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Massive stranding of gelatinous zooplankton on the west coast of India

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Original Article

Abstract

A rare event of massive stranding of gelatinous zooplanktons was recorded in September 2022 off the Mangrol shore, Gujarat, the west coast of India. Four gelatinous species- three cnidarians, and one chordate- were recorded in the lot. The cnidarians *Porpita porpita* and *Physalia physalis* were stranded in the Indian waters during the post-monsoon. However, a *Aurelia* sp. and the planktonic tunicate *Salpa* sp. were the prime components. From satellite-derived data on chlorophyll-a (Chl-a), sea surface temperature (SST), and wind speed, it was observed that plankton blooms occurred during the post-monsoon season, following the mixing of freshwater nutrient components. Additionally, the beach stranding of jellyfish was attributed to their drifting shoreward as a result of wind speed. Thus, we conclude multiple factors may facilitate the movement of jellyfish to the shore, culminating in the mass stranding.

Keywords: *Mass stranding, jellyfish, thaliacea, MODIS-Aqua, west coast India*

Introduction

Jellyfish abundances are particularly impacted by tides, winds, and currents, which cause them to aggregate close to the coast. The thaliaceans and jellyfish are primary pelagic planktonic groups of tunicates (pelagic chordates) and cnidarians. A comprehensive inventory of Cnidaria in Indian waters described 842 species, of which 212 species were hydrozoans, 34 species were scyphozoans, and 6 species were cubozoans (Chakrapany, 1984; Nisa *et al.*, 2021). Jellyfish aggregations, other mass occurrences, and beach strandings have been documented at more than 23 locations along the coast of India in the last four decades (Siddique *et al.*, 2022). Jellyfish strandings may result from the interaction of various abiotic and biotic factors affecting populations over time and specific routes.

Global warming impacts coastal ecosystems through elevated sea water temperatures, rising sea levels, and heightened water acidity (Nazarnia *et al.*, 2020). In contrast, jellyfish with high tolerance to environmental changes can exploit ecological imbalances and proliferate into mass occurrences in warm, high-salinity, turbid, and nutrient-rich waters (Purcell, 2012). Such imbalances might occur due to factors like pollution, climate change, or other human-induced alterations in the environment. Overfishing might further contribute to jellyfish proliferation by reducing predation and competition for food, as it eliminates organisms at higher trophic levels (Boero, 2013). Additionally, the marine ecosystem often experiences hypoxic conditions caused by water effluents from power plants and eutrophication. This eutrophication results from riverine influxes of phosphates and organic matter into the ocean, particularly during heavy monsoon rainfall (Boero *et al.*, 2008; Siddique *et al.*, 2022). Jellyfish possess unique adaptations, such as a low metabolic rate and, in some species, the ability to store oxygen in their tissues (Rutherford and Thuesen, 2005). Thus, jellyfish in general are presumed to be more tolerant of hypoxic conditions compared to other marine organisms.

Salpa is a genus of planktonic tunicate, a gelatinous marine organism that is part of the zooplankton community. Although all gelatinous zooplankton scattered across the metazoan branch of the tree of life have converged on phenotypes including low-carbon growth strategies (Arai, 1997; Wrobel and Mills, 1998) transparency (Hamner, 1985), drifting, and buoyancy (Bone, 2005), each has many unique characteristics due to their distinct evolutionary histories and, presumably, different selective landscapes (Lucas and Dawson, 2014). The combination of watery, low-carbon bodies in *Salpa*, along with their filter-feeding habits and physiological ecology resembling many cnidarians and ctenophores, grants them a competitive edge in the heterogeneous food environments prevalent in numerous pelagic ecosystems (Sutherland and Madin, 2010; Lucas and Dawson, 2014). Due to seasonal and oceanographic factors, salps are usually found in low abundance during the winter and en masse seasonally over shelf areas in the spring and summer (Andersen, 1985; Henschke *et al.*, 2016; Groeneveld *et al.,* 2020). Numerous environmental factors have been associated with salp blooms, but it is still unclear which one or a combination of these factors causes them. Observations show that salp blooms can occur irregularly, ranging from dense outbreaks without regular interannual patterns to complete absence (Brattstrom, 1972; Henschke *et al.*, 2018; Ariffian *et al.,* 2024).

There are factors such as wind speed and tidal current that serve as predictable elements, enabling management authorities to plan and regulate beach use and swimming activities effectively. (Zavodnik, 1987; Graham *et al.*, 2001; Keesing *et al.*, 2016). Beach stranding of Jellyfish is regularly noticed along beaches of India such as Puri, Gopalpur, Kochi, Odissa, Chennai, Rameswaram, Goa, Mumbai, Dwarka, Mandvi and Veraval (Sahu and Panigrahy, 2013; Riyas and Biju Kumar, 2017; Baliarsingh *et al.*, 2020; Sahu *et al.*, 2020; Shah and Shah, 2021; Sabapara *et al.*, 2022). Continuous monitoring of natural parameters, such as wind speed, tidal currents, water temperature, salinity, turbidity, and dissolved oxygen, alongside anthropogenic factors, including water quality deterioration, overfishing, and habitat modification, is essential for devising effective strategies to mitigate jellyfish strandings along shorelines.

Material and methods

From 2020 to 2023, monthly field surveys were carried out to examine marine biodiversity and environmental conditions along the Mangrol coast (21.10°N, 70.10°E). In September 2022, a 2 km section of the coastline experienced a mass jellyfish stranding event. A random quadrat sampling technique (0.25 m^2) was used along a belt transect to measure species abundance. For systematic data collection, a 100-meter section of the 2 km area was chosen at random. From the shoreline to the deeper tidal mark, the belt transects were laid out in a zigzag pattern. A total of five transects were laid across the selected stretch, with ten quadrats (each 0.25 m^2) placed along each transect. Instead of being positioned at predetermined intervals, quadrats were positioned at random points along the belt transects. Photographic documentation was used in addition to visual observations made in the field to identify the species.

To investigate potential environmental factors influencing the jellyfish stranding event, remote sensing data were utilised. Chlorophyll-a (chl-a) concentration and sea

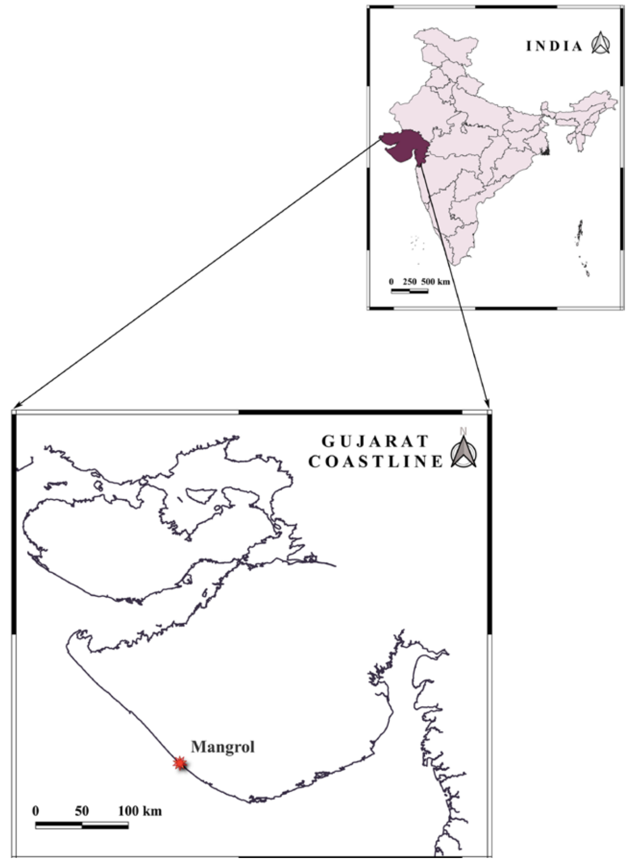

Fig. 1. Map showing the study location, Mangrol, where gelatinous zooplankton were stranded along the west coast of India

surface temperature (SST) for the selected coastal region were retrieved from the Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) satellite, providing insights into oceanographic conditions (https://oceancolor.gsfc.nasa.gov/about/missions/aqua). Additionally, wind speed data were sourced from Windy.com (https://www.windy.com), aiding in the evaluation of meteorological influences on jellyfish dispersal and accumulation along the shore.

Results

The first recorded instance of a mass stranding of salps and jellyfish was observed in September 2022 along the West Coast of India at Mangrol. Environmental factors surrounding these events are reported using MODIS Aqua satellite data for chlorophyll-a (chl-a) concentration and sea surface temperature (SST) were summarised over three years (2021–2023).

Chlorophyll-a variability

The retrieved satellite-derived chl-a data demonstrated that monthly variations were relatively consistent in 2021 and 2023.

Table 1. Monthly variation in oceanic chlorophyll-a (chl-a) along the West coast (Mangrol) of India

Months	Chlorophyll-a concentration	Chlorophyll range (mg/m^3)
Year- 2021		
Jan- Feb	Moderate	1.5-2.5
Mar-May	Low	0.5-0.7
Jun-Aug	-	Sun glint
Sep-Oct	Moderate	0.5-1
Nov- Dec	High	2-3
Year- 2022		
Jan-Feb	Moderate	1-2
Mar-Apr	Low	0.5-1
May	Low	<0.5
Jun-Aug	-	Sun glint
Sep-Nov	High	2.5-4
Dec	High	4.5
Year- 2023		
Jan- Feb	2-3	High
Mar	1-2	Moderate
Apr-Jun	0.3-0.5	Low
Jul-Sep	-	Sun glint
Oct	1-2	Moderate
Nov- Dec	2-4	High

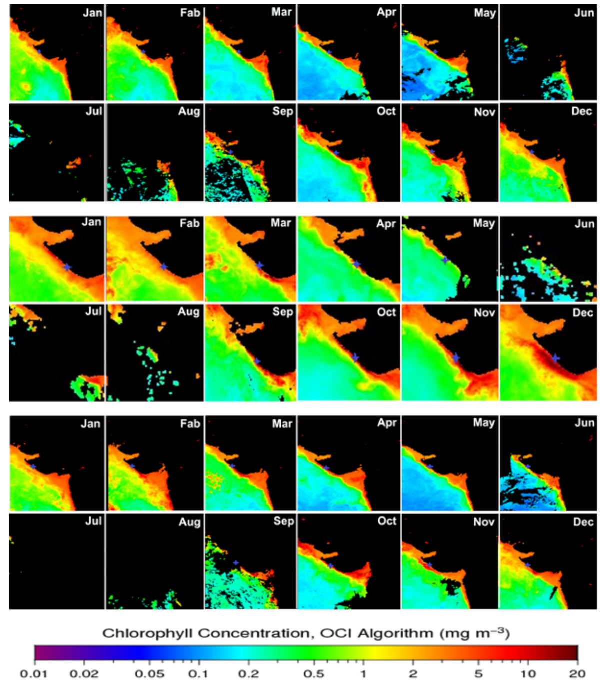

Fig. 2. NASA MODIS-Aqua-derived monthly averaged chlorophyll-a (Chl-a) concentration data for the Mangrol site from 2021 to 2023

During September and October 2021, chl-a concentrations were low, ranging between 0.5 to 1 mg/m^3. In contrast, moderate concentrations (1–2 mg/m^3) were observed in October 2023. Notably, the year 2022 exhibited elevated chl-a levels during the post-monsoon season (September–December), ranging between 2.5 and 4.5 mg/m^3, indicating enhanced primary production (Table 1; Fig. 2).

Sea surface temperature (SST)

The monthly average SST data revealed a consistent seasonal pattern across all three years. SSTs were lowest during December to February (20–24°C) and gradually increased from April to July, peaking at 28–32°C (Table 2; Fig. 3). In 2022, sea surface temperature (SST) along the Mangrol coast ranged between 22 °C and 30 °C, with a gradual increase from April to July, reaching peak values between 28 °C and 30°C.

Wind speed patterns

Satellite-derived average wind speed data indicated notable interannual variations. In 2021 and 2022, wind speeds increased from June to July, ranging from 23.2 km/h to 27.2 km/h and 20.3 km/h to 27.2 km/h, respectively. In 2023, wind speeds began rising earlier, from May to June (20.8 km/h to 27.8 km/h).

Table 2. Monthly variation in Sea surface temperature along the west coast (Mangrol) of India

Months	SST Grade	SST range (°C)
Year- 2021		
Jan- Feb	Low	20-22
Mar-Apr	Moderate	26-28
May-Jul	High	30-32
Aug-Oct	High	28-30
Nov-Dec	Moderate	24-26
Year- 2022		
Dec- Feb	Low	22-24
Mar	Moderate	26
Apr- July	High	28-30
Aug- Nov	High	26-28
Year- 2023		
Dec-Feb	Low	20-22
Mar	Moderate	22-24
Apr	High	28-30
May-Jun	High	30-32
July-Sep	Moderate	26-28
Oct- Nov	High	28-30

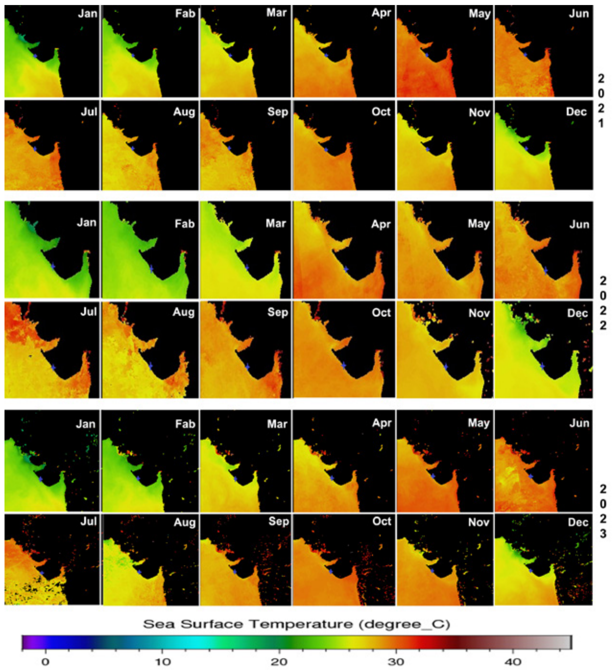

Fig. 3. NASA MODIS-Aqua-derived monthly averaged Sea surface temperature (SST) data for the Mangrol site from 2021 to 2023

After July, wind speeds generally declined in 2021 and 2023. However, in 2022, a sudden and significant decline in wind speed was observed between July and September (24 km/h to 15.1 km/h), representing the lowest wind speeds recorded during the three years (Fig. 4). The highest wind speed of 24 km/h was recorded in July.

Mass stranding

Mass stranding events of jellyfish species, including *Porpita porpita*, *Physalia physalis*, a *Aurelia* sp. and *Salpa* sp., were documented at the Mangrol coast in mid-September (Fig. 5, 6). Notably, an exceptionally high number of *Salpa* species was observed stranded along the coast. In contrast, live individuals of *Porpita porpita* and *Physalia physalis* were found along a 2 km stretch of the coastline. Additionally, two to three individuals of *Aurelia* sp. were observed stranded in the upper and middle littoral zones. This is the first reported instance of massive stranding of *Salpa* sp. in the West coast (Mangrol) of the Indian coastline.

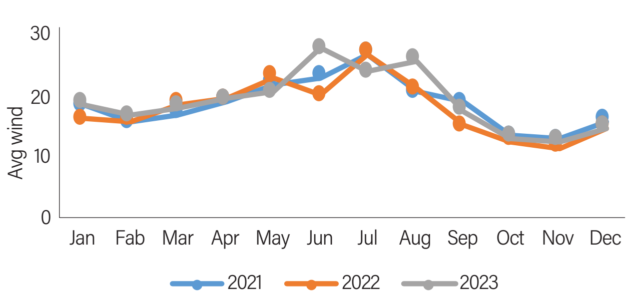

Fig. 4. Monthly averaged wind speed data along the west coast of India (Mangrol) from 2021 to 2023

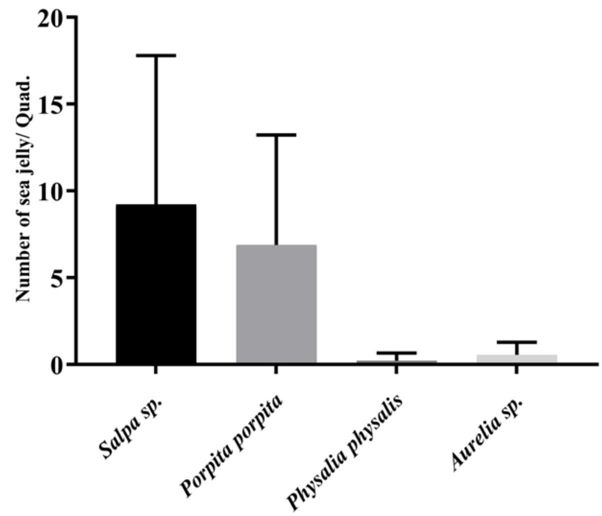

Fig. 5. Number of gelatinous zooplankton recorded per Quadrat (0.25m^2) among selected stretches of Mangrol coast on 25th September 2022

Fig. 6. Gelatinous zooplankton at the Mangrol coast. a. *Porpita porpita*; b. *Physalia physalis*; c. Mass Stranded *Porpita porpita*; d. *Aurelia* sp.,; f. *Salpa* sp. e, g and h. Stranded colonies of *Salpa* sp.

Discussion

Mass stranding events of jellyfish have become a periodic phenomenon along the coastal waters of India. Jellyfish mass occurrences as well as beach strandings have been reported from both the west (eastern Arabian Sea) and east (western Bay of Bengal) coasts of India (Kumar *et al*., 2020). Jellyfish can survive under adverse environmental conditions and can quickly multiply during favourable ones. Their accumulation can be triggered by various natural factors such as sea surface temperature, wind speed, tidal fronts, surface currents, dissolved oxygen, water, salinity, and turbidity and anthropogenic factors like deteriorated water quality, overfishing, habitat change and introduction of exotic species (Richardson *et al*., 2009; Baliarsingh *et al*., 2020; Siddique *et al*., 2022).

There have been reports of *P. porpita* strandings along the Indian coastline in a number of places and during various seasons. During the monsoon season, a considerable number of *P. porpita* were seen washing ashore along the Veraval coast (CMFRI, 2010). Similarly, Gopalpur's tourist beaches were affected by a significant number of dead jellyfish in 2012 (Sahu and Panigrahy, 2013). Cyclone Nivar has been blamed for the beach stranding of *P. porpita* along the Rameswaram coastline in the Gulf of Mannar, as it pushed aggregations of the species toward the shore (Tharik *et al.,* 2021). *P. porpita* strandings along the Odisha coast are caused by several environmental factors, such as sea surface temperatures (SSTs), wind patterns, shoreward currents, and concentrations of Chl-a (Sahu *et al.,* 2020). There have been reports of similar findings for other species of jellyfish. For example, Padate *et al.* (2020) found that the main cause of the drift of *Pelagia noctiluca* blooms along the Gujarat coast is oceanic currents. In August, it was discovered that a significant biomass of *P. porpita* was transported from the southern coast of the Gulf of Kutch to its northern coastal regions by strong south-westerly monsoon winds (Shah and Shah, 2021). Additionally, during the summer months, *P. porpita* mass stranding events were documented along Visakhapatnam's beaches (Pattnayak *et al*., 2023). Coastal current patterns have been closely linked to jellyfish aggregations in Kalpakkam's coastal waters (Masilamoni *et al*., 2000). The significant increase in jellyfish abundance during July–August may be linked to the reproductive cycles of scyphozoans and hydrozoans, which are known to proliferate in warmer waters with temperatures ranging between 26–28 °C (Baliarsingh *et al*., 2020).

This study documents the first documented mass salp stranding on the Mangrol coast, as well as a significant jellyfish beach stranding in September 2022. These planktonic species' mass stranding tentatively seems to be related to changes in the environment. Increased primary production is indicated by elevated Chl-a levels (2.5–4.5 mg/m^3) in 2022, which could support larger populations of gelatinous zooplankton. Although SST patterns stayed the same, post-monsoon temperature increases might have facilitated zooplankton growth, also supporting jellyfish blooms. While the significant decrease in wind speed from 24 km/h in July to 15.1 km/h in September probably decreased coastal water mixing and contributed to stranding events, as higher wind speed pushes the jellyfish offshore. Because salps are ephemeral and their oceanic appearance is unpredictable, it can be difficult to collect them and perform additional analysis. Though there has been discussion regarding which of these factors are the main triggers based on long-term observations of salps, particularly in the North Atlantic and South Pacific regions, temperature, salinity, and the concentration of Chl-a are the three main environmental factors that typically correlate with salp blooms (Henschke *et al*., 2011, Ishak *et al*., 2020, Kawaguchi *et al*., 2004, Licandro, 2006, Stone and Steinberg, 2014). The possible impact of oceanographic and environmental factors on gelatinous zooplankton populations is indicated by the mass stranding events of jellyfish species, such as *P. porpita, P. physalis,* the *Aurelia* sp., and *Salpa* sp. that were observed along the Mangrol coast in mid-September. Numerous biotic and abiotic variables, such as variations in sea surface temperature, ocean currents, wind patterns, and nutrient availability, have been linked to jellyfish strandings (Purcell *et al*., 2007). Monsoonal upwelling, nutrient enrichment, and the ensuing phytoplankton blooms—which are the salps' main food source-may be responsible for the unusually high number of *Salpa* sp. seen during this event (Henschke *et al*., 2016). It is possible that increased food availability caused the population to grow quickly, and that prevailing currents and wind-driven migration carried them passively towards the coast. Given that both species rely on gas-filled floats for buoyancy, the presence of *P. porpita* and *P. physalis* along a coastal stretch suggests transport by surface currents and wind drift. Onshore winds have a major impact on *P. physalis* dispersal, which may be the cause of its accumulation (Graham *et al*., 2001). Compared to other species recorded during this event, *Aurelia* sp. may be less likely to become stranded, as evidenced by the comparatively small number of individuals of the stranded medusa in the upper and middle littoral zones.

Further research is required to identify the precise environmental factors causing this phenomenon, as this is the first documented case of massive *Salpa* sp. stranding in Mangrol. Insights into the spatiotemporal dynamics of gelatinous zooplankton populations in this area may be gained through long-term monitoring of oceanographic parameters such as sea surface temperature, salinity, dissolved oxygen, and chlorophyll-a concentrations. Furthermore, evaluating how anthropogenic activities and climate change affect the distribution and stranding patterns of jellyfish may help us better understand how ecosystems react to environmental disturbances.

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Author contributions

Conceptualisation: DSA; Methodology: DSA, NKG; Data Collection: DSA, NKG; Data Analysis: DSA, NKG; Writing Original Draft: DSA; Writing – Review and Editing: DSA, RSK; Supervision: RSK

Data availability

The data are available and can be requested from the corresponding author.

Conflict of interest

The authors declare that they have no conflict of financial or non-financial interests that could have influenced the outcome or interpretation of the results.

Ethical statement

No ethical approval is required as the study does not include activities that require ethical approval or involve protected organisms/ human subjects/ collection of sensitive samples/ protected environments.

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