Climate Ambition and Sustainability Action

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Noctiluca Scintillans in the Maritime Domain

Implications for India

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Key Messages >>>

- Climate change and marine pollution are leading to changes in the physical, chemical and biological conditions in the Arabian Sea, and these changed conditions are, in turn, becoming more conducive to the exponential proliferation of invasive species such as Noctiluca Scintillans in recent years.
- Being mixotrophs, with no prominent predator, Noctiluca Scintillans are known to have cascading implications on the marine food web, with a potentially colossal shift in traditional ecosystems, and expansion of the Permanent Oxygen Minimum Zone (OMZ) in the Arabian Sea
- Coastal sectors stand threatened, with long term ramifications on food and economic security, the Blue Economy, incidences of IUU (Illegal, Unregulated, and Unreported) fishing, and, critical maritime infrastructure. The social, economic, and security importance of the Arabian Sea to India's Gross Domestic Product (GDP) highlights the need to scientifically evaluate the causes of Noctiluca Scintillans outbreaks and their impacts upon India's maritime domain.
- There is a need for rigorous monitoring systems and a wider and more profound range of regional studies that incorporate multiple perspectives of science, policy, economy, marine biodiversity, and security, through interagency and interdisciplinary approaches with institutions, agencies in maritime governance, and local actors.

- This articulation of concerned high-risk sectors and regions in the Arabian Sea would provide opportunities within the Blue Economy for India to establish itself as a regional leader in maintaining the health of the Arabian Sea.

Introduction

In October 2020, bright blue sparkling waters were reported on the shores of the western Indian coasts, which were presented with excitement by residents of coastal cities and tourists in the face of the cold and demeaning fervor of the ongoing pandemic meltdown, restrictions and losses. The blue 'bioluminescence' along the western coastal shores of India, which was much bigger in regional expanse, duration, and visibility, than the previous year, was, however, noted with dismay and nervous documentation by field biologists, climate scientists, fishers and policymakers.

Noctiluca Scintillans, depicted in **Figure 1**, is a large dinoflagellate– a type of phytoplankton, whose sightings date back to 500 BC and is responsible for creating prominent green-murky tides by day and phosphorescent blue tides by night, during winter months in the eastern Arabian Sea[1] (West Coast of India).

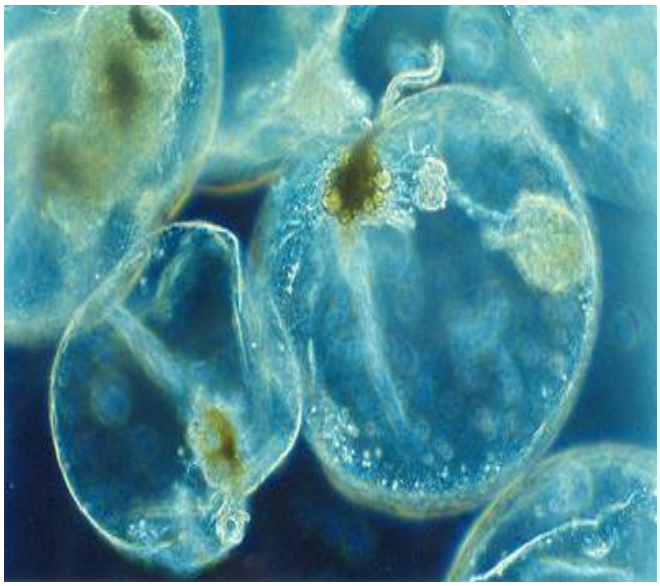

Figure 1: Green Noctiluca S. cells under a microscope

Source: Maria Antónia Sampayo, Instituto de Oceanografia, Faculdade Ciências da Universidade de Lisboa - http://planktonnet.awi.de (provided under a Creative Commons Attribution 3.0 License)

Marine bioluminescence is mainly blue in color and is produced by a few organisms such as the green *Noctiluca Scintillans*, which have light producing organs that harbor symbiotic bioluminescent cells. [Refer to **Figure 1**]. The light is produced in response to mechanical stimulation, and is commonly referred to as 'sea sparkle' due to its nocturnal appearance.[2] These organisms are opportunistic and evolving, with strong resilience to changing conditions and exhibit high rates of growth and reproductivity in a single given season.[3] The green and red types of *Noctiluca Scintillans* are known to create cascading negative impacts on the marine food web by eliminating healthy traditional populations of diatoms and aggressively feeding on a variety of nutrients and available food supply such as fish eggs.[4] Environmental alterations, caused by anthropogenic influences in the face of climate change, have provided favorable conditions for *noctiluca scintillans* to exponentially grow and expand across the Arabian Sea and several other tropical regions in the world.[5]

[1] L C Thomas et al, "Understanding the Dietary Relationship between Extensive Noctiluca Bloom Outbreaks and Jellyfish Swarms along the Eastern Arabian Sea (West coast of India)," *Indian Journal of Geo Marine Sciences* 49, (2020): 1389.

[2] Martha Valiadi et al, "Understanding Bioluminescence in Dinoflagellates—How Far Have We Come?," *Microorganisms* 1, No 1 (2013): 3-25, https://doi.org/10.3390/microorganisms1010003.

[3] Thomas et al, "Understanding the Dietary Relationship between Extensive Noctiluca Bloom Outbreaks and Jellyfish Swarms along the Eastern Arabian Sea (West coast of India)," 1389.

[4] Sheng-Fang Tsai et al, "The Dynamics of a Dominant Dinoflagellate, Noctiluca Scintillans, in the Subtropical Coastal Waters of the Matsu Archipelago," *Marine Pollution Bulletin* 127, (2018): 553.

[5] Thomas et al, *Supra* note 1.

Fish are known to avoid regions with a high presence of noctiluca blooms, probably due to the presence of low levels of dissolved oxygen from the decay and death of the bloom or metabolites released by lysing cells.[6] Moreover, excessive sewage and industrial effluent run-offs lead to conditions suitable for eutrophication in the Arabian Sea. The untreated outflow provides for the nutrient and food supply for noctiluca to thrive better than other phytoplankton and fish species.[7] The subsequent impacts of these outbreaks are reported through dead shoals of fish being washed ashore, reduced quality of fish catch, damage to coastal infrastructure and machinery, and challenges to biodiversity management in marine protected areas.[8] These causes, which lead to a conducive environment for *Noctiluca* to increase exponentially in the Arabian Sea, have been linked to climate change — more specifically the melting of the glaciers in the Himalayan Tibetan plateau, the expanding and quasi-permanent Oxygen Minimum Zone (OMZ) of the Arabian Sea, and, human factors such as the impact of air pollution and the outflow of high quantities of untreated domestic sewage, as also industrial effluent-discharge from bordering countries.[9]

The social, economic, and security importance of the Arabian Sea to India's Gross Domestic Product (GDP) highlights the need to scientifically evaluate the causes of *Noctiluca Scintillans* blooms/ outbreaks and their impacts upon India's maritime domain. This article will focus on the current scientific understanding of the characteristics and causes leading to the unprecedented outbreak of green *Noctiluca Scintillans* (hereafter referred to as *Noctiluca*) and its present and predicted implications for and impacts upon the different maritime sectors of interest to India.

Unique/Invasive Characteristics of *Noctiluca Scintillans*

As already stated above, *Noctiluca Scintillans* is a large and conspicuous dinoflagellate, about 0.2 millimeters (mm) in diameter, which is common in coastal and marine environments around the world.[10] Dinoflagellates, along with diatoms, are a type of phytoplankton commonly found in aquatic and marine systems bearing a single cell and two dissimilar flagella, and have characteristics of both plants and animals.[11] They are free-moving organisms of red and green varieties and are distributed among tropical and subtropical waters.[12] Recent outbreaks of the green *Noctiluca Scintillans*, which is famously known to cause incidences of bright blue bioluminescence (the production and emission of light by a living organism) at night, has sparked the interest of the scientific and strategic communities, as well as local coastal communities, due to the significant, wide-ranging impacts that these organisms have on the marine food-web and on the different sectors of the coastal economy, directly or indirectly.[13]

The cell wall of a dinoflagellate is made of cellulose, while diatoms have a cell wall comprising silica.[14] Dinoflagellates, like noctiluca, result in widespread blooms, leading to cascading impacts on the marine food web and coastal sectors.[15] *Noctiluca* are voracious, invasive mixotrophs and can feed on a large variety of organisms like bacteria, algae, fish eggs, and their commonly-found phytoplankton relatives, namely, diatoms.[16] Their growth rate and subsequent outbreak depend upon the availability of food, nutrients, and, atmospheric and oceanic conditions such as wind speed, salinity and temperature.[17] *Noctiluca* is known to

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[6] S Nayar et al, "Bloom of *Noctiluca scintillans* MaCartney in the Arabian Sea Off Mangalore Southwest India," *Asian Fisheries Science* 14 (2001): 77-82.

[7] Thomas et al, *Supra* Note 1.

[8] Anil Kumar Sastry, '"Sea Sparkle' has Affected Marine Food Chain: CMFRI," *The Hindu*, 28 November 2020. https://www.thehindu.com/news/national/karnataka/sea-sparkle-has-affected-marine-food-chain-cmfri/article33195894.ece

[9] Joaquim I Goes et al, "Ecosystem State Change in the Arabian Sea Fuelled by Recent Loss of Snow over the Himalayan-Tibetan Plateau," *Scientific Reports* 10, 7422 (2020), https://doi.org/10.1038/s41598-020-64360-2.

[10] Per J Hansen et al, "Green *Noctiluca scintillans*: a Dinoflagellate with its own Greenhouse," *Marine Ecology Progress Series* 275, (2004): 79-87.

[11] "Dinoflagellate", *Encyclopaedia Britannica* (2017), https://www.britannica.com/science/dinoflagellate.

[12] Tsai et al, *Supra* note 4.

[13] "Bioluminescence", *National Oceanic and Atmospheric Administration (NOAA),* (2021)

https://oceanservice.noaa.gov/facts/biolum.html.

[14] Samanthi, "Difference between diatoms and dinoflagellates," *Science and Nature*, Difference between.com (2018) https://www.differencebetween.com/?s=diatoms+and+dinoflagellates.

[15] Helga do Rosario Gomes et al, "Massive outbreaks of Noctiluca Scintillans blooms in the Arabian Sea due to spread of hypoxia," *Nature Communications* 5, 4862 (2014), https://doi.org/10.1038/ncomms5862.

[16] Tsai et al, *Supra* note 4.

Also see: Nayar et al, *Supra* note 6.

[17] Tsai et al, *Supra* note 4.

feed on traditional diatoms — phytoplankton that form the basis of the marine food chain — and can invade entire populations of diatom-rich waters, with an established predator-prey relationship.[18]

Additionally, in the absence of prey, green *Noctiluca* is known to photosynthesize and produce its own food.[19] This allows the organism to survive even in the winter monsoon months of enhanced stratification, during which the availability of prey like diatoms and other varieties of organisms is low.[20] A recent study found that *Noctiluca* can survive in hypoxic conditions, enabling the species to thrive in the 'dead' OMZs of the Arabian Sea (see **Figure 2**).[21]

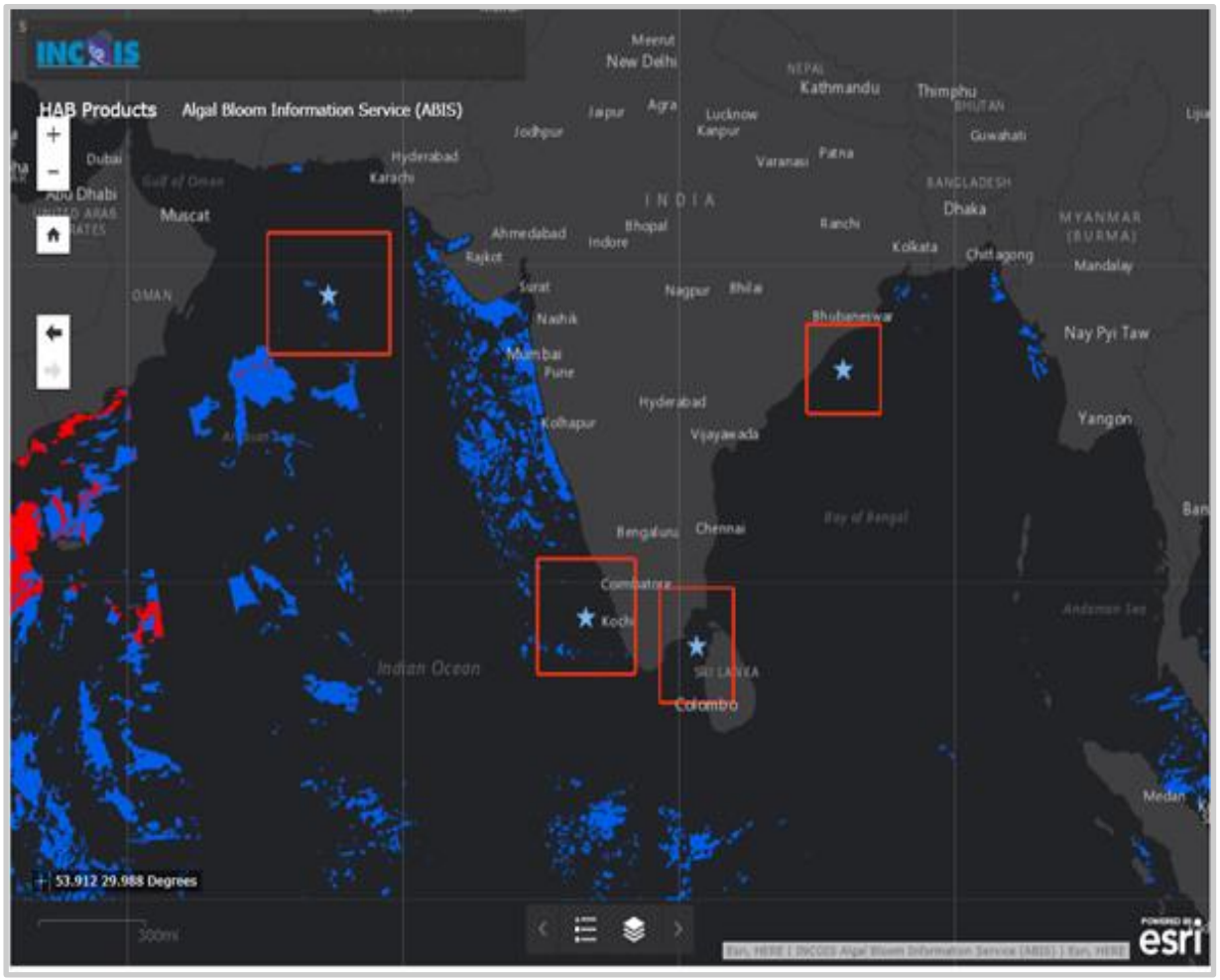

Figure 2: Detection of Noctiluca Scintillans in the Arabian Sea

Source: INCOIS (2020) https://incois.gov.in/portal/hab.jsp

Due to their large size and high concentration of ammonia, green *Noctiluca Scintillans* are avoided by other predators within the marine food web. They are mostly consumed by gelatinous zooplankton—mainly jellyfish and salps.[22] Located further up the marine food chain, jellyfish have high reproduction rates and experience very few predators. Sea turtles do prey upon jellyfish but their own populations are severely endangered.[23]

[18] Gomes et al, "Massive outbreaks of Noctiluca Scintillans blooms in the Arabian Sea due to spread of hypoxia."

[19] Hansen et al, *Supra* note 10.

[20] Gomes et al, "Massive Outbreaks of Noctiluca Scintillans Blooms in the Arabian Sea due to Spread of Hypoxia."

[21] Goes et al, *Supra* note 9.

[22] Thomas et al, *Supra* note 1.

[23] *Ibid*

Also see: A Abreu-Grobois and P Plotkin, "Lepidochelys olivacea. The IUCN Red List of Threatened Species," IUCN SSC Marine Turtle Specialist Group, (2008).

Climate-change Connections in the Arabian Sea

If there is one factor—other than the ongoing COVID-19 pandemic—that exemplifies the interconnectedness of our planetary and societal systems, it is climate change. All natural processes beyond our sight, whether occurring on land, in the oceans, or in the atmosphere that envelops our planet, are intertwined with one another, often through complex mechanisms. One example of this is the manner in which mountain glaciers in the Himalayan region regulate the annual Indian monsoon, which, in turn, regulates the flora across South Asia and the primary productivity and, subsequently, the marine species across the Northern Indian Ocean.[24] For thousands of years, millions of inhabitants of this region have relied on these connections for freshwater (from the mountain glaciers), agriculture (supported by monsoon rains), seafood (dependent upon healthy ocean biodiversity), and the myriad other benefits provided by these natural systems. However, these mechanisms are now being increasingly altered and disrupted by human interventions, directly through overexploitation, pollution and industrial activity, and, indirectly through anthropogenic climate change.

In recent decades, the Himalayan region, also known as the "third pole" of the planet, has been warming at an accelerating pace, primarily due to increasing greenhouse gas emissions into the atmosphere, generated by human activity. Rising temperatures are leading to increased melting of the mountain glaciers. As the glaciers melt, the snow-covered white surface is replaced by dark-colored rocks or vegetation, which absorb more solar radiation, resulting in more warming which causes more melting of the snow caps, thus entering a self-reinforcing cycle of melting snow and rising temperatures.[25] This melting is further exacerbated by other human-engendered factors, such as the deposition onto the surface of the glaciers of black soot particles originating from the industrial and vehicular pollution or forest fires in South and East Asia. These soot particles darken the surface of the glacier, causing it to absorb more solar radiation, which leads to more severe and rapid melting of the glaciers.[26] The rapid warming of the Himalayan region has a number of knock-on effects with significant socio-economic consequences. In the context of this article, the changing land-air-sea dynamics, triggered by the loss of snow cover in the Himalayas, may be responsible for the proliferation of *Noctiluca Scintillans* in the Arabian Sea in recent years.

In general, during summer months, the South Asian landmass gets much warmer than the Indian Ocean, creating a low-pressure region over the landmass and a high-pressure region over the ocean. This leads to 'monsoon winds' flowing from the south-west to the north-east direction. The strength of the winds depends upon the temperature gradient between the land and the ocean. An emerging scientific theory argues that due to declining snow cover and increasing temperatures over the landmass, the land-ocean temperature gradient is increasing, leading to stronger winds which, in turn, lead to more upwelling in the ocean and nutrient-rich surface waters.[27] All autotrophic plankton species need these nutrients, such as nitrogen and phosphorous, which are dissolved in the water, for photosynthesis. Nutrient-rich waters should, therefore, in principle, support all plankton species, but, *Noctiluca* ends up dominating the others because it can actually feed on other phytoplankton as well, and also the generally oxygen-depleted waters of the Arabian Sea give it an edge in terms of survival.

During the winter months, the situation is reversed. As temperatures begin to drop, the landmass cools down faster than the ocean due to the relatively slower process of heat exchange between different layers in the ocean. As a result, the landmass ends up being relatively cooler than the ocean which means the temperature gradient and the wind direction is reversed in the winter months. Now, the winter monsoon winds flow from the north-east to the south-west. Over the Arabian Sea, these winds are typically far weaker than the summer monsoon winds, and therefore, there is much less upwelling but much more stratification. This stratification is accentuated by the increasing temperature of the Himalayan region due to increased loss of snow cover, which further reduces the land-sea temperature gradient. However, even in these relatively unfavorable

[24] Massimo Bollasina and Sam Benedict, "The Role of the Himalayas and the Tibetan Plateau within the Asian Monsoon System", *Bulletin of the American Meteorological Society* 85, No 7 (July 2004): 1001-1004, https://www.jstor.org/stable/26216990.

[25] Raghavan Krishnan et al, "Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes", in The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People, eds Philippus Wester et al., (Switzerland: Springer Nature, 2019), 57-98.

[26] Rishika Pardikar, "Soot on Himalayan Glaciers Accelerates Melting", India Climate Dialogue, 17 March 2020 https://indiaclimatedialogue.net/2020/03/17/soot-on-himalayan-glaciers-accelerates-melting/.

[27] Goes et al, *Supra* note 9.

conditions, *Noctiluca* still thrives because it can rely on its heterotrophic properties to grow, while suppressing its autotrophic properties in the face of the unavailability of nutrients in surface waters.

Impact of Oceanic Pollution

Human activities have a widespread impact on the world's oceans.[28] The burning of biomass and industrial development in countries of South and East Asia have led to an increase in aerosol and dust pollutants — with satellite imagery detecting the coverage of aerosol and dust pollution extending from China to the foothills of the Himalayan plateau and all the way to the southern reaches of the Arabian Sea.[29] The South Asian and East Asian regions are the largest sources of black soot in the world and this unhappy situation is predicted to persist into the near-term future. The land temperature pressure-gradient has altered the intensity-characteristics of India's South-West monsoon wind, largely due to the accelerated melting of glacial ice caused by soot and dust deposition from bordering Asian countries. This increase of air pollution in South Asia has been documented in several studies, using measurement methods such as MODIS (Moderate Resolution Imaging Spectroradiometer) /CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) and GEOS (NASA Goddard Earth Observing System).[30]

Figure 3: Sewage outflow into the sea

Source: Image via Canva

In 1988, a team of scientists from the India's "National Institute of Oceanography" (NIO), which is headquartered in Goa, conducted several studies aboard the research vessel, *Sagar Kanya*, to monitor the status of marine pollution along India's coast and its exclusive economic zone.[31] The results of their study confirmed high concentrations of domestic sewage, metal concentration, pesticide run-off and oil spills.[32] A decade later, in July of the year 2018, the NCCR (National Centre for Coastal Research), through their flagship projects COMAPS (Coastal Ocean Monitoring and Prediction System) and SWQM (Sea Water Quality Monitoring Program), monitored the quality of seawater around India's coastline over the period from 1990 to 2015.[33] The study found that the estimated sewage generated from domestic sources in India was about 61,754 million litres per day (MLD), of which only 22,963 MLD was treated sewage, while a staggering 38,791 MLD was

[28] Sandra Díaz et al, "Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services," *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (2019).

[29] TN Krishnamurti et al, "Impact of Arabian Sea pollution on the Bay of Bengal winter monsoon rains," *Journal of Geophysical Research* 114, D6 (2009), https://doi.org/10.1029/2008JD010679.

[30] *Ibid*

[31] SZ Qasim et al, "Pollution of the seas around India," *Proceedings of the Indian Academy of Sciences (Animal Sciences)* 97, No 2 (March 1988): 117-131, https://link.springer.com/article/10.1007/BF03179939.

[32] *Ibid*

[33] National Centre for Coastal Research (NCCR), "Status Report – Seawater Quality Monitoring," *Ministry of Earth Sciences, Government of India* (2018).

untreated sewage released directly into the sea. 66 per cent of India's domestic sewage reaches the country's marine and aquatic systems – untreated (see **Figure 3**).

The study also found high concentrations of Ammonia-N as the dominant contributor of dissolved inorganic nitrogen on India's coastal stretches.[34]

Of particular relevance to this paper, the NCCR-COMAPS-SWQM study indicated an alarming abundance of phytoplankton along India's north-western coast. The rising trend of high levels of nutrients, such as ammonia and phosphate concentrations from sewage and agricultural-pesticide run-offs, will increase incidences of eutrophication and fuel phytoplankton blooms such as *Noctiluca*, while increasing hypoxia and anoxia in the Arabian Sea as a whole.[35]

Expansion of the Permanent Oxygen Minimum Zone (OMZ) in the Arabian Sea

OMZs are regions within the marine system that have permanent suboxic (oxygen lower than normal concentrations) conditions, leading to a decline in primary productivity.[36] The Arabian Sea is one of the few oceanic regions in the world that has quasi-permanent OMZs that stretch for several hundreds of meters, both vertically and horizontally, wherein oxygen values are below 0.1 milliliters per liter of seawater (ml/L).[37] These naturally occurring, oxygen-deficient waters are seasonally influenced and it is very important to map and to study them, as these conditions allow the process of denitrification, where dissolved nitrate in the ocean is converted to nitrogen gas, making it readily available for plants, algae, microbes, thus balancing the nitrogen cycle.[38] The suboxic zones in the Arabian Sea are one of the three major water column denitrification sites in the world's oceans.[39] The Arabian Sea OMZs have a delicate biological response-relationship between pelagic species of fish and other organism distributions. It would be obvious that the extent of changes in such zones needs to be actively monitored.

Recent reports confirm that the OMZ in the Arabian Sea is expanding at a greater pace due to climate change and human pressures.[40] These human pressures result in increased organic matter and nutrient overload, leading to eutrophication from untreated sewage and industrial outflow from not just India, but also from bordering countries of the Arabian Sea.[41] It is reiterated that this further enhances the competitive edge of *Noctiluca* over other species in the region due to the capability of the former to survive even in hypoxic conditions.[42]

Maritime Implications for India

The increasing range of *Noctiluca* is observed and, further, predicted, to have significantly deleterious impacts upon a number of important coastal and maritime economic sectors such as aquaculture, fisheries and tourism.[43] Green *Noctiluca Scintillans* outbreaks, commonly referred to as *'Noctiluca blooms'*, are known to occur prominently in the winter-monsoon months when the temperature-pressure gradient of the Arabian Sea is reversed, and enhanced stratification is observed.[44] The observations of these outbreaks are marked by the increased extent of bioluminescence and have been documented by several institutions and coastal monitoring system services including the ABIS (Algal Bloom Information Service) and INCOIS (Indian National Centre for Ocean Information Services).

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[34] Ibid

[35] Ibid

[36] Karen F. Wishner et al, "Living in suboxia: Ecology of an Arabian Sea oxygen minimum zone copepod," Limnology and Oceanography: Journal of the American Society of Limnology and Oceanography 45, No 7 (2000): 1576-1593, https://doi.org/10.4319/lo.2000.45.7.1576.

[37] Ibid

[38] Kenneth S. Johnson et al, "Oxygen Variability Controls Denitrification in the Bay of Bengal Oxygen Minimum Zone," Geophysical Research Letter 46, No 2 (2019): 804-811, https://doi.org/10.1029/2018GL079881.

[39] Ibid

[40] Goes et al, Supra note 9.

[41] Ibid

[42] Wishner et al, "Living in suboxia: Ecology of an Arabian Sea oxygen minimum zone copepod," 1576-1593.

[43] David J Mcleod et al, "Climate-driven range expansion of the red-tide dinoflagellate Noctiluca scintillans into the Southern Ocean," Journal of Plankton Research 34, No 4 (April 2012): 332–337, https://doi.org/10.1093/plankt/fbr112.

[44] Goes et al, Supra note 9.

The domino effect created by the blooms has current and future implications for the health of the Arabian Sea and the ecosystems and services that it provides to human beings.

Fisheries

The impact of green *Noctiluca Scintillans* in the Arabian has been widely reported. Fishermen report avoiding regions where the blooms occur because fish themselves are known to avoid these regions due to the low dissolved oxygen presence from death and decay of the bloom.[45] There is insufficient scientific evidence to definitively establish the correlation between the rates of overall fish catch and *Noctiluca* blooms in the Arabian Sea, but empirical and anecdotal reports from fishermen and other observers indicate that the quality and quantity of certain species of fish have reduced due to these recurring events, not to mention the net damage to nets caused by the subsequent jellyfish bloom.[46] The causes for a reduction in overall fish catch can be debated between *Noctiluca* blooms and plain overfishing within the coastal stretches of the Arabian Sea.[47] One the one hand, a study conducted in 2010 by the Space Applications Centre (SAC) of the Indian Space Research Organization (ISRO), National Institute of Oceanography (NIO) and Central Institute of Fishery Technology (Kochi) found no adverse impacts of *Noctiluca* blooms on the ecosystem. The study noted enhanced fish populations and tuna catches using longline fishing, even during the blooming stages of *Noctiluca*.[48] On the other, the study also mentioned seasonal reports and observations of dead shoals of fish washing ashore and attributed them to the low dissolved oxygen from the decay of *Noctiluca* due to seasonal-climatic shifts.[49] Other studies have reported the clogging of fish gills due to the large size of *Noctiluca* and its subsequent impact on the quality and quantity of the fish catch.[50] Such discrepancies in recent observations indicate that more studies, with more rigorous measurements, and more robust data-analyses, would be required to understand the linkages and the degree of impact that *Noctiluca* blooms have on the marine biodiversity of the region and, in turn, on the broader fisheries sector.

Coastal Tourism

The bright blue bioluminescence seawater of the Matsu archipelago, also known as the sea of 'blue tears' due to the annual bloom of the large green *Noctiluca Scintillans*,[51] has become an infamous tourist attraction in the distant waters of the East China Sea. However, even much closer home, *Noctiluca* could cause cascading impacts on the coastal tourism industry in terms of reduced water quality, hazards from subsequent jellyfish blooms, and the unseemliness of the murky green color of nearshore waters during the day.[52] The subsequent increase in jellyfish populations are reported to cause painful stings to beach goers, tourists and the diving community. In December of 2020, 385 cases of jellyfish stings were officially reported by lifeguards in Goa.[53] Alongside jellyfish stings, the murky green waters reduce the shore's visibility and aesthetics, further impacting local livelihoods and activities such as diving by local operators. These factors also affect marine protected areas (MPAs) and pose challenges in the management of biodiversity and habitat.

Maritime Security

Maritime security is essential to ensure a holistic approach towards the governance, use and maintenance of the oceans. The security challenges that a nation can face are divided into traditional and non-traditional threats. Glowing phytoplankton have a long naval history. In 1918, the German U-boat *U-34* was sunk by allied forces in the Strait of Gibraltar, when it encountered a school of bioluminescent plankton, and revealed

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[45] Thomas et al, *Supra* note 1.

[46] RM Dwivedi et al, "Study of ecological consequence of the bloom (Noctiluca Milaris) in offshore waters of the Northern Arabian Sea," *Indian Journal of Geo Marine Sciences* 41, No 4 (August 2012): 304-313.

[47] Goes et al, *Supra* note 9.

[48] Dwivedi et al, "Study of ecological consequence of the bloom (Noctiluca Milaris) in offshore waters of the Northern Arabian Sea," 304-313.

[49] *Ibid*

[50] Malavika Vyawahare, "Noctiluca scintillans – the Sea Sparkle That Threatens the Arabian Sea" *The Wire*, 21 January 2021. https://science.thewire.in/environment/noctiluca-scintillans-sea-sparkle-arabian-sea/

[51] Tsai et al, *Supra* note 4.

[52] Malavika Vyawahare, "Noctiluca scintillans – the Sea Sparkle That Threatens the Arabian Sea" *The Wire*, 21 January 2021. https://science.thewire.in/environment/noctiluca-scintillans-sea-sparkle-arabian-sea/

[53] DNHS, "Jellyfish continue to 'sting' Goa tourists; 20 cases reported per day," *Deccan Herald*, 05 December 2020. https://www.deccanherald.com/national/west/jellyfish-continue-to-sting-goa-tourists-20-cases-reported-per-day-923832.html

itself to a major enemy base.[54] Marine scientists, in the United States and Russia, have long tried to study the power of bioluminescence in detecting the location of submarines. A submarine wake can trigger surface phytoplankton, especially *Noctiluca* blooms, to glow and increase chances of detection (see **Figure 4**).[55] In June 1999, Ukrainian border guards confiscated a poster presentation, created by a group of marine biologists, describing the mapping of phytoplankton by bioluminescence for a symposium in Lithuania.[56] However, due to the unpredictable nature and occurrence of blooms, opportunities in the study of bioluminescence, for underwater detection, often hits a brick wall.[57]

Maritime security agencies are prepared to counter traditional threats but also face frontiers of non-traditional threats that have traits of unpredictability.

Figure 4: Noctiluca S. blooms detected through the naked eye

Source: Ricky –Flickr/Aqua Views Online Scuba Magazine. Retrieved from https://www.leisurepro.com/blog/explore-the-blue/marine-bioluminescence/

Non-traditional maritime threats include impacts of climate change such as increasing ocean temperatures, ocean acidification and sea-level rise, marine pollution, declining marine ecology, lack of marine data and information, etc. These non-traditional security risks affect India's maritime strategy, policy, operations, capacity building, and management.[58] According to one study, *Noctiluca* could also bloom in the summer months of upwelling in coastal stretches of Oman, Yemen and Somalia. This would impact the traditional summer bloom of diatom populations due to the invasive mixotrophic characteristics of *Noctiluca*, and impact regional-artisanal fisheries.[59] This would then, in turn, further impact the food-security of these regions, especially for countries such as Yemen and Somalia, where fish is a major source of protein and income, further exacerbating socio-economic loss and turmoil.[60] The non-traditional threats emanating from the

[54] Kyle Mizokami, "The U.S. and Soviet Union Once Investigated Bioluminescence as a Way to Track Submarines." *Popular Mechanics*, 12 January 2019. https://www.popularmechanics.com/military/research/a15856465/the-us-and-soviet-union-once-investigated-bioluminescence-as-a-way-to-track-submarines/

[55] Jon Kopley and Duncan Graham-Rowe, "The Cold War resurfaces," *News Scientist Magazine*, 20 November 1999.

[56] *Ibid*

[57] *Ibid*

[58] TERI-KAS Resource Dialogue V, "Conference Summary -The Emerging Global Maritime Order - India's Strategy," Chennai, 07-09 March 2019.

[59] Goes et al, *Supra* note 9.

[60] *Ibid*

impacts of *Noctiluca*, and their cascading implications for coastal sectors like fisheries, maritime infrastructure and tourism in the Arabian Sea need to be monitored and comprehensively assessed in India.

Long-term Implications

Current trends and climate-model-based future projections suggest that climate change will continue at an accelerating pace for many decades or even centuries unless we take urgent, transformative action. This implies that the biophysical changes, described earlier in this article, occurring in the marine environment as a result of climate change, will also continue worsen. Similarly, with growing population, urbanization and industrialization, the human impacts on the marine environment will, in all likelihood, continue to grow unless we, as a global civilization, take significant measures to address the root causes of the problem. These human impacts will, in turn, continue to make environmental conditions even more conducive for *Noctiluca* to flourish. Due to their own invasive nature and in the absence of a prominent predator, the natural tendency of species such as *Noctiluca Scintillans* is to keep expanding and consuming as much as they can, until they exhaust the resources available in the region. The expanding *Noctiluca* blooms and the potentially colossal shift in traditional (diatom-maintained) ecosystems will have long term ramifications on food and economic security, the Blue Economy, incidences of IUU (Illegal, Unregulated, and Unreported) fishing, and, critical maritime infrastructure. In the medium to long term, these impacts could lead to a significant loss of livelihood in key economic sectors such as tourism and fisheries, which would increase pressures on economic and food security, leading to a rise in poaching, illegal fishing, and allied activities. These medium to long-term implications pose a major challenge and warrant greater attention in the planning and implementation of India's Blue Economy model.

Policy Recommendations and Mitigation Pathways

The discovery of *Noctiluca* blooms in the Arabian Sea is relatively recent (the early 2000s). Consequently, scientific understanding of the causes and impacts of these blooms in this particular region is also at a very nascent stage where new hypotheses are frequently being proposed by scientists. Considering the potentially widespread, wide-ranging and significant knock-on impacts that *Noctiluca* blooms could have on the maritime domain, there is a need to conduct many more studies incorporating multiple perspectives (science, policy, economy, marine biodiversity, and security).

While the exact mechanisms through which climatic changes and human exploitation may be contributing to increased proliferation of *Noctiluca* may be open to debate, it is clear that climate change and human-caused marine pollution are leading to changes in the physical, chemical and biological conditions in the Arabian Sea, and these changed conditions are, in turn, becoming more conducive to invasive species such as *Noctiluca.* This adds another strong reason to the already long list of reasons for why we should act urgently and drastically to tackle the issues of climate change and growing marine pollution and overexploitation of marine living resources. Climate change-related impacts will be continual, with low availability of quick-fix mitigation options. The prevailing understanding of *Noctiluca* blooms is still in a nascent stage and requires a wider and more profound range of regional studies and rigorous monitoring efforts to comprehend and find methods to predict the high bloom periods in the Arabian Sea and their subsequent impacts.

Policy and mitigation steps could be explored for human-led impacts concerning pollution and resource management. However, this would require inter-disciplinary and multi-stakeholder approaches to ensure bottom-up implementation processes.

Addressing Research and Technological Gaps

Available methods of studying mechanisms that trigger the bloom and seasonal variations of *Noctiluca Scintillans* are poorly investigated. The relationship between *Noctiluca* outbreaks and jellyfish blooms should certainly be investigated further and incorporated into existing monitoring systems, so as to alert stakeholders of high-risk coastal sectors (which includes most of all sectors along India's West Coast) that are vulnerable to such blooms. Interagency and interdisciplinary approaches with institutions, agencies in maritime governance, and local actors, have considerable potential in terms of addressing gaps within data and technological deficits.

A case in point is the impact on India's maritime infrastructure. A study undertaken on the coastline of Oman has highlighted the damage that *Noctiluca* and the subsequent jellyfish blooms cause to desalination plants, oil refineries, and natural gas plants, to the point where they have been forced to shut down during high bloom episodes. The implications for India's maritime infrastructure and damage caused by *Noctiluca* and jellyfish blooms have simply not been assessed thus far. The combined value of several sectors and their current and predicted infrastructure requirements, such as port-development, fisheries, trade, tourism, and related sectors, need to be assessed to understand the cumulative impact of *Noctiluca* and subsequent impacts of jellyfish blooms on critical maritime infrastructure.

Opportunities within the Blue Economy

The objectives of the Blue Economy in addressing pollution, and climate-change mitigation measures, such as the restoration of degraded ecosystems, enhanced sustainability of fishing and tourism practices, and overall marine resource-management, all require further deliberation towards determining the optimal steps that could enable India to establish itself as a regional leader and exemplar in maintaining the health of the Arabian Sea. These opportunities require the articulation of high-risk sectors and regions in the Arabian Sea impacted by seasonal *Noctiluca* blooms.

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