International Journal of Fisheries and Aquatic Research
www.fishjournals.com
ISSN: 2456-7248
Received: 05-03-2024, Accepted: 03-04-2024, Published: 19-04-2024
Volume 9, Issue 1, 2024, Page No. 44-48

A study of jellyfish on the coast of Ratnagiri, Maharashtra-India

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Abstract
Jellyfish aggregations focused on India's coastal waters was conducted, with the aim to enhance understanding of conducive conditions and subsequent ecological impacts. Jellyfish swarming, as well as their beach strandings, have been reported from many areas of the Ratnagiri district. - including Indians coastal waters. A variety of species were found in the coastal waters of Ratnagiri district. In the turbid water and other factors naturally (winds, tidal fronts, surface currents, water temperature, salinity, turbidity, dissolved oxygen) and anthropogenic (water quality deterioration, overfishing, translocation, habitat modification) factors play pivotal roles in triggering jellyfish aggregations. Jellyfish aggregation events in the forms of their swarming in coastal waters and beach strandings have resulted in ephemeral nuisances such as water quality deterioration, food chain alterations, hindrance in seawater uptake by power plants, clogging of nets during fishing operations, and tourism declines. Despite recurrence of such events, jellyfishes are relatively less scientifically investigated and monitored in Ratnagiri coastal waters.

Keywords: Jellyfish aggregations, Ratnagiri coastal waters, Swarming and beach strandings, Ecological impacts, Anthropogenic and natural factors

Introduction

Jellyfish and sea jellies are the informal common names given to the medusa-phase of certain gelatinous members of the subphylum Medusozoa, a major part of the phylum Cnidaria. Jellyfish are mainly free-swimming marine animals with umbrella-shaped bells and trailing tentacles, although a few are anchored to the seabed by stalks rather than being mobile. The bell can pulsate to provide propulsion for highly efficient locomotion. The tentacles are armed with stinging cells and may be used to capture prey and defend against predators. Jellyfish have a complex life cycle; the medusa is normally the sexual phase, which produces planula larva that disperse widely and enter a sedentary polyp phase before reaching sexual maturity.

Jellyfish, also known as sea jellies, are the medusa-phase of certain gelatinous members of the subphylum Medusozoa, which is a major part of the phylum Cnidaria. Domain-Eukaryota, Kingdom-Animalia, Phylum Cnidaria, Subphylum-medusozoa. Jellyfishes constitute an important group of marine animals, which are broadly distributed in many coastal and open ocean regions. These gelatinous animals occur as meroplankton (transient planktonic phases) and holoplankton (permanent pelagic residents) (Richardson *et al*. 2009 [45]; Sahu and Panigrahy 2013) [47]. Some jellyfish species form dense aggregations during favourable environmental conditions. Jellyfish growth and reproduction rates vary extensively with changes in environmental conditions, which lead to characteristic patchy distributions, dense aggregations, and subsequent population collapses (Purcell 2005) [42]. Jellyfish aggregations in coastal regions include swarming events and beach strandings that often result in water quality deterioration, trophic disturbance, and socio-economic losses (Richardson *et al*. 2009) [45]. In addition, jellyfish outbreaks exert significant impacts on tourism, recreational activities, and human health through toxic stinging from their nematocysts (Burnett 2001 [13]; Macrokanis *et al*. 2004) [36]. Episodes of jellyfish swarming have received substantial attention in recent times. However, the study of these organisms remains very subjective due to broad definitions and limited observational techniques (Brotz *et al*. 2012) [11]. In peninsular Indian seas and coastal regions, jellyfish swarming and beach strandings have been reported sporadically (Fig. 1). Nuisances have included adverse impacts on tourism, fishing, and water intake by coastal power plants. On this backdrop, this review emphasizes (i) the environmental parameters conducive for jellyfish swarming, (ii) impacts of swarming on the environment and socio-economy, (iii) documentation of swarming/beach strandings in Indian coastal waters/beaches, and (iv) a conceptual framework for possible monitoring.

Environmental variable for jellyfish swarming

Jellyfishes can survive under adverse environmental conditions and can quickly multiply during favorable ones. Their swarming can be triggered by natural (winds, tidal fronts, surface currents, water temperature, salinity, turbidity, dissolved oxygen) and anthropogenic (water quality deterioration, overfishing, translocation, habitat modification) factors (Richardson *et al*. 2009) [45]. Local weather conditions, such as wind direction, play an essential role in accumulations of jellyfish assemblages in coastal waters. Onshore wind bursts also trigger localized jellyfish aggregations (Kaneda *et al*. 2007) [30]. Oceanic physical processes such as tidal fronts (Brodeur *et al*. 1997) [10], convergent flow (Graham *et al*. 2001) [26], and small linear surface convergences during Langmuir circulation also lead to jellyfish accumulations (Graham *et al*. 2001) [26]. Oceanic warming conditions often result in higher jellyfish densities. Rising temperatures in global seas may trigger the success of some jellyfish species and change species distributions (Xu *et al*. 2013; Sullivan *et al*. 2001). Jellyfishes match the ionic concentration of the surrounding seawater and tend to behaviorally remain in isohalines leading to localized accumulation (Graham *et al*. 2001) [26]. Freshwater pulses from river discharge lead to reductions of jellyfish aggregations (Amorim *et al*. 2018) [3]. Hence, obstructing the natural flow of rivers, by break walls, harbors, and other barriers, can influence the salinity of nearshore waters and possibly set up conducive conditions for jellyfish aggregations. Accidental introductions of invasive/alien jellyfishes can result in mass aggregations (Purcell *et al*. 2007) [44]. Jellyfish swarms often occur in surface waters, with surface currents providing advection (Johnson *et al*. 2005 [29]; Zavodnik 1987). Hence, jellyfish aggregations frequently occur at transport barriers due to alongshore currents (Franks 1992) [22]. Regional re-distribution or re-dispersion in density of a persistent jellyfish assemblage also may occur (Graham *et al*. 2001) [26]. In addition, deterioration of water quality, higher turbidity, and lower dissolved oxygen concentration can lead to patchy aggregation and swarms (Purcell *et al*. 2007) [44]. Aquaculture may inadvertently favor growth of jellyfish assemblages through several means, including dissolution of surplus fish food and artificial constructions—such as cages—can provide support for polyps and their subsequent strobilation (Purcell *et al*. 2007) [44].

Harmful consequences of jellyfish swarming

Jellyfish swarms disturb marine ecosystems and can exert significant socio-economic effects. They predate on zooplankton, competing with fishes, leading to possible declines (Purcell 2003; Purcell *et al*. 2007) [44]. At higher density, jellyfish assemblages can interfere in aquatic nutrient cycling (Pitt *et al*. 2005) [40]. Further, jellyfish swarming during their decline phase contribute to the bottomward transport of organic carbon. Decomposed jellyfish material sinks quickly to the ocean floor and serves as food for benthic biota, in turn influencing benthic species' distributions (Billett *et al*. 2006 [9]; Sweetman and Chapman 2011). Dense jellyfish patches can choke fishing nets and hinder commercial catches (Graham *et al*. 2003).

When predominant, jellyfishes also may result in fish population declines by preying on fish eggs, larvae, and juveniles and may alter food webs (Lynam *et al*. 2005, 2006) [35]. For instance, the capture fishery declined significantly in the Black Sea subsequent to jellyfish invasion by *Mnemiopsis leidyi*, introduced through ship ballast water (Shiganova 1998) [48]. Jellyfish dominance also may affect coastal aquaculture causing toxic stinging, metabolic distress, and mass mortality of fishes (Purcell *et al*. 2013) [43]. As a consequence of stinging, fish growth may slow, resulting in economic loss for fishery and aquaculture industries (Baxter *et al*. 2011) [6]. Jellyfish can kill fish in aquaculture cages by irritating their gills, resulting in haemorrhage and asphyxiation (Purcell *et al*. 2007) [44]. Indirectly, jellyfish aggregations around mariculture cages interfere with water exchange, which may lead to hypoxia and fish suffocation (Doyle *et al*. 2008; Lucas *et al*. 2014) [33].

Jellyfish may exert indirect deleterious impacts on coastal industries and tourism. Ingress of large quantities of jellyfish into seawater-based cooling systems of coastal power plants and desalination industries clog intake screens, resulting in temporary shutdowns (Masilamoni *et al*. 2000 [37]; Purcell *et al*. 2007) [44]. Such jellyfish outbreaks have hindered seawater intake by coastal power and desalination plants in China and Israel (Galil *et al*. 2009 [23]; Dong *et al*. 2010) [19]. Coastal tourism provides one of the major revenues of several sea-bordering countries. Shallow coastal water tourism resources include swimming, snorkeling, diving, and beach recreational activities. Jellyfish swarming in coastal waters and beach strandings sometimes impact tourism. For example, jellyfish proliferation along coastal stretches of Israel affected tourism, resulting in revenue loss (Ghermandi *et al*. 2015) [24]. Jellyfish toxic stings can cause several human medical complications, including respiratory arrest, abdominal cramps, nausea, vomiting, headache, anxiety, and hypertension (Lucas *et al*. 2014) [33]. Jellyfish stinging, for example, has emerged as a human health hazard for beachgoers in southern Italy (De Donno *et al*. 2014) [16].

Jellyfish swarming in Indian coastal waters

Jellyfish swarms as well as beach strandings have been reported from both the west (eastern Arabian Sea) and east (western Bay of Bengal) coasts of India. Jellyfish aggregations and resultant environmental deterioration in Indian coastal waters are evident from several scientific publications, as well as local print and electronic media reports. Despite that, jellyfish are relatively poorly investigated and monitored in Indian coastal waters (Sahu and Panigrahy 2013 [47]; Baliarsingh *et al*. 2015) [5]. Available reports suggest that a greater number of swarms and beach strandings have occurred on the east coast of India than on the west coast. Jellyfish aggregations also have been observed to hinder fishing operations in Indian coastal waters. Clogging of fishing nets was observed in estuaries and coastal waters of Kerala due to jellyfish swarms (The Economic Times 2014; The Statesman 2018). Seasonal (November–December and April–May) jellyfish infestation in coastal waters of Jakhau clog gillnets that mainly are operated by motorized boats (Cadalmin 2010) [12]. However, fishermen have taken an adaptive option to harvest jellyfishes due to heavy demand from China and South East Asian markets, reaching up to ~ 800 tonnes in a season (Cadalmin 2010) [12]. Similarly, an edible jellyfish (*Crambionella annandalei*) is harvested from Andhra Pradesh, on the Indian east coast during the pre-southwest monsoon period (Behera *et al*. 2020) [7].

The prevalence of large numbers of jellyfishes in coastal waters of the northwestern Bay of Bengal also has influenced plankton ecology. Jellyfishes provide a competitive advantage to the heterotrophic dinoflagellate *Noctiluca scintillans* by preying upon its food grazers, which cause red tides that have resulted in water quality deterioration in coastal Gopalpur, along the east coast of India (Baliarsingh *et al*. 2016) [4]. On the other hand, jellyfish prevalence in coastal northwestern Bay of Bengal, particularly off Gopalpur, serves as food for migratory sea turtles (Sahu and Panigrahy 2013) [47]. In general, although jellyfishes often are considered as "dead-ends" in marine trophic webs, they supply food for several other top-level consumers including commercially valuable fishes, sea turtles, and even humans (Purcell *et al*. 2007) [44].

The Turritopsis dohrnii jelly species were found in Ratnagiri coast

Vulnerability of jellyfish aggregations in Indian coastal regions

India has a vast coastline of ~ 7500 km encompassing the west coast, east coast, and islands. The coastline's geographic structure varies among different pockets that can entrap wind-/current-driven jellyfish assemblages. Moreover, increasing pollutant loads in these coastal waters can deteriorate water quality, favoring jellyfish growth/proliferation. Coastal aquaculture is a fastest growing industry in India. According to a recent (2017–2018) report, a total of 152,595 ha area in nine Indian maritime states are under shrimp culture producing 680,018 metric tonnes (MPEDA 2020). Rapidly increasing aquaculture/mariculture/cage culture practices also can act as a catalyst for jellyfish swarming by providing substrate for their benthic stages.

Jellyfish aggregations have been monitored through field observations, acoustics, Lagrangian particle tracking, video profiling, aerial survey, now-cast model currents, and unmanned aerial vehicles in various regions of the World Ocean (Graham *et al*. 2003 [25]; Johnson *et al*. 2005 [29]; Houghton *et al*. 2006 [28]; Nickell *et al*. 2010 [39]; Berline *et al*. 2013 [8]; Kim *et al*. 2015). However, in Indian waters, such methods have not been adopted yet. The conducive environmental conditions of ecological regions can be monitored with autonomous acoustic observations (Colombo *et al*. 2008 [15]; Han and Uye 2009). The major advantage of this approach is that continuous real-time monitoring could be beneficial for power plant operations. Along with acoustics, in situ observations of jellyfish and physico-chemical parameters need to be collected to understand what triggers outbreaks. Subsequent monitoring can be done using earth observation data from satellite and oceanographic models. In this context, a conceptual framework is hereby proposed to develop a jellyfish monitoring system for Indian waters (Fig. 1).

The proposed detection and monitoring approach is based on environmental data from autonomous in situ instruments, satellites, and models. Wind velocity, ocean currents, sea surface temperature, chlorophyll, phytoplankton groups, and algal bloom scenarios can be retrieved efficiently from ocean observing remote sensing techniques. Other components of the conceptual framework such as salinity, dissolved oxygen, nutrient, and river discharge can be recorded through automated buoy-based observatories.

Conclusions

The gelatinous plankton community, including jellyfishes, is an important component of marine food webs. Although jellyfishes often are regarded as "dead-ends" in these food webs, they supply food of several top level consumers—including fishes, sea turtles, and even humans. However, their recurring swarms and beach strandings exert adverse impacts on aquatic ecology and human enterprises. Although jellyfish swarming plays an important role in ecosystem dynamics of coastal waters, environmental variables favouring their aggregations are not well understood. The present review thus highlighted the environmental concerns associated with coastal jellyfish swarming and beach strandings. In Indian coastal waters, jellyfish swarming and strandings have been observed to recur in several pockets, including estuaries and nearshore waters. Physical-chemical-biological parameters that influence growth, reproduction rate, and accumulation of jellyfishes need to be understood for monitoring their swarm dynamics. It would be economically and ecologically useful to develop an early warning system to alert power stations about incoming swarms of jellyfish. We thus here recommend a conceptual framework for a possible jellyfish aggregation monitoring advisory using coupled physical–biogeochemical model outputs. On another note, harvest of edible jellyfishes for human consumption will also be helpful for strategic management of jellyfish aggregations in Indian coastal waters.

Acknowledgements

"The authors gratefully acknowledge the financial support given by the Earth System Science Organization (ESSO) – Indian National Centre or Ocean Information Services (INCOIS), Ministry OF Earth Sciences, Government of India" to conduct this research.

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