological values on the stranding day. Nearshore chl-*a* often exceeded 1 mg m^{-3}, indicating enhanced productivity and prey availability. Pelagic barnacles were frequently attached to the stranded *P. porpita*. Post-stranding decomposition of colonies produced a strong odour and temporarily disrupted tourism and recreational activities. These conditions resemble those of earlier strandings on the Odisha coast but are also typical of the pre-monsoon season. The findings illustrate how physical forcing, thermal conditions, and biological productivity were associated with this stranding event and underscore the need for early warning systems along the Indian coast. Long-term monitoring of these variables, supported by nearshore observations, is needed before such events can be reliably anticipated.

Keywords Jellyfish · Beach stranding · Remote Sensing · Sea Surface Temperature · Surface Current · Wind

Introduction

The blue button jellyfish (*Porpita porpita*) is a tropical and subtropical marine hydrozoan. This pleustonic organism is characterized by a rounded floating hydroid colony with a gas-filled disc, numerous tentacles, and vibrant blue colouration (Santiago-Valentín et al. 2024). The unique morphology enables *P. porpita* to float at the ocean surface. *P. porpita* feeds on carnivorous copepods, ichthyoplankton, fish eggs, chaetognaths, and megalopae (Pattnayak et al. 2023). It serves as prey for small invertebrates and fish. It can be easily transported over long distances by wind and surface water currents (Chowdhury et al. 2016; Sahu et al. 2020). Mass beach strandings of *P. porpita* have been reported from various coastal regions worldwide. Most of the events typically occur in tropical and subtropical waters during favourable environmental conditions (Sahu et al. 2020; Bhowmik et al. 2025). Along the Indian coast, aggregation hotspots include Bheemunipatnam, Konark, Astaranga, South Odisha, the Gulf of Mannar, and Pulicat Lagoon on the east

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coast (Pattnayak et al. 2023; Sahu et al. 2020; Barik et al. 2025; Tharik et al. 2021; Ramanibai et al. 2014). On the west coast, aggregations occur in Gujarat, including Jakhau, Aadri, Saurashtra, Narara, Mandvi, Dwarka, and Kavaratti of Lakshadweep Island (Pandya 2013; Shah and Shah 2021; Sabapara et al. 2022; Marimuthu et al. 2022). These stranding events result in ephemeral beach pollution and hinder fishing operations. They also temporarily disrupt tourism and recreational activities (Barik et al. 2025).

Environmental factors play a crucial role in driving *P. porpita* aggregations and subsequent beach strandings. Sea Surface Temperature (SST) within the range commonly reported for the species accompanies its occurrence and growth (Sahu et al. 2020; Pattnayak et al. 2023). Elevated chlorophyll-*a* (chl-*a*) concentrations indicate enhanced primary productivity. This suggests greater food availability through the pelagic food web (Barik et al. 2025). Wind direction and velocity, together with surface currents, influence the passive transport of these neustonic organisms. The strong southwest monsoon winds drive an intrusion of coastward surface currents into the Bay of Bengal (Vinayachandran et al. 1999), which likely facilitates the transport and accumulation of *P. porpita* in nearshore waters (Chowdhury et al. 2016). The concurrence of favourable thermal conditions and physical forcing mechanisms creates conditions conducive to mass aggregation events (Graham et al. 2001).

Recent studies have highlighted the association between *P. porpita* and pelagic barnacles. Unusually high abundances of barnacles are recorded in coastal waters during *P. porpita* aggregation events (Bhowmik et al. 2025). These observations of epibiotic associations support the trophic associations and feeding preferences of barnacles on *P. porpita* colonies. Such ecological relationships underscore the complexity of pleustonic communities. They demonstrate the importance of gelatinous zooplankton in marine ecosystems. Beach stranding events generate significant socio-ecological impacts. The decomposition of stranded organisms produces strong, pungent odours along the beach. This results in temporary disruptions to recreational activities and tourism. Local fishermen report clogging of fishing nets during aggregation events (Barik et al. 2025). Although *P. porpita* stings are generally mild, contact with stranded specimens can cause localized skin irritation due to nematocysts. Beachgoers exposed to stranded specimens may experience discomfort. The aesthetic degradation of beaches affects coastal communities that depend on tourism revenue (Purcell et al. 2007; Richardson et al. 2009).

Understanding the environmental drivers of *P. porpita* aggregations is essential for coastal ecosystem management. The integration of oceanographic observations with ecological surveys provides insights into stranding mechanisms. Well-documented records of individual stranding events, together with the conditions under which they occurred, are needed to build the regional baseline on which any early warning approach would depend. It enables coastal communities to anticipate and mitigate the impacts of mass aggregation events. The present study investigates the complex interplay between physical forcing, biological productivity, and socio-ecological consequences in the context of mass coastal aggregation and beach stranding of *P. porpita*. The present study is a descriptive case study of a *P. porpita* stranding at Gopalpur on 17 April 2025. Its aims were to (i) document the scale and characteristics of the event, (ii) describe the wind, surface current, SST, chl-*a*, and salinity conditions during the preceding 17 days using satellite and reanalysis data, and (iii) compare these conditions with climatology and with earlier strandings on the Odisha coast. The intention of this study is to provide a plausible scientific basis for interpreting the event, rather than to establish a causal mechanism.

Materials and Methods

Study Area

The Gopalpur Coast lies along the northwestern coast of the Bay of Bengal, on the eastern seaboard of India (Fig. 1). The Bay of Bengal is a semi-enclosed basin characterized by unique oceanographic features and complex monsoon dynamics (Shenoi et al. 2002). The surface circulation pattern exhibits high variability due to seasonal reversal of western boundary currents (McCreary et al. 1996; Schott and McCreary 2001; Le et al. 2025). The region experiences excess precipitation over evaporation due to monsoon wind forcing patterns (Rao and Sivakumar 2003). During the summer monsoon, freshwater influx from major river systems causes surface freshening and establishes a barrier layer (Durand et al. 2011; Thadathil et al. 2007). This leads to density stratification, altering the hydrological properties of the ocean surface layer (Rao and Sivakumar 2003). The biogeochemical cycling in the region is influenced by monsoonal nutrient enrichment. Enhanced primary productivity occurs during favourable upwelling conditions (Bhaskar et al. 2016). Jellyfish aggregation events alter biogeochemical cycling and drive shifts in nutrient dynamics (Pitt et al. 2009). The interaction among physical forcing, biological productivity, and tropical cyclones creates conditions conducive to the formation of gelatinous zooplankton aggregations along this ecologically important coastline (Baliarsingh et al. 2020, 2023).

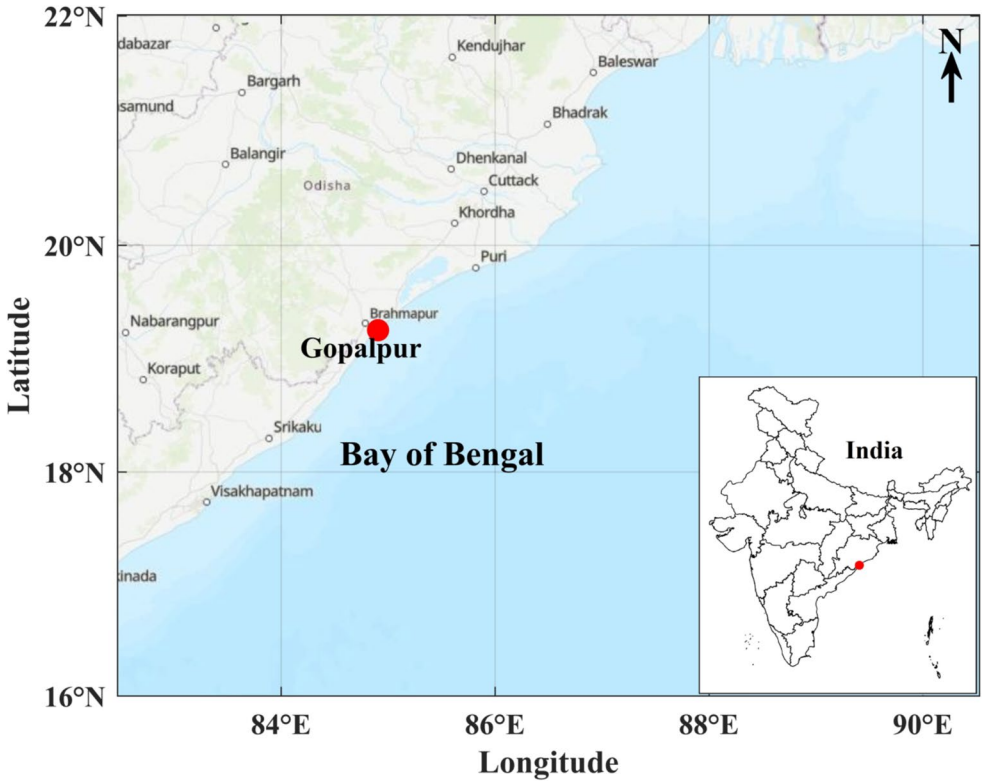


Fig. 1 Geographical location of the study area showing the Gopalpur coast along the northern Bay of Bengal on the east coast of India. The red circle indicates the coastal sampling station off Gopalpur, Odisha, and the inset map shows the study site's location within India

Methodology

On 17 April 2025, a beach stranding event of jellyfish was observed at the tourist beach of Gopalpur during a regular field visit. The specimens were collected and preserved in 4% formaldehyde for taxonomic identification. The spatial scale of the stranding was estimated semi-quantitatively in the field. As the survey was opportunistic, the width of the deposition band was estimated at several points along the shore, and colony density was approximated by counting colonies within representative reference areas of known dimensions rather than by a formal quadrat survey. The persistence of the stranding and the clearance of the material were assessed during checks on the following days and from conversations with local beachgoers and fishermen. No dissolved oxygen, water quality, tourism, or fishing-loss measurements were made during the event, and no structured stakeholder survey was conducted. Information from local beachgoers and fishermen is therefore treated as anecdotal.

Satellite and Reanalysis Data

The environmental conditions associated with the stranding were described using satellite-derived and reanalysis datasets of chl-*a*, SST, surface wind, sea surface currents (SSC), and sea surface salinity (SSS). The product name, spatial and temporal resolution, and data source of each dataset are provided in Table 1. Daily fields for 1–17 April 2025 were

Table 1 Satellite and reanalysis datasets used for oceanographic and atmospheric variables in the study, including their spatial and temporal resolutions

Geophysical Variable	Product / Dataset Name	Spatial Resolution (km)	Temporal Resolution	Data available since	Data Provider / Source Portal
Chlorophyll-*a*	Moderate Resolution Imaging Spectroradiometer-Aqua Level-3 (MODISA L3)	4 km	Daily	2002	oceandata.sci.gsfc.nasa.gov
Chlorophyll-*a* (Interpolated)	European Space Agency Ocean Colour – Climate Change Initiative (ESA OC-CCI)	4 km	Daily	2010	climate.esa.int
Sea Surface Temperature	Optimum Interpolation Sea Surface Temperature (OISST)	~25 km	Daily	1982	ncei.noaa.gov
Surface Wind	ECMWF Reanalysis, 5th Generation (ERA5 Reanalysis)	~25 km	Hourly	1940	cds.climate.copernicus.eu
Sea Surface Current	Global Ocean Physics Analysis	~8 km	Daily	1993	data.marine.copernicus.eu
Sea Surface Salinity	Multi-Observation Global Ocean Sea Surface Salinity	~12.5 km	Daily	1993	data.marine.copernicus.eu

mapped over the coastal waters off Gopalpur. Time-series of SST and chl-*a* at the station (Fig. 1) were compared with 10-year (2015–2024) daily climatologies prepared from the same datasets. Wind and current directions were interpreted relative to the local shoreline orientation. Published records of earlier strandings along the Odisha coast were compiled for comparison. The analysis is descriptive. It examines whether the conditions before the event resembled those reported for earlier strandings, but it does not test causal relationships. The datasets have spatial resolutions of about 4 to 25 km (Table 1). They describe shelf-scale conditions but do not resolve tides, waves, or circulation within the surf zone.

Results and Discussion

Event Characterization and Spatial Distribution

A mass beach stranding event of *P. porpita* was documented along the Gopalpur Coast in the north-western Bay of Bengal (Fig. 1). The event was characterized by extensive surface accumulations in nearshore waters, followed by widespread beaching along the upper intertidal zone. The stranded specimens were observed in discrete patches distributed over a considerable stretch of the sandy beach. Each individual colony exhibited the characteristic circular chitinous disc with blue tentacles radiating outward (Fig. 2c, d). A prominent observation during this event was the unusually high abundance of pelagic barnacles attached to the surface of the stranded *P. porpita* colonies (Fig. 2a, b). This co-occurrence is significant and is discussed in subsequent sections.

The stranded colonies formed patchy accumulations extending over a stretch of about 1 km centred on the main Gopalpur tourist beach. The deposition band occupied the upper intertidal zone as a roughly 2 to 4 m wide strip. Colony density within the band averaged about 5 colonies m^{-2}. Individual colonies had disc diameters of approximately 8–25 mm. On this basis, the total stranded population corresponded to an estimated wet biomass of a few hundred kilograms. Enquiries with local beachgoers and fishermen indicated that fresh beaching was confined to the morning of 17 April, and no further stranding was recorded during checks on the following days. Visible decomposition and the associated odour developed over the following two to three days, and tidal action together largely cleared the material within about one week. A substantial fraction of the stranded colonies bore attached pelagic barnacles. These semi-quantitative estimates are consistent with regional records for the Bay of Bengal. The estimated colony density exceeded the 1.3 colonies m^{-2} reported for the Teknaf stranding on the

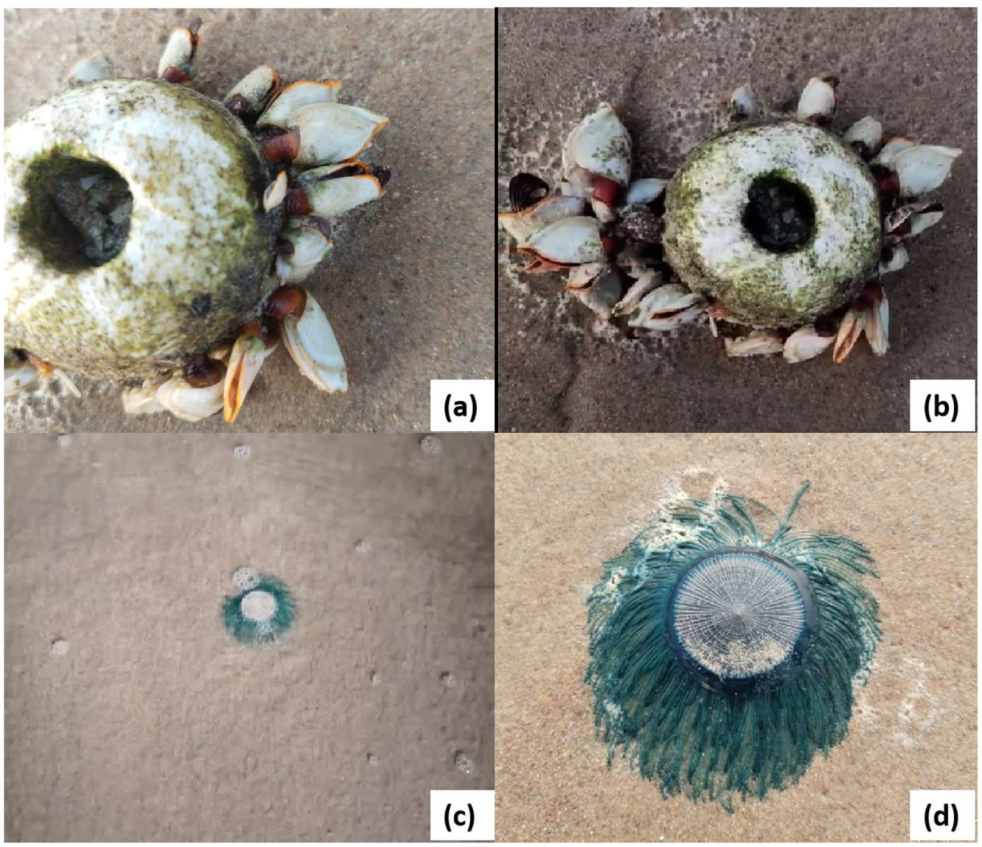


Fig. 2 Photographic plate showing (**a**, **b**) Barnacles attached on the surface of a substratum; (**c**, **d**) Hydrozooid colony of *Porpita porpita*

Bangladesh coast, and the disc-diameter range fell within the 4.6 to 34.5 mm span documented for that event (Bhowmik et al. 2025). The alongshore extent was smaller than the multi-beach stranding that spanned about 60 km from Astaranga to Puri (Sahu et al. 2020). The Gopalpur event was therefore a single localized beaching rather than a coast-wide event. The study reports semi-quantitative field estimates and is intended to convey the order of magnitude of the stranding rather than precise measurements.

Mass beach strandings of *P. porpita* along the Odisha coast have been documented in previous studies. Sahu et al. (2020) reported the stranding of blue button jellies from Astaranga to Puri during May 2016. Sahu and Panigrahy (2013) documented a jellyfish bloom along the south coast of Odisha. More recently, Barik et al. (2025) reported a stranding event at Astaranga in September 2024, while Jena et al. (2025) linked a jellyfish stranding at Puri to the landfall of tropical cyclone Mocha. These repeated events indicate that the coastal waters of Odisha represent a recurring site of *P. porpita* aggregation. The present event at Gopalpur further documented a record of major stranding occurrences along the Odisha coastline. Most of the reported events along the east coast of India occurred during the pre-monsoon and summer months (March to May), suggesting a seasonal predisposition that aligns with elevated SST and favourable current patterns that flow northward (Sahu et al. 2020; Pattnayak et al. 2023; Barik et al. 2025).

Physical Forcing and Passive Transport Mechanisms

The daily surface wind fields during 1–17 April 2025 along the Odisha coast are presented in Fig. 3. During the first week of April, the wind field was dominated by persistent southwesterly to southerly winds with moderate to strong magnitudes (4–10 m s^{-1}). The vectors were directed predominantly towards the north-northeast. Relative to the shoreline, this gave a dominant alongshore component and a weaker but persistent onshore (northwestward) component in the nearshore zone around the study site. A notable reduction in wind speed was observed during the second week of April, with magnitudes declining to 2–4 m s^{-1} near Gopalpur. However, the onshore wind direction persisted. During the stranding phase, the wind speed intensified again, with stronger southwesterly to southerly vectors, shortly before the stranding. This intensification enhanced the shoreward drift of surface floating organisms. The daily wind field for the whole of April 2025 (Supplementary Fig. S1) shows that the vectors near the Gopalpur grid point remained directed towards the north to northeast throughout the month, and that wind speed increased from about 16 April.

The daily SSC fields during 1–17 April 2025 are displayed in Fig. 4. A persistent, strong northward current was evident along the Odisha shelf throughout the study period. The SSC speed ranged from approximately 0.3 to 1.4 m s^{-1}, with higher magnitudes along the shelf edge and weaker flows in the offshore region. Near Gopalpur, the flow was mainly alongshore at the resolution of the product, with a cross-shelf component.

Possible Transport Pathway to the Shore

P. porpita is a free-floating hydrozoan colony that lacks active locomotion. Its transport and distribution are therefore governed by physical forcing, particularly the magnitude and direction of surface winds and coastal currents. Because these colonies float at the air-sea interface with the chitinous disc partly exposed, their motion is set by the combination of the surface current and the direct wind drag (windage) on the exposed float, rather than by the depth-integrated Ekman transport of the water column (Graham et al. 2001; Thiel and Gutow 2004). Classical depth-integrated Ekman theory deflects the wind-driven water transport approximately 90° to the right of the winds in the Northern Hemisphere, which would be offshore under the observed winds. Unlike the depth-integrated Ekman transport, the near-surface current is typically deflected much less from the wind direction, with an angle of approximately 45° only in the idealized deep-water Ekman solution, and often substantially smaller in shallow coastal environments where bottom friction compresses the Ekman spiral (Graham et al. 2001; Thiel and Gutow 2004). Consequently, wind-driven drift remained largely aligned with the prevailing southerly to southwesterly winds, producing a net northward and onshore displacement of the floating colonies. Owing to the local geometry, the southerly component of the wind provided the shore-normal (northwestward) push towards the beach, whereas the southwesterly component acted along the shore. This would explain why the resolved satellite fields appear alongshore-dominant even though a persistent onshore drift was present.

Alongshore drift can concentrate floating material where the coastline curves or where structures interrupt the flow. At Gopalpur, the peripheral structures of the Gopalpur port, and the outflow of the adjacent Haripur Creek may promote such localized convergence, where buoyant material can accumulate. The final deposition was completed within the surf zone by wave-driven onshore drift and swash, which strand floating material near the high-water line, after which the falling tide would leave the colonies exposed across the intertidal zone (Graham et al. 2001; Keesing et al. 2016). These nearshore and surf-zone processes operate below the 4–25 km resolution of the datasets, so this final part of the pathway is inferred rather than observed. The renewed strengthening of the winds on 16–17 April coincided with

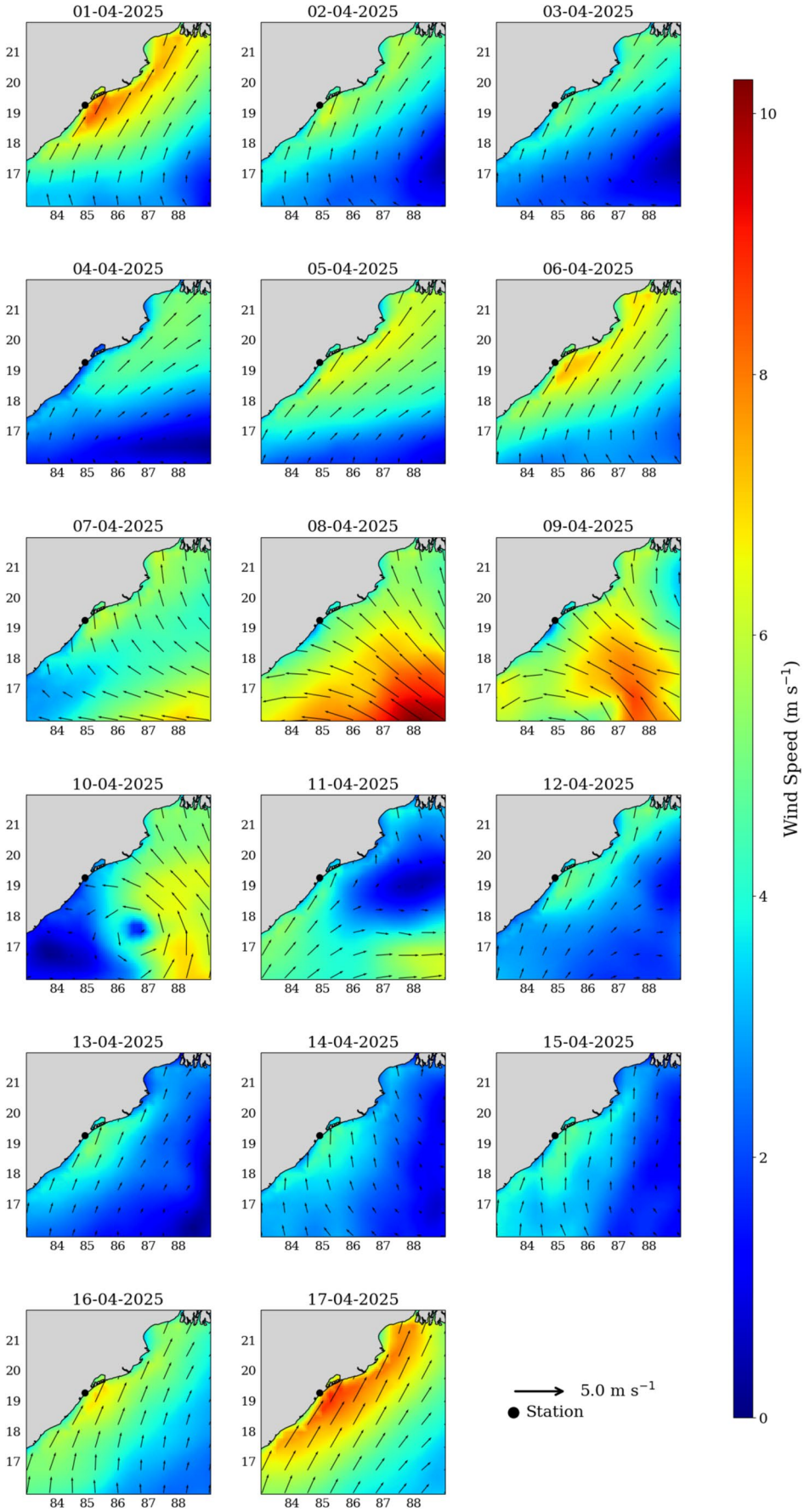


Fig. 3 Daily mean sea surface wind speed (colour shading, m s^{-1}) and wind direction (vectors) over the coastal waters of Gopalpur, east coast of India, during 01–17 April 2025. Warmer colours indicate stronger winds, and arrows show the prevailing wind direction and relative magnitude (reference vector shown). The blue dot marks the sampling/station location

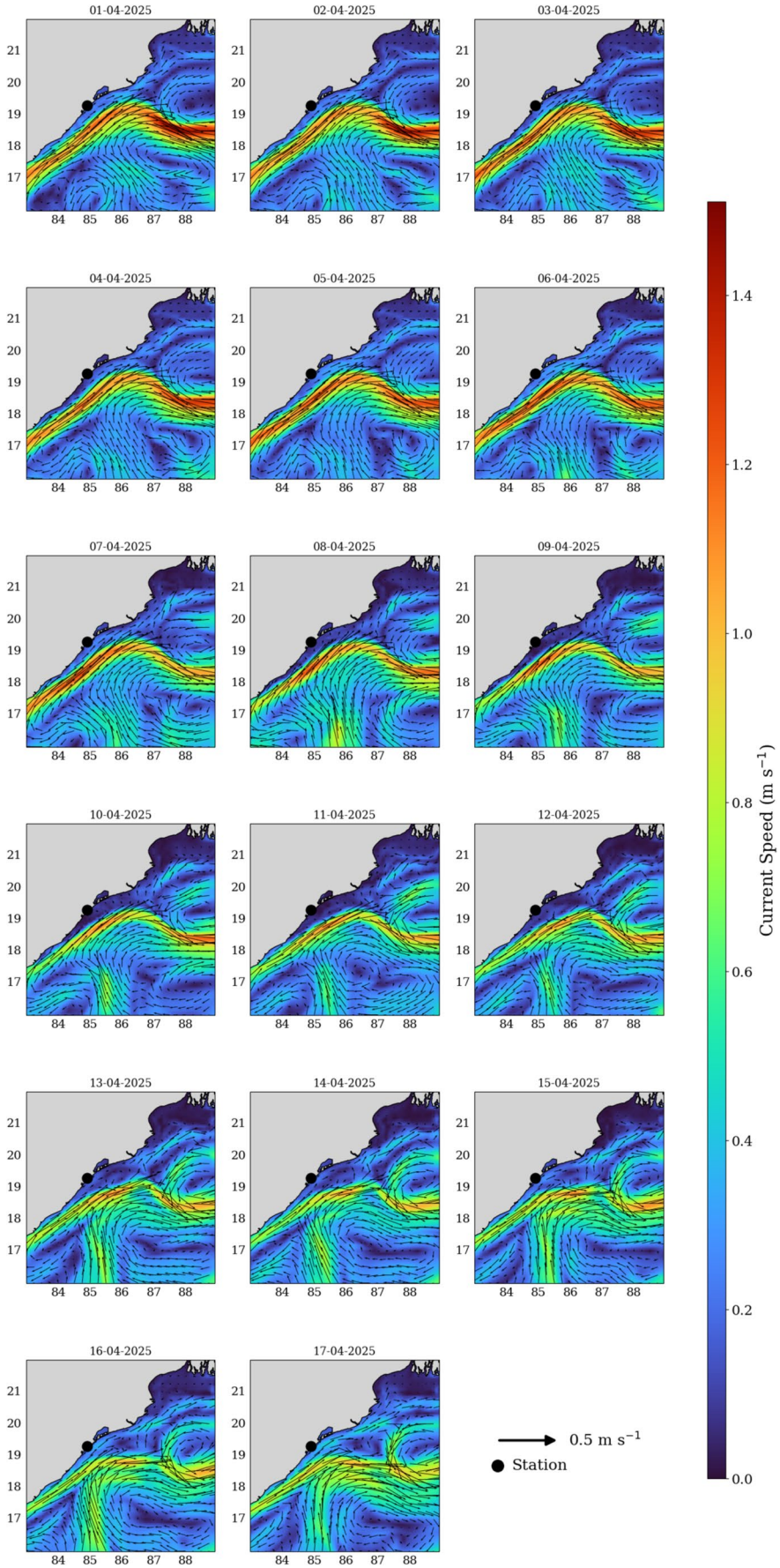


Fig. 4 Daily sea surface current speed (colour shading, m s^{-1}) and current direction (vectors) over the coastal waters of Gopalpur, east coast of India, during 01–17 April 2025. Warmer colours denote stronger currents, and arrows indicate the prevailing flow direction and relative magnitude (reference vector shown). The blue dot marks the sampling/station location

the stranding. Keesing et al. (2016) similarly found that winds and tides set the timing of beach strandings of *Crambione mastigophora* on the Australian coast.

The coupling of onshore wind and strong alongshore to cross-shelf currents created a convergent transport regime near the coast. This mechanism is consistent with previous observations along the Indian coast. Sahu et al. (2020) demonstrated that shoreward currents and winds led to beach stranding of *P. porpita* along the Odisha coast in May 2016. Similarly, Barik et al. (2025) attributed the September 2024 stranding at Astaranga to coastward surface currents driven by a local depression. Jena et al. (2025) linked the jellyfish stranding at Puri to the enhanced surface Ekman mass transport during cyclone Mocha. In the present case, no tropical cyclone preceded the event. The stranding coincided with seasonal pre-monsoon wind and current patterns characteristic of the north-western Bay of Bengal. Because these patterns recur every year from March to May, their presence alone does not explain why the stranding occurred on this day or at this site. However, this framework does not adequately describe the movement of surface-trapped pleuston. *P. porpita* floats at the air-sea interface, so its drift is controlled by the surface current and by direct wind drag on the exposed float.

Chlorophyll-*a* Distribution

The spatial distribution of daily chl-*a* concentration along the Odisha coast during 1–17 April 2025 is presented in Fig. 5. The maps show a strong nearshore to offshore gradient throughout the study period. Nearshore chl-*a* frequently exceeded 1 mg m^{-3} and reached 3–5 mg m^{-3} in some patches, values that fall within the bloom category defined by Raulo et al. (2025). In contrast, the offshore waters were oligotrophic, with concentrations below 0.3 mg m^{-3}. Cloud cover and satellite swath limitations caused frequent data gaps in the daily maps, as is common during this season.

Sea Surface Temperature

The daily SST distribution along the Gopalpur coast for 1–17 April 2025 is presented in Fig. 6. SST ranged between 28.0 and 30.5 °C across the study domain and increased steadily over the period. Near the Gopalpur station, SST commenced at approximately 28.6 °C on 1 April, then increased progressively. It reached 29.1 °C by the end of the second week and was approximately 29.2 °C on the day of stranding (17 April). This warming is typical of the pre-monsoon season in the north-western Bay of Bengal, when SST peaks due to strong solar radiation and reduced cloud cover (Neogi 2025).

Comparison with Climatology and Previous Events

Comparison of time-series for April 2025 at the station and with the 10-year daily SST climatology (2015–2024) revealed a persistent positive anomaly in April 2025 (Fig. 7b). SST values during April 2025 were consistently above the climatological mean, with anomalies ranging from 0.1 to 1.3 °C. The anomaly was strongest during early April (exceeding 1 °C) and gradually decreased towards the stranding day, where the observed SST nearly converged with the climatological value. The stranding therefore did not coincide with unusually warm water at the station, and the SST remained within the range reported for *P. porpita* occurrences.

For chl-*a* (Fig. 7a), the climatological values ranged from 0.1 to approximately 0.8 mg m^{-3}, with a peak around 7 April. The OC-CCI interpolated values for 2025 ranged from 0.2 to 0.6 mg m^{-3} and closely followed the climatology. The MODISA daily values were generally below 0.4 mg m^{-3}, except for a peak of approximately 3.4 mg m^{-3} on 8 April. This peak is probably an artefact of limited coverage under cloud, which biased the few valid pixels towards the productive nearshore zone. On the day of stranding, the interpolated chl-*a* at the station was approximately 0.5 mg m^{-3}, within the climatological range. High chl-*a* was therefore a feature of the nearshore band rather than an anomaly at the station.

Previous records of *P. porpita* stranding events along the Indian coast indicate a consistent association with SST in the range of 28–30 °C (Pandya 2013; Gul and Gravili 2014; Ramanibai et al. 2014; Chowdhury et al. 2016; Sahu et al. 2020; Barik et al. 2025; Guzzi et al. 2025). A comparison of mean SSTs of present event and past stranding events on the Odisha coast is shown in Fig. 7c. The data from Sahu et al. (2020) showed SSTs ranging from approximately 28.8 to 30.0 °C. Barik et al. (2025) reported values between 29.3 and 29.6 °C. The present study recorded SSTs between 28.6 and 29.2 °C. All three events thus fall within the 28–30 °C range reported for the species. This range describes where *P. porpita* has commonly been recorded, and is not equivalent to an experimentally established physiological optimum. Elevated temperatures can enhance near-surface stratification, which has been suggested to confine neustonic organisms near the surface and facilitate their accumulation (Quinones et al. 2018; Jena et al. 2025). No vertical profiles were available to examine this in the present study.

Sea Surface Salinity

The daily SSS distribution during 1–17 April 2025 is shown in Fig. 8. SSS values across the study domain ranged from 31.0 to 33.5 PSU. The nearshore waters around the

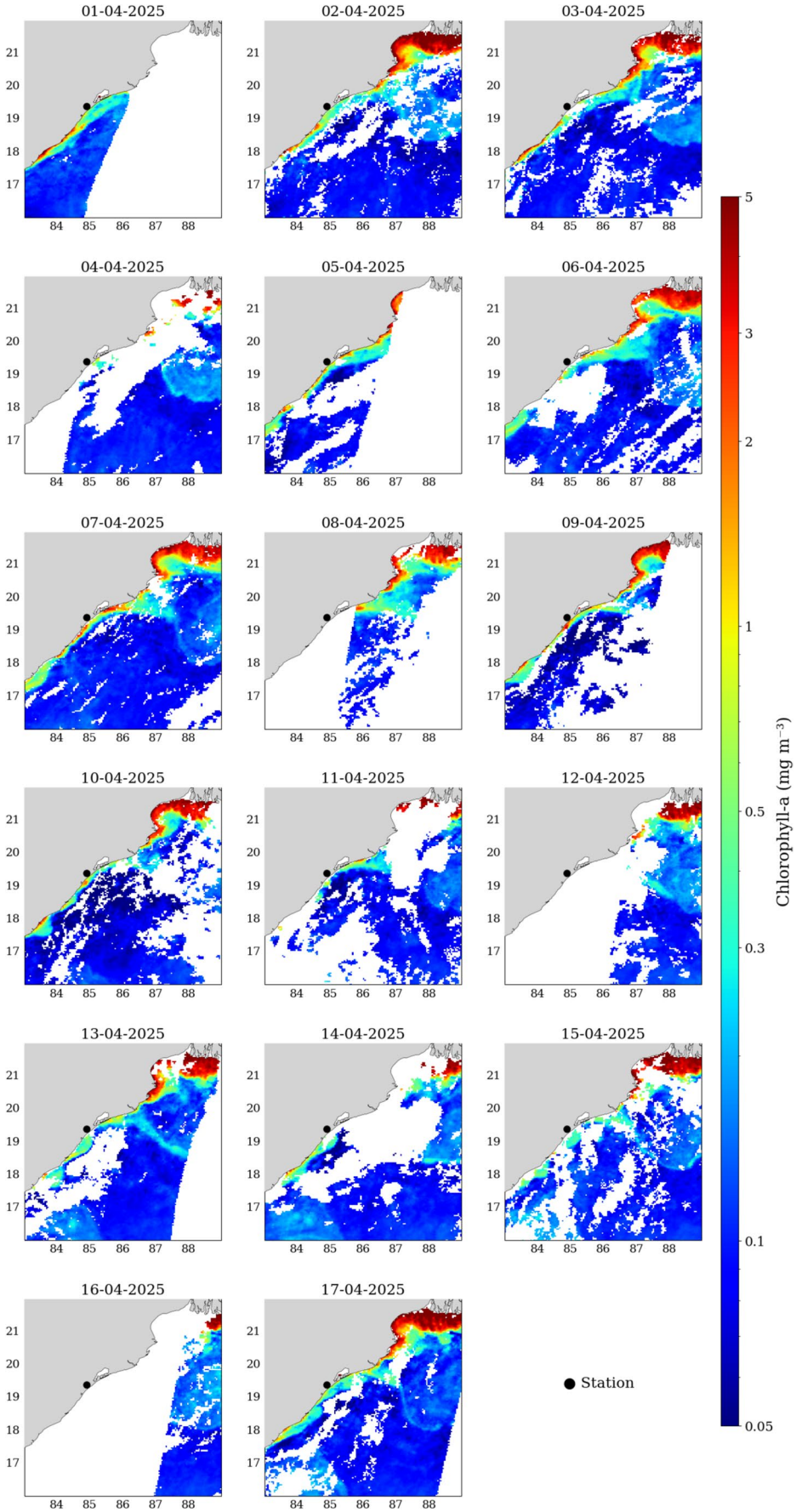


Fig. 5 Daily mean satellite-derived chlorophyll-*a* concentration (mg m^{-3}) in the coastal waters of Gopalpur, east coast of India, during 01–17 April 2025. Colour shading represents chlorophyll-*a* levels, with warmer colours indicating higher phytoplankton biomass and cooler colours indicating lower concentrations. The blue dot marks the sampling/station location

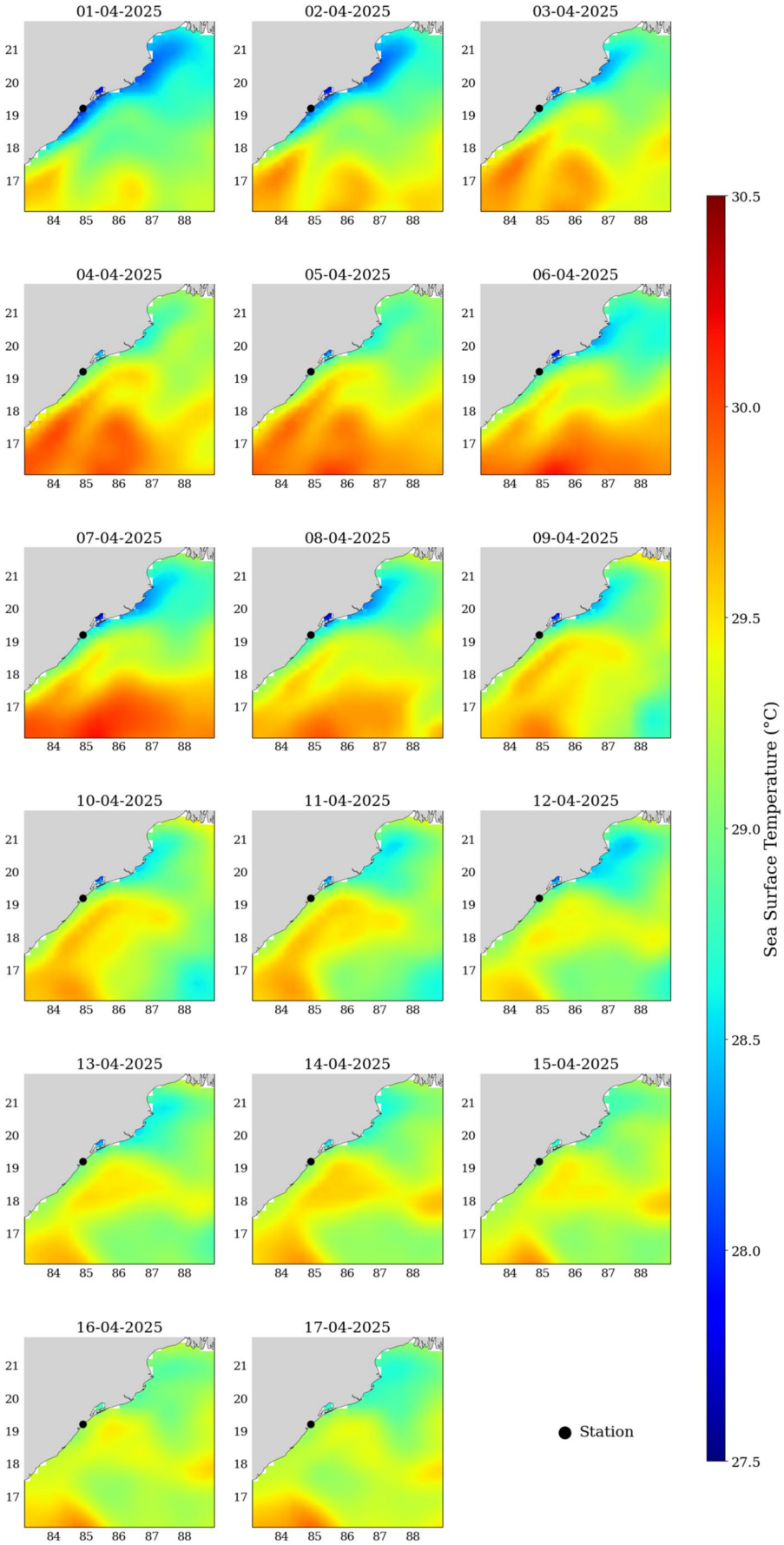


Fig. 6 Daily mean sea surface temperature (°C) distribution in the coastal waters of Gopalpur, east coast of India, during 01–17 April 2025. Colour shading represents temperature variability, with warmer colours indicating higher sea surface temperature and cooler colours indicating lower values. The blue dot denotes the sampling/station location

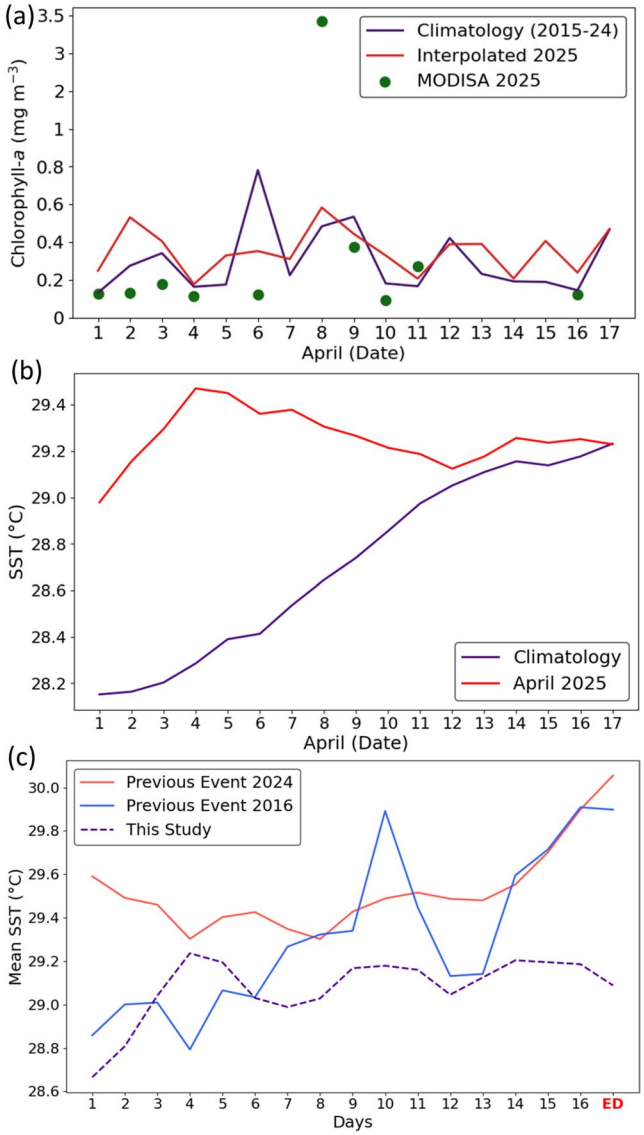


Fig. 7 Comparison of chlorophyll-*a* and sea surface temperature (SST) variability in the coastal waters of Gopalpur, east coast of India. **a** Daily chlorophyll-*a* concentration (mg m^{-3}) showing climatology (2015–2024), MODISA observations, and interpolated values for April 2025. **b** Daily SST (°C) comparison between long-term climatology and April 2025. **c** Mean SST (°C) during the aggregation/stranding events along the Odisha coast observed during 2016 and 2024 from previous studies reported by Sahu et al. 2020 (blue line) and Barik et al. 2025 (Red line), respectively, and the present study (Dashed). ED: Event Date

Gopalpur station exhibited slightly lower salinity (31.0–32.5 PSU) than the offshore region (>33.0 PSU), owing to residual discharge from the adjacent estuarine systems. The salinity distribution remained relatively stable throughout the study period, with no significant anomalous fluctuations. These values are typical of the pre-monsoon conditions in the north-western Bay of Bengal, when river discharge is minimal (Rao and Sivakumar 2003; Durand et al. 2011). Salinity, therefore, showed no change that could be related to the timing of the stranding event.

Productivity Context

The persistently elevated chl-*a* levels in nearshore waters indicate sustained primary productivity throughout the study period, in which zooplankton prey may have been abundant. This biological productivity, coupled with the active surface circulation, supports the growth of phytoplankton biomass. The northward coastal current and the persistent southerly to southwesterly winds facilitate the convergence of productive water masses along the coast. This convergence enriches the food availability for pleustonic organisms. *P. porpita* is a secondary consumer that feeds on zooplankton, including copepods, barnacle cyprid larvae, and fish larvae (Bieri 1970). These adequate food resources may create favourable conditions for the sustenance of *P. porpita* colonies in the region. A similar linkage between elevated chl-*a* and jellyfish aggregation has been demonstrated by Jena et al. (2025) and Barik et al. (2025) for the Odisha coast. Goldstein and Steiner (2020) also identified adequate food resources as a critical factor influencing jellyfish aggregation.

Trophic Associations: Pelagic Barnacles and *P. porpita*

A notable observation during the present stranding event was the co-occurrence of pelagic barnacles with *P. porpita* colonies (Fig. 2a, b). The attached barnacles were identified from photographic and morphological examination of the collected specimens. The capitulum was white and composed of five closely packed calcareous plates, comprising paired scuta and terga together with a median carina. The apex of the carina extended towards the tergum, and the carinal base was forked. Filamentary appendages and a caudal appendage were present, and the mandible bore five teeth. On the basis of these characters, the specimens were identified as *Lepas* sp. (Linnaeus 1758). The occurrence of this genus along the Odisha coast is further supported by the faunal inventory of Roy and Rath (2017). The barnacles were not resolved to species level, and the proportion of colonies bearing barnacles and the number of barnacles per colony were not quantified.

Intertidal barnacles are commonly observed attached to hard substrates near the shore. Pelagic barnacles such as *Lepas*, in contrast, attach to floating objects, including neustonic organisms, and drift with them along ocean currents (Bieri 1966; Thiel and Gutow 2004). The association observed here is therefore best described as epibiotic and probably commensal relationships with neustonic species,

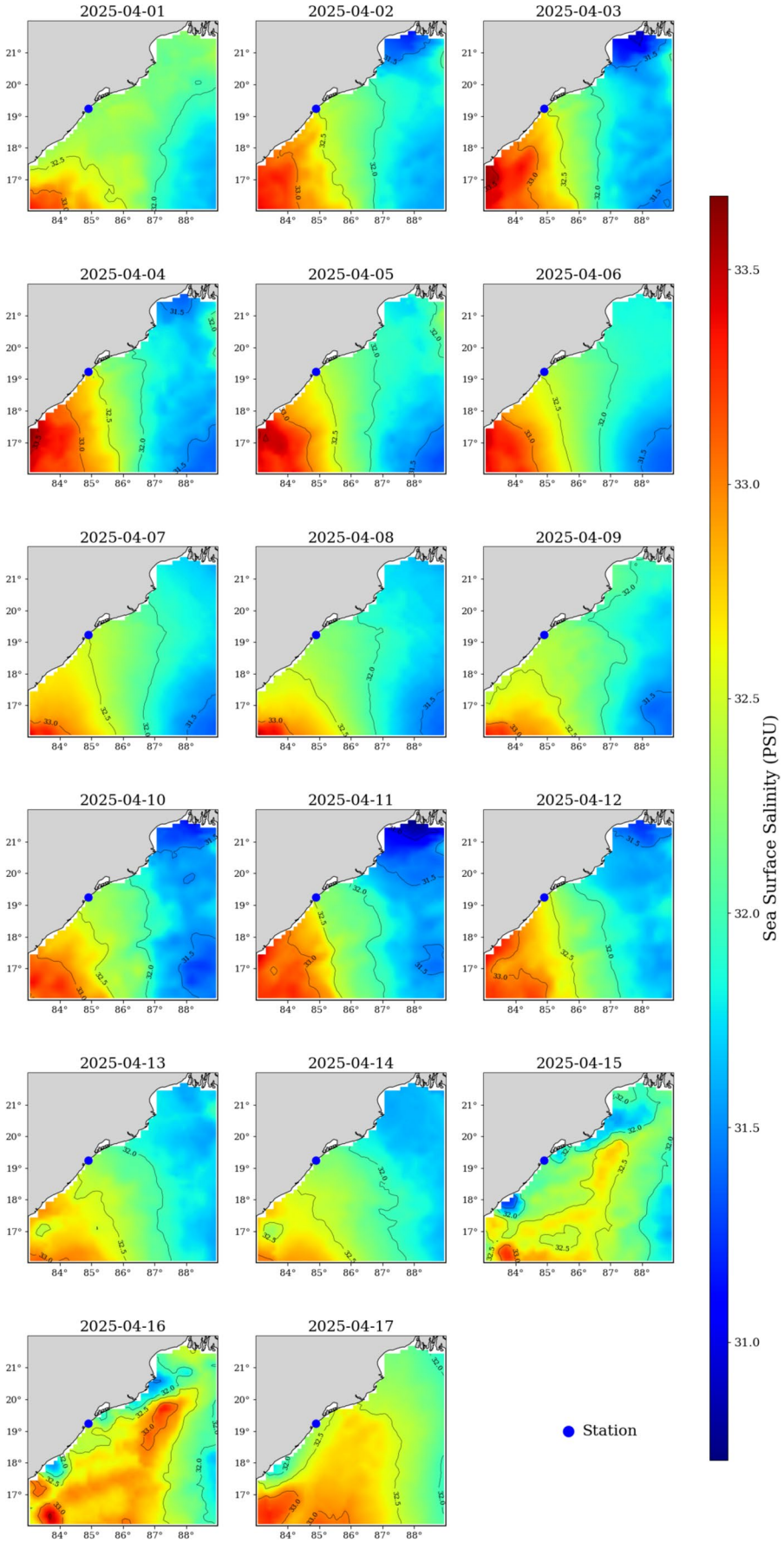


Fig. 8 Daily mean sea surface salinity (PSU) distribution in the coastal waters of Gopalpur, east coast of India, during 01–17 April 2025

with the float providing a buoyant platform for attachment (Bieri 1966; Thiel and Gutow 2004). This relationship enables the barnacles to hitchhike along ocean currents, exploiting the buoyant platform provided by their hosts. Gut content analysis provides significant evidence on the trophic interactions between the oceanic chondrophore *P. porpita* and zooplankton. This indicates the secondary carnivorous nature of *P. porpita* among the pleustonic species (Bieri 1970). *P. porpita* has separately been reported to ingest barnacle cyprid larvae, which is a trophic interaction rather than evidence of mutualism. Bhowmik et al. (2025) also recorded high barnacle abundances during a *P. porpita* aggregation in the Bay of Bengal, which suggests that such barnacle loads may be common during these events.

Post-Stranding Socio-Ecological Impacts

Following the mass stranding event, the jellyfish biomass underwent rapid decomposition on the beach. The impacts described here are separated into effects directly observed during the Gopalpur event, anecdotal accounts from local stakeholders, and effects inferred from previous studies. The stranding colonies decomposed on the beach over two to three days and had immediate consequences for local tourism and recreational activities. The mass beaching of *P. porpita* and subsequent decomposition created an unpleasant environment. The pungent odour deterred beachgoers and temporarily disrupted beach activities. The Gopalpur beach is a popular tourist destination along the south Odisha coast, but the economic effect of the stranding on tourism was not measured. Although *P. porpita* stings are generally mild, the presence of nematocysts poses a risk of localized skin irritation to beachgoers who come into contact with stranded specimens (Gershwin et al. 2010).

The coastal communities of Gopalpur are heavily dependent on fisheries and coastal tourism. Local fishermen reported that, during swarming events, jellyfish biomass clogs fishing nets, increasing the cost of fishing operations and requiring additional manpower. These accounts are anecdotal and were not quantified in this study. Reports from other Indian coastal regions corroborate these impacts. In Kerala, jellyfish aggregations damage fishing gear and reduce fishing days (Biju Kumar et al. 2017). In Goa and Maharashtra, fishermen periodically suspend fishing activities during peak jellyfish swarming seasons (Times of India 2017; The Indian Express 2020). The Odisha coast, particularly the Puri region, has experienced frequent swarming and stranding events in recent years (Sahu et al. 2020; Dash et al. 2023; Jena et al. 2025; Barik et al. 2025). Jellyfish aggregation followed by stranding has both ecological and economic impacts on coastal communities (Purcell et al. 2007; De Donno et al. 2014; Graham et al. 2014). These recurring events highlight the vulnerability of coastal communities and underscore the need for integrated management strategies.

Studies elsewhere show that decomposing jellyfish can enhance microbial activity and alter the biogeochemical properties of both the benthic and pelagic environment (Condon et al. 2011; Qu et al. 2015). Microbial decomposition of stranded jellyfish releases dissolved organic matter, which is dominated by ammonia, while the particulate organic matter is enriched in organic nitrogen and inorganic phosphorus (Condon et al. 2011; Purcell 2012; Blanchet et al. 2015). Jellyfish blooms can thereby influence carbon, nitrogen, and phosphorus cycling (Pitt et al. 2009). In other settings, the rise in microbial populations increases oxygen demand, and the nearshore waters, which are typically well-oxygenated, may experience transient hypoxic conditions (Titelman et al. 2006; Condon et al. 2011). The degradation of jellyfish biomass also produces sulphur compounds, which are the primary cause of the foul odour associated with stranding events (Purcell 2012). Previous reports from the Odisha coast have confirmed the occurrence of such foul smell following jellyfish decomposition (Sahu and Panigrahy 2013). Dissolved oxygen and nutrients were not measured at Gopalpur, so these biogeochemical effects could not be assessed.

Synthesis and Scope of the Case Study

The present study indicates that the mass coastal aggregation and beaching of *P. porpita* at Gopalpur is best explained by a combination of interlinked physical, thermal, and biological factors. The Gopalpur stranding occurred under persistent southerly to southwesterly winds that strengthened shortly before the event, a strong northward coastal current, SST within the range reported for earlier strandings, and a productive nearshore band. This combination resembles the conditions reported for earlier strandings on the Odisha coast (Sahu et al. 2020; Barik et al. 2025). The same conditions are, however, typical of the pre-monsoon season in the north-western Bay of Bengal. This study describes a single event without a comparison period in which no stranding occurred, and the offshore abundance of *P. porpita* before the event was unknown. The observations are therefore consistent with wind- and current-driven transport of an existing offshore population towards the coast, but they cannot show why the stranding occurred on 17 April or at this site.

The co-occurrence of pelagic barnacles with *P. porpita* is reported as an incidental epibiotic association; the attachment and the reported ingestion of barnacle larvae are distinct interactions and do not by themselves indicate mutualism. The post-stranding impacts, including decomposition-driven odour, disruption to tourism, and interference with

fishing operations, demonstrate the socio-economic vulnerability of coastal communities to such episodic events. The increasing frequency of *P. porpita* stranding events along the Indian coast is consistent with the globally observed trend of rising jellyfish populations (Brotz et al. 2012; Purcell 2012; Richardson et al. 2009). Climate change-driven ocean warming, coastal eutrophication, and overfishing are hypothesized to underlie this increase (Richardson et al. 2009; Purcell et al. 2007; Siddique et al. 2022).

Three steps would strengthen future analyses of such events. First, the alongshore and cross-shore decomposition of the wind and current fields, and any Lagrangian drift simulations, would allow the transport pathway proposed here to be tested. Second, comparing stranding and non-stranding periods over several years would show whether the conditions described here are distinctive. Third, moored coastal buoys and dedicated observatories at ecologically sensitive nearshore hotspots and known stranding sites would provide the high-frequency, near-surface measurements of currents, waves, and hydrography where model, reanalysis products and satellite products cannot supply close to the shore.

Conclusion

The present study documented and analysed a mass coastal aggregation and beach stranding event of *Porpita porpita* during April 2025 along the Gopalpur Coast, north-western Bay of Bengal. The analysis indicates that the event is best explained by the combined influence of physical forcing, favourable thermal conditions, and enhanced biological productivity, although these are inferred associations rather than a demonstrated mechanism. The stranding was localized, covering about 1 km of shoreline with a mean density of about 5 colonies m^{-2}. During the preceding weeks, persistent southwesterly to southerly onshore winds blew towards the north-northeast and strong northward coastal currents provided the physical transport mechanism for the shoreward advection of neustonic colonies. Relative to the local coastline, these conditions combined a dominant alongshore drift with a weaker onshore component, consistent with passive transport of floating colonies towards the beach. The sea surface temperature remained within the 28–30 °C range reported for the earlier strandings of the species. The positive SST anomalies were strongest early in the period and had largely diminished by the stranding date. Elevated nearshore chl-*a* concentrations supported enhanced primary productivity, ensuring adequate prey availability. The co-occurrence of *Lepas* pelagic barnacles with *P. porpita* colonies is reported as an incidental epibiotic association within the pleustonic community. The post-stranding decomposition produced foul odours and temporarily disrupted tourism and recreational activities at the beach. These conditions resemble those of earlier strandings on the Odisha coast, but they are also typical of the pre-monsoon season. The findings demonstrate the complex interplay between oceanographic processes and socio-ecological consequences of jellyfish stranding events.

The recurring nature of such events along the Odisha coast supports routine monitoring of wind, currents, SST, and chl-*a*, combined with citizen science-based jellyfish reporting and nearshore observation. A longer record that includes both stranding and non-stranding periods would facilitate the development of regionally tuned prediction models. Such efforts would benefit coastal management authorities, fishermen, and tourism stakeholders in mitigating the impacts of future stranding events.

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Data Availability The datasets will be made available upon reasonable request.

Declarations

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