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Coastal Catastrophe: Coastal Shrimp Farms under Siege by Jellyfish - A Study from Maharashtra Coast of India

Naga Kalpitha Shree N. N.[1], Ashpel Mano M. R.[1], Abuthagir Iburahim S.[1], Asha T. Landge[1], Nayak B. B.[1], Ramkumar S.[2], Karankumar Ramteke[1], Tarachand Kumawat[3], Ranjith Lakshmanan[4] and Raju Saravanan[4]

[1]Dept. of Fisheries Resources Management, ICAR-Central Institute of Fisheries Education, Mumbai (400 061), India
[2]Marine Biodiversity and Environment Management Division, ICAR-Central Marine Fisheries Research Institute, Mumbai (400 061), India
[3]Germplasm Exploration, Evaluation and Conservation, ICAR-National Bureau of Fish Genetic Resources, Lucknow, U.P. (226 002), India
[4]Marine Biodiversity and Environment Management Division, ICAR-Central Marine Fisheries Research Institute, Mandapam, Tamil Nadu (623 520), India

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Corresponding iburahim@cife.edu.in

0000-0002-7354-2690

ABSTRACT

This study was conducted from October, 2022 to July, 2023, in shrimp culture ponds in northern Maharashtra, India, examined the dynamics of these organisms in aquaculture systems. It investigated the emergence and ecological impacts of gelatinous zooplankton in shrimp culture ponds along the northern Maharashtra coast of India. Aquaculture, recognized as the fastest-growing global food-producing sector, was increasingly threatened by the proliferation of gelatinous zooplankton, particularly jellyfish species, in coastal ecosystems. Field investigations in *Penaeus* (*Litopenaeus*) *vannamei* shrimp ponds revealed a noticeable rise in the populations of *Tripedalia cystophora* (mangrove box jellyfish), *Blackfordia* sp., *Turritopsis* sp. (immortal jellyfish), and the ctenophore *Pleurobrachia pileus* (sea gooseberry). These blooms led to severe disruptions in shrimp growth and survival due to competition for feed and oxygen, and direct physical damage to post-larvae caused by nematocyst stings. The study identified inlet channels connected to coastal waters as a major route for zooplankton intrusion into culture systems. Satellite-derived environmental data showed a positive correlation between sea surface temperature (SST), chlorophyll-a concentrations, and the occurrence of gelatinous zooplankton. Laboratory trials tested mitigation strategies, with tea seed cake (2.5 ppm) demonstrating effectiveness in eradicating jellyfish and ctenophores without negatively impacting shrimp larger than 1 g. This research highlighted the growing threat of gelatinous organisms in aquaculture and underscores the urgent need for continued monitoring, improved water management, and targeted control measures. Strategic adaptation was critical in response to climate-driven changes, especially rising SSTs and eutrophication, along India's vulnerable coastal aquaculture zones.

KEYWORDS: Gelatinous zooplankton, coastal aquaculture, proliferation, ecological, economic consequences

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Aquaculture is a key sector in India's economy (Patil and Sharma, 2020). The production of aquatic animals reached 87.5 mt (Anonymous, 2022). Inland and coastal aquaculture (also referred to as mariculture) are its two broad categories. Due to its rapid growth, marine aquaculture is now a major contributor to global food production (Anonymous, 2020). In India, the contribution of mariculture and coastal aquaculture to national aquaculture production is estimated at 8.3 mt, valued at USD 36.2 billion (Anonymous, 2021). Over the last 10 to 15 years, there has been an increase in reports of jellyfish blooms adversely affecting the health of farmed fish and finfish mariculture facilities (Bosch-Belmar et al., 2020). As coastal aquaculture continues to expand, jellyfish have become more frequent nuisances, resulting in harmful interactions with aquaculture systems. Hydrozoan colonies have been reported to negatively affect fouling assemblages in aquaculture cages, as they often come into contact with medusae or larvae possessing stinging cells (Bosch-Belmar et al., 2019; Fitridge et al., 2012). The expansion of aquaculture into previously undeveloped coastal areas has contributed to increased blooms of scyphozoan jellyfish by providing new large-scale habitats for polyp colonization and reproduction (Dong et al., 2010; Duarte et al., 2013; Lo et al., 2008; Purcell, 2012; Richardson et al., 2009). In addition, large swarms and outbreaks of gelatinous zooplankton are known to have adverse effects on multiple sea-based human activities, including tourism, fisheries, aquaculture, and coastal industrial installations (Purcell et al., 2013). While *Rhopilema esculentum* blooms are commercially exploited for their nutritional value (Dong et al., 2009), blooms of *Aurelia coerulea*, *Cyanea nozakii*, and *Nemopilema nomurai* have been identified as harmful to fisheries, aquaculture, and tourism industries (Dong et al., 2010). Maharashtra is one of the maritime states of India, with a coastline of 720 km divided into seven districts: Thane, Palghar, Mumbai City, Mumbai Suburbs, Raigad, Ratnagiri, and Sindhudurg. These coastal areas offer vast potential for the expansion of brackishwater shrimp farming, an increasingly important industry. Along Maharashtra's coastline and adjoining streams, there are approximately 52,001 acres of brackishwater resources, out of which 10,400 acres are reportedly suitable for shrimp farming (Patil and Sharma, 2020). However, farmers engaged in coastal aquaculture encounter difficulties related to productivity, marketing, finances, and environmental sustainability. Ecological issues include natural disasters, social disturbances, Coastal Regulation Zone (CRZ) restrictions, environmental impacts of shrimp farming, and mangrove degradation (Patil and Sharma, 2020). In recent years, jellyfish and ctenophores have emerged as serious problems for shrimp farmers along Maharashtra's coast. Despite the absence of a scientific consensus on global jellyfish bloom trends, their negative impacts on human coastal activities are becoming increasingly frequent and severe (Brotz and Pauly, 2012; Condon et al., 2013; Purcell et al., 2007). Numerous incidents of jellyfish and ctenophores have been reported in the marine environment, including sudden blooms, beach strandings, by-catch landings, and clogging of industrial cooling plants. These organisms often degrade water quality, cause trophic disruptions, and result in socio-economic losses (Richardson et al., 2009). As mentioned by Narayanamma et al. (2023), where IPM reduced yield losses, similar strategies could help shrimp farmers manage stressors like jellyfish. A total of 842 species of *Cnidaria* have been recorded in Indian marine waters, including 212 Hydrozoa, 34 Scyphozoa, and 6 Cubozoa species (Saravanan, 2018; Abbas et al., 2019; Siddique et al., 2022). However, no published studies have documented jellyfish as a nuisance in coastal shrimp farms in Maharashtra. Hence, a study was conducted in northern Maharashtra to investigate the growth of jellyfish and ctenophores in coastal shrimp ponds.

2. MATERIALS AND METHODS

The On-site fortnightly sampling was carried out from October 2022 to July 2023 in the coastal ponds and Vaitarna creek at the region of Palghar district in Maharashtra, India (Figure 1). The type of pond utilized for shrimp culture (*Penaeus vannamei*) was an extensive earthen pond with the average pond area ranging from 2.5 acres to 3 acres and depth ranging from 1.5 m to 3 m. A Zooplankton net of 250-micron size was utilized to sample location, and sampling surveys were carried out in the early morning hours (Figure 2).

The samples were brought live and preserved in 95% alcohol and 4% formaldehyde in seawater. Photographs were taken from the live sample in situ using Canon EOS 80D, and microscopic organisms were captured using the Stereo zoom microscope and Dissection microscope. The water source

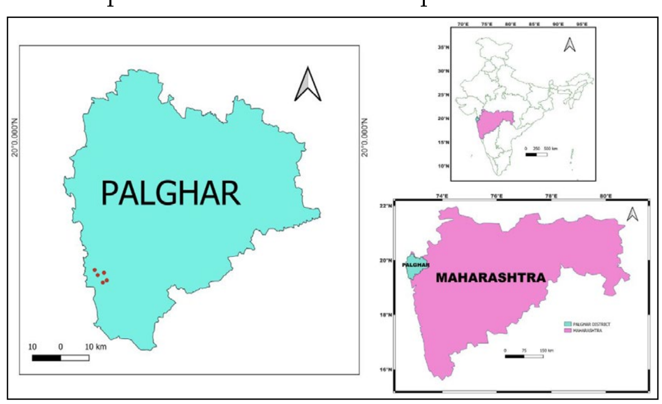

Figure 1: Sampling sites in coastal aquaculture farms in Palghar district of Maharashtra, India

Figure 2: a: Shrimp culture pond; b: Inlet of the Pond; c: Fishermen sieving the pond infested with gelatinous zooplankton; d: Huge numbers of *Pleurobranchia pileus* collected from the coastal ponds

and pond edges were also investigated. The identification of the species was based on the World Atlas of jellyfish (Jarms and Morandini, 2019) and Ctenophore (Greve, 1975; Kunne, 1939; Liley, 1958; Moser, 1903), and many experiments were carried out in situ to eliminate the jellyfish using different chemicals. The oceanographic parameters like the Sea surface temperature (SST) and Chlorophyll-a concentration data covering the targeted sampling sites along the northern coastal districts of Maharashtra from October, 2022 to June, 2023 were obtained from Internet-based sources like NASA internet servers Ocean Color Web. The Sea surface temperature (SST) and Chlorophyll-a concentration data were extracted in the Aqua-MODIS instrument. MODIS (Moderate Resolution Imaging Spectroradiometer) was a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. The capability of geophysical products from MODIS (Moderate Resolution Imaging Spectroradiometer), Level 3 and 4 browser at 4 km of the spatial resolution, were assessed for the targeted parameters, and monthly data were taken. MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery data was imported to QGIS and transformed to raster data on which a pixel of 4 km^2 has its own value. The MODIS data was extracted in Sea DASS and SNAP software for some locations. The Sea surface temperature (SST) data and Chlorophyll-a concentration data were extracted in degrees Celsius (°C) and Milligram per cubic metre (mg m^{-3}), respectively.

3. RESULTS AND DISCUSSION

The study indicated the presence of the *Tripedalia cystophora* (mangrove box jellyfish) *Blackfordia* sp., *Turritopsis* sp. (immortal jellyfish) and the ctenophore species *Pleurobranchia pileus* (sea gooseberry) in the culture ponds and adjacent Vaitarna creek (Figure 3).

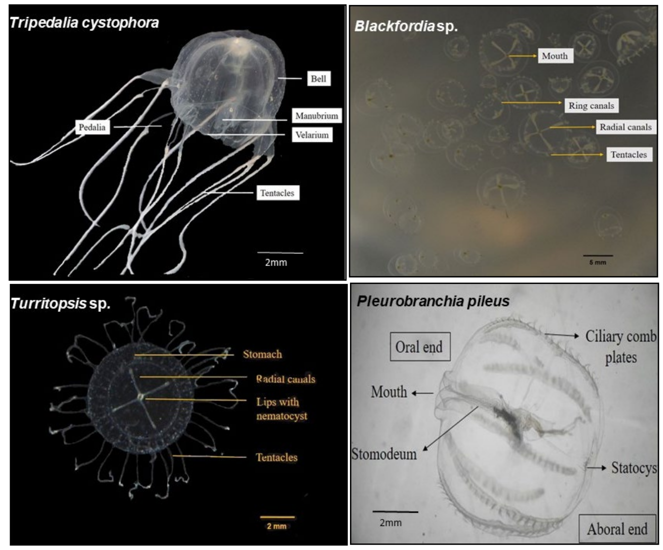

Figure 3: Diversity of gelatinous zooplankton in Coastal farm and Vaitarna creek, Maharashtra, India

The salinity of the pond was tested, and it ranged from 10–30 ppt during different months. The ctenophore was actively swimming in the pond, and it even exhibited bioluminescence under dark conditions in the laboratory (Figure 3). The number of individuals of the Ctenophores was seen in more numbers, like the swarm formation in the shrimp culture pond, compared to the box jellyfish, which was very easy to count with the naked eye. It was found that the sudden bloom of these organisms in the culture pond of the *Penaeus vannemei* was interfering with the growth of the shrimps and being a competitor for food, space, and oxygen. The box jellyfish is one of the deadliest organisms in the world because of the nematocysts that have a venom that was very much potent that could even kill human beings; so, in this case, the post-larvae in the shrimp ponds were severely being attacked by their tentacles and the farmers were losing the shrimp crops with huge loss. The nematocysts of the box jellyfish was affected the gills of the postlarvae. The farmers tried to eradicate these organisms without affecting the shrimp culture. Still, all the less harmful experiments on the shrimps were not successful in eliminating the jellyfish and ctenophores. So, the only way followed in that shrimp culture pond was manual removal with shrimp harvest nets. Many shrimp cultures were even aborted due to the infestation of the jellyfish and the ctenophore species. The shrimp farmers of regions were facing this sudden swarm only after the stocking of the post-larvae. This was a problematic situation leading to significant economic losses for the farmers. A few experiments was conducted with the Tea seed cake and found that 2.5 ppm of the Tea seed cake effectively eradicates the jellyfish and ctenophores and is noticed as safe for shrimp weighing more than 1 g. Possible entry might be through the water collected for the shrimp culture from the Vaitarna Creek flowing near the shrimp culture farm (Figure 4). The creek stretched for approximately 38 km, making it a substantial waterway in the region. The adjacent areas of Vaitarna Creek supported agriculture and aquaculture activities, providing livelihoods to local communities. The water from the creek was used for irrigation and aquaculture.

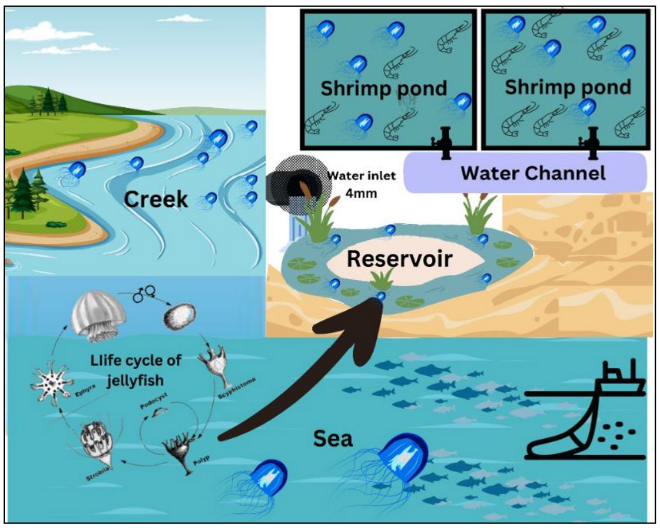

Figure 4: Illustration of Gelatinous zooplankton proliferation in the coastal shrimp pond

The lifecycle of the jellyfish was very complex. It had different stages, like the ephyra and planula with medusae and polyp-type body forms, so the larvae might be present in the waters that they used for the shrimp culture. They matured when the post-larvae were stocked and grown bigger in nutrient-rich water, consuming all the essential nutrients given to the shrimp. The jellyfish were even brought to the laboratory, and many chemical treatments and conditions were maintained to see their mortality and from this experiment, the EDTA was most effective in bringing mortality to the jellyfish but this could not be used because it also affected the shrimp post-larvae.

Positive correlation was found out between the Chl-a, SST of the environment and presence of jellyfish was found out (Figure 5, 6). The 3-D plot correlating the SST, Chl-a and the species were depicted in the graph (Figure 7). The maximum SST of Vaitarna Creek observed during the month of January was 34.979°C .The maximum Chl-a concentration of Vaitarna Creek was found during the month of January was 7.505 mg m^{-3}.

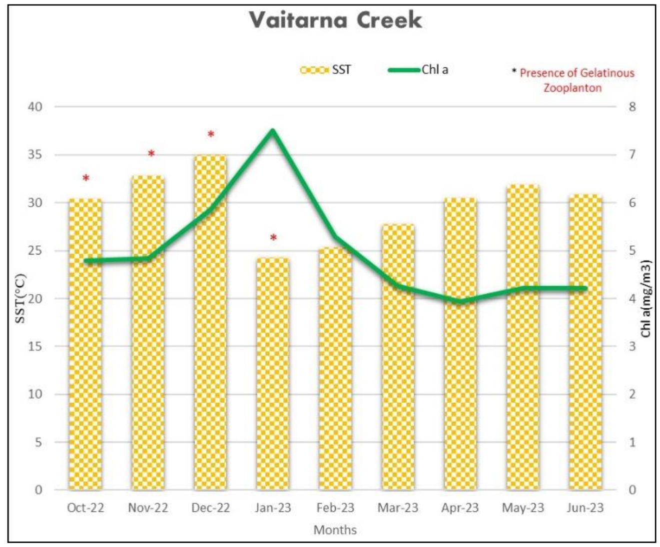

Figure 5: Correlation of jellyfish presence with Chl a and SST in vaitrana creek

The 3-D graph clearly showed the monthly variation and occurrence of species in the months of October, November, December, January and March. During the months of high SST and Chlorophyll-a, there was occurrence of species in the Vaitarna Creek. This showed that the species in this region were positively correlated with the SST and Chlorophyll-a. In the months of October, November and December, there was occurrence of three species (*Tripedalia cystophora*, *Blackfordia* sp., and *Turritopsis* sp.). In January, it was dominated by two species (*Tripedalia cystophora* and *Pleurobrachia pileus*). In March there was occurrence of only one species (*Pleurobrachia pileus*). As the SST and the Chlorophyll-a tend to rise, the Gelatinous zooplankton

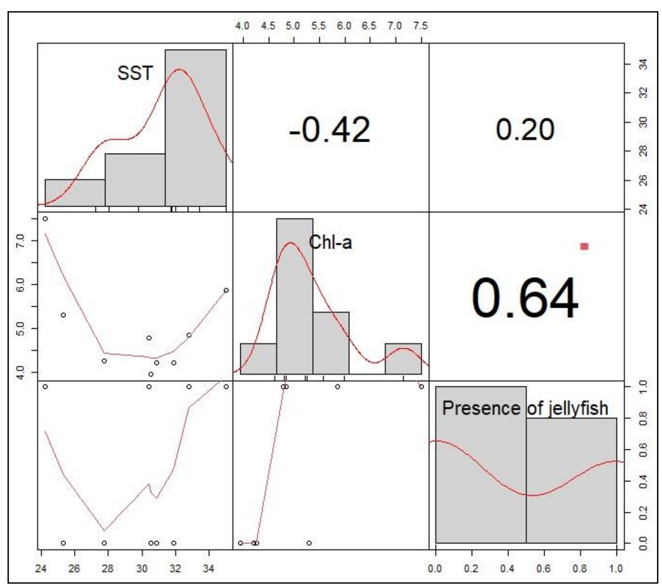

Figure 6: Correlation Matrix of jellyfish with Chl-a and SST in vaitrana creek

started to occur in the Vaitarna creek.

In the 3-D graph, the SST and Chl-a were depicted in the x-axis and y-axis respectively. The number of species that occurred was given in the z-axis. Here the data points tended to rise with the increase in the SST value. The number of species was found to occur with the increasing SST value. With increase in the values of Chlorophyll-a, it showed the occurrence of the gelatinous zooplankton. Thus, from the 3-D plot, it clearly depicted the correlation between them. Thus, it was evident that the SST and the Chlorophyll-a had a significant positive correlation with the occurrence of Gelatinous zooplankton in Vaitarna creek.

3.1. Jellyfish impacts on mariculture-global evidences

Several fish mortality events or health concerns in marine-farmed fish have been linked to jellyfish over the last three decades (Purcell et al., 2007). Gelatinous zooplankton could harm aquaculture species directly by stinging their body parts like skin and gills, or indirectly reducing the oxygen availability from the surrounding waters (Båmstedt et al.,

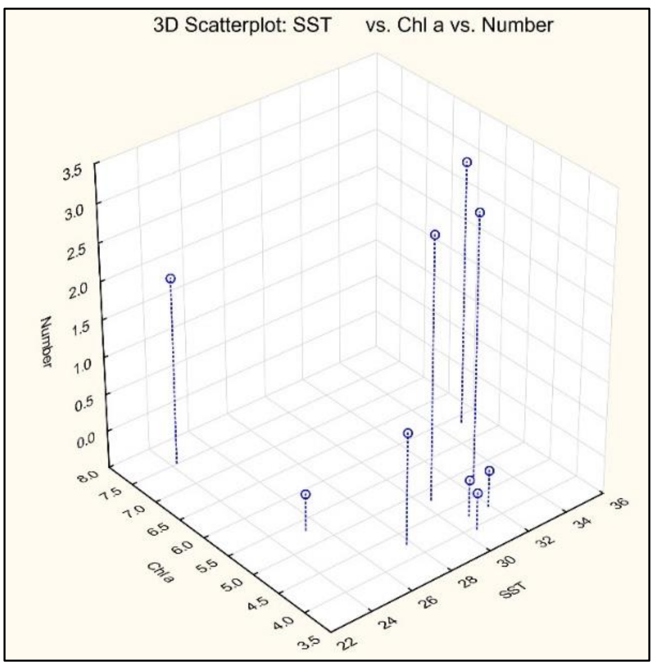

Figure 7: 3-D graphical representation of correlation between SST, Chl-a and Species in Vaitarna Creek

1998). Blooms of Aurelia sp. were reported to affect the sea cucumber production ponds in China by disturbing the digestive system of sea cucumbers (Dong et al., 2017b). Jellyfish blooms have caused significant economic losses for Northern European aquaculture by killing hundreds of thousands of farmed salmon in Ireland and Scotland on multiple occasions (Doyle et al., 2008; Marcos-López et al., 2016). The discharge of jellyfish nematocysts and the injection of venom typically resulted in a local inflammatory response, cell toxicity, and histopathology (Helmholz et al., 2010; Marcos-López et al., 2016; Rodger et al., 2011). In addition, these organisms caused serious financial losses by impeding water movement in marine cage cultures. In the future years, consequences on the shrimp farming industry would become increasingly severe. Jellyfish were considered a growing hazard to shrimp culture. In the aquaculture industry, jellyfish outbreaks have caused significant economic losses. Negative interactions of jellyfish with marine aquaculture have typically gone unreported or got only little attention; however, in recent decades, fish farmers, scientists, and other sectoral stakeholders have become more aware of the risks and concerns connected with jellyfish blooms. In-person interviews with farm owners revealed that the swarms first appeared two years ago and have since posed a significant danger. Even though it was presumed that these organisms entered through the water source, the apparent cause of their bloom remains unknown. Tea saponin had effect on significant morphological changes and imparted mortality to the *Aurelia* sp. under laboratory conditions when exposed to 28 hrs and 48 hrs in 1.9 mg l^{-1} after and 1.1 mg l^{-1} (Dong et al., 2017a). Similar to this study, the tea-saponin concentration of 2.5 ppm was used in this shrimp pond and found to be an effective treatment for eradicating jellyfish and ctenophore blooms without harming shrimps weighing 1 g or more. These jellyfishes have cnidocysts that ejected the venom affecting the gills of these shrimps and competing with the culture shrimps for food and space.

One of the major variables contributing to increased *Aurelia* spp. abundance and blooms were coastal eutrophication (Arai, 2001; Dong et al., 2010; Purcell et al., 2007; Richardson et al., 2009). Even local wind systems revealed that there was a correlation between ephyrae distribution and wind direction. Global warming was also thought to boost jellyfish populations by influencing distribution, growth, and ephyrae production (Dong et al., 2010; Richardson et al., 2009).

Furthermore, aquaculture activities might have led to an increase in jellyfish populations by providing an additional appropriate substrate for the colonisation and proliferation of benthic polyps (Lo et al., 2008; Purcell, 2013). Jellyfish blooms in Indian seas could be caused by a number of different things, and while many theories have been proposed, the true explanation for these blooms was difficult to pin down.

3.2. Possible solutions

Studies (Baxter et al., 2011a,b; Mitchell et al., 2011) indicated that pervasive, routine monitoring of jellyfish near marine fish farms was required and understanding of the relationship between jellyfish blooms and harmful effects on fish. To determine the seasonal and inter-annual abundance and occurrence of harmful species and to emphasize danger periods for each place, information at a site-specific level was crucial (Lynam et al., 2006; Purcell et al., 2013). Some measures for pond soil management could also be taken like removing the first 10 cm of the pond soil followed by sun drying and ploughing. By increasing the mesh size of the inlet to 150 microns could also prevent the entry of these organisms. According to certain research, the water jet was effective at eliminating polyps stuck to the pond's bottom. Chemical approaches could be employed to manage the blooms in enclosed spaces such as coastal aquaculture ponds and coastal power facilities (Dong et al., 2017a; Dong, 2019). Water filtration could be done more appropriately with step wise filtration unit and also the water that was used for culture could be treated in reservoir and then let into the pond for culture. In case of a semi-intensive culture system treatment of water with ozone and chlorine could also be done. To tackle the problem of net-fouling hydroids, non-toxic anti-fouling suited for use on organic farms, such as silicon-coated netting, which dramatically decreased fouling in Tasmania (Hodson et al., 2000), could be developed. According to Bosch-Belmar et al. (2017), the implementation of jellyfish and biofouling monitoring programs at aquaculture farms might make it possible to implement appropriate preventive countermeasures at a time when blooms were anticipated. The idea of co-managing fisheries could also be utilized in this context, where the collaboration between commercial fish growers and research institutes specializing in fisheries could result in the development of an approach that addressed the problems now being caused by jellyfish. It would be beneficial for fishermen to participate in training programs that educated them on the expanding blooms, the effects of those blooms, the potential mitigation and adaptation methods, and other related topics.

4. CONCLUSION

Gelatinous zooplankton, including various jellyfish species, appeared in distinct seasonal peaks influenced by temperature and monsoonal changes. The findings emphasized the urgent need to address their impact on aquaculture through preventive measures, as control after bloom onset proved challenging. Understanding their distribution and triggers was considered vital for developing effective physical, chemical, and technological interventions to minimize economic losses in mariculture systems. Enhanced monitoring and early warning systems could further support timely mitigation efforts.

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