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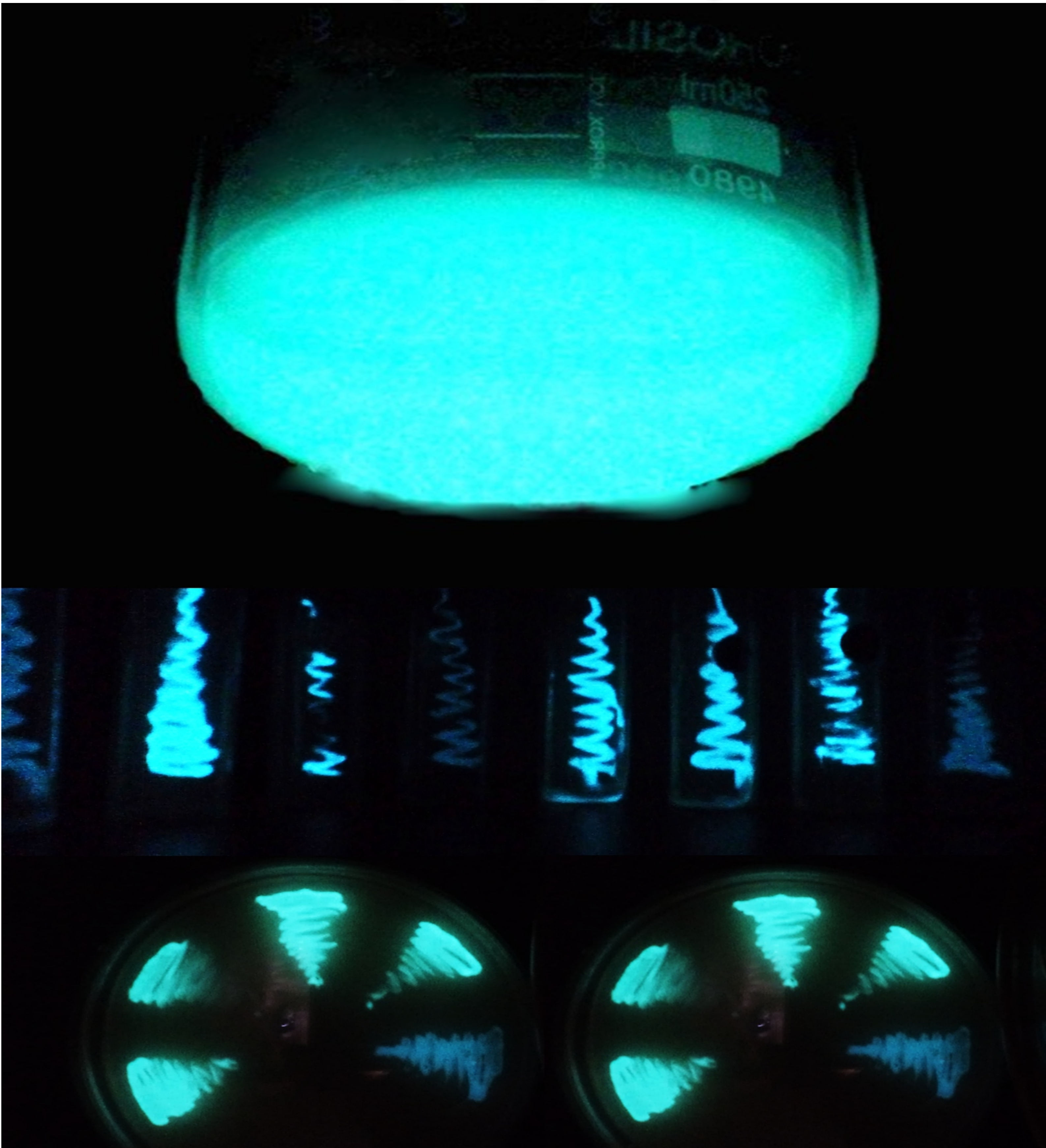

Bioluminescence in the twilight zone and beyond: Functions and future scope

Chatragadda Ramesh
Biological Oceanography Division
CSIR-National Institute of Oceanography
(CSIR-NIO)
Dona Paula-403004, Goa, India
Correspondence: chramesh@nio.org

Light emission from marine organisms had been a mesmerizing research topic since ancient times (Moline et al., 2013). Luminous organisms belonging to different taxonomic group use various luciferin molecules to produce light upon oxidation reaction in presence of luciferase enzyme (Haddock et al., 2010). Most bioluminescent organism use light for defense, offense, counterillumination, burglar alarm, illumination, intraspecific communication, and aposematism purposes. It was earlier believed that many of the known marine bioluminescent organisms produce light through their own light emitting chemical systems. But, recent literature infers that majority of marine luminous organisms acquire luciferin molecules from the other organisms through various sources (Ramesh and Bessho-Uehara, 2021). In contrast, some organisms display bioluminescence only under certain stimuli (Ramesh and Meyer-Rochow, 2021). In most taxonomic groups, the homologies of luciferases are identical but luciferins are not identical, indicating the importance of luminous organisms and their chemical reaction systems in evolutionary aspects.

The diversity and distribution of bioluminescent organisms from the surface waters to the bottom have been well investigated from the Indo-Pacific region (Martini et al., 2019; Martini and Haddock, 2017). In India, the bioluminescent dinoflagellate, *Noctiluca scintillans* has widely been reported from different coastal regions. Except *N. scintillans* and luminous bacteria, other bioluminescent organisms (Ramesh, 2020), are lesser known from the Indian Ocean due to various factors such as lack of expertise and lack of night field survey experiences. In the context of bioluminescence research in India, the Indian Ocean still remained an unexplored area in the ocean studies. While, the exploration of deep-sea biodiversity of Indian Ocean is still under infancy due to lack of sophisticated underwater vehicles and other equipment.

The Deep Ocean Mission (DOM) program initiation is one of the major ocean study initiatives undertaken by the Ministry of Earth Sciences, New Delhi, to explore the deep-sea resources for the benefit of science and society. Bioluminescence is the only light available in the twilight zone and beyond, and serves as a potential ecological indicator in the aphotic zone. However, the importance of bioluminescence in the Indian Ocean has not been highlighted in the DOM program. The chemistry of luminous organisms had been explored early in the 19th century and fetched the global attention via a myriad of biotechnological applications. Bioluminescence is being used in toxicological studies as biosensor to detect a wide spectrum of toxic pollutants in different samples. The genes and proteins responsible for the light emission are being used to track the cell development and tumour progression in clinical studies (Kaskova et al., 2016). In this way, luminous organism are transforming the panorama of biological studies to translational research. Therefore exploration of luminous organisms is important in Indian scenario to explore the multifaceted applications for societal benefits.

On the other hand, the function of deep-sea bioluminescence as an ecological indictor has to be explored to understand the impact of bioluminescence on biogeochemical cycles and other photoreductive reactions in the twilight zone and beyond. Further, the water quality of deep-ocean can be monitored by quantifying the visibility of bioluminescence intensity levels emitted from the luminous organisms (that are present in a biodiversity rich hotspot or from a region with high primary productivity). For example, deep-sea mining activities can not only generate turbid environments but also impacts the biodiversity. The quality of water and biodiversity damage done by the mining activity can be assessed by quantifying the bioluminescence during pre-and post-mining activities. Therefore, studying deep-sea bioluminescence is necessary to conserve the deep-sea biodiversity and to study the changes occurring in the deep-ocean compartments due to climate change.

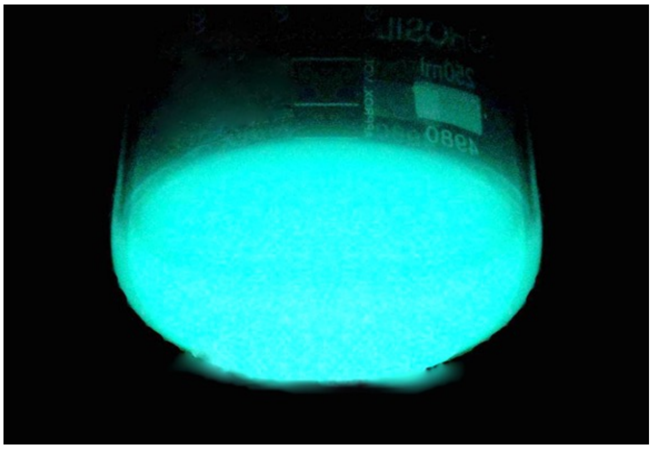

Fig. 1. Bioluminescence of *Vibrio* bacterium in broth media

References

Haddock, S.H.D., Moline, M.A., Case, J.F., 2010. Bioluminescence in the sea. Annu. Rev. Mar. Sci. 2, 443–493.

Kaskova, Z.M., Tsarkova, A.S., Yampolsky, I. V, 2016. 1001 lights: luciferins, luciferases, their mechanisms of action and applications in chemical analysis, biology and medicine. Chem. Soc. Rev. 45, 6048–6077.

Martini, S., Haddock, S.H.D., 2017. Quantification of bioluminescence from the surface to the deep sea demonstrates its predominance as an ecological trait. Sci. Rep. 7, 45750.

Martini, S., Kuhnz, L., Mallefet, J., Haddock, S.H.D., 2019. Distribution and quantifcation of bioluminescence as an ecological trait in the deep sea benthos. Sci. Rep. 9, 14654.

Moline, M.A., Oliver, M.J., Orrico, C., Zaneveld, R., Shulman, I., 2013. Bioluminescence in the sea, in: Subsea Optics and Imaging. Woodhead Publishing Limited, pp. 134–170. https://doi.org/10.1533/9780857093523.2.134

Ramesh, C., 2020. Terrestrial and marine bioluminescent organisms from the Indian subcontinent: a review. Environ. Monit. Assess. 192, 747. https://doi.org/10.1007/s10661-020-08685-5

Ramesh, C.H., Bessho-Uehara, M., 2021. Acquisition of bioluminescent trait by non-luminous organisms from luminous organisms through various origins. Photochem. Photobiol. Sci. 20, 1547–1562.

Ramesh, C.H., Meyer-Rochow, V.B., 2021.Bioluminescence in aquatic and terrestrial organisms elicited through various kinds of stimulation. Aquat. Ecol. 55, 737–764.

Ocean Digest

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Research Highlights

Living coccolithophores contribute substantially to the nanophytoplankton community: first report from the northwestern coast of India


Haimanti Biswas[1*] and
Mintu Chowdhury[1,2]

[1]Biological Oceanography Division, CSIR National Institute of Oceanography, Dona Paula, Goa 403004, India
[2]Current affiliation: Centre for Marine Living Resources & Ecology (MOES), Atal Bhavan, Puthuvype, Kochi-682508, India
[*]Corresponding author: haimanti.biswas@nio.org

This article is the summary of the following research article: Chowdhury Mintu, Biswas Haimanti Sharma, D., Silori, S., & Winter, A. (2022). Distribution of extant coccolithophores from the northwest continental shelf of India during the summer monsoon. Phycologia, 1-15.

Coccolithophores are nanoplanktonic (2–20 µm) (Taylor et al. 2017) autotrophic single-celled algae (class prymnesiophyceae or haptophyceae), and contribute between 1 to 10% to total marine primary production and are found in cold as well as warm waters from the tropics to the pole (Poulton et al. 2007). These algae are unique due to the presence of calcite scales, called "coccoliths" on their cell surface and make a coccosphere. In today's ocean, nearly 200 species of this calcifying algae are reported (Young et al. 2003). They sink efficiently to the ocean floor and contribute to a large fraction of sedimentary calcium carbonate (Broecker and Clark, 2009).

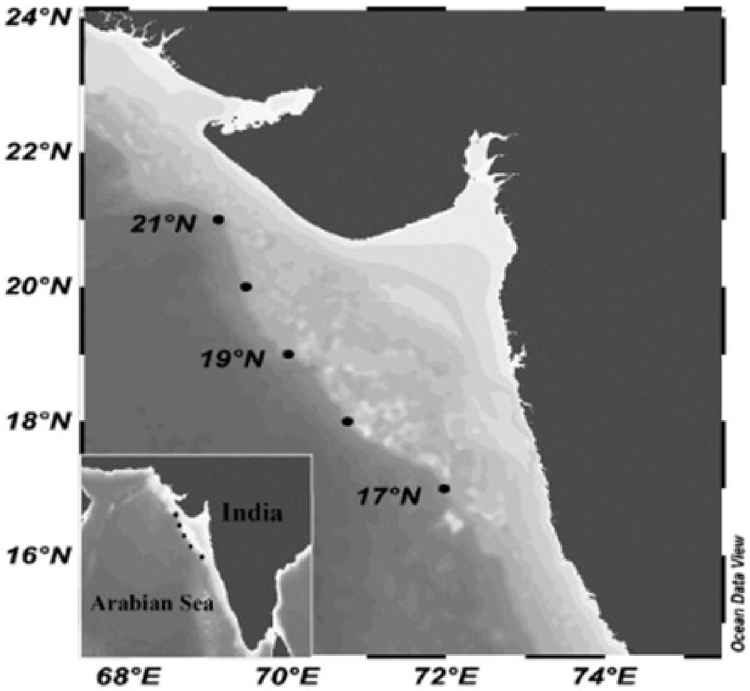

Figure 1. Station locations along the Indian northwestern shelf (200-m isobaths).

The studies addressing the distribution and abundance of extant coccolithophore in the North Indian ocean are scarce (Liu et al. 2018). The presence of coccolithophores has been documented from the sediment trap, sediment core as well as water column from the different parts of the north Indian ocean, but their occurrence in the Indian coastal waters has never been reported. Most of the available literature was on surface sediments and trap samples (Rogalla & Andruleit 2005; Mergulhao et al. 2006). However, during the last Joint global ocean flux study program (JGOFS) between 1994 –1997, some studies were conducted on living coccolithophores from the central and western Arabian Sea (Balch et al. 2000; Guptha et al. 1995). Nevertheless, the eastern Arabian Sea and the Indian shelf waters were never studied to check the distribution of coccolithophores. To fill this gap we have collected samples from the 5 stations (17 N to 21 °N) (Fig. 1) from the Indian northwestern shelf water along the 200 m isobaths during the summer monsoon in August 2018 onboard RV SindhuSadhana. All ancillary parameters including nutrients, dissolved oxygen, and chlorophyll were also analyzed. The enumeration of coccolithophore was done using a scanning electron microscope (JEOL-JSM IT300 JEOL Ltd., Tokyo, Japan) at the central analytical facility at the CSIR-NIO, Goa.

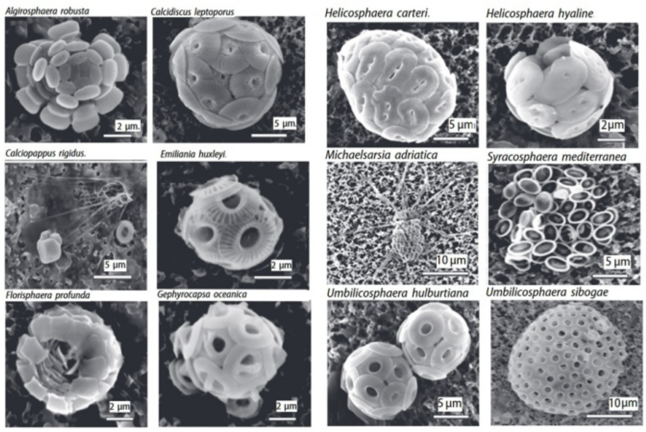

Figure 2. Scanning electron microscope photographs of coccolithophore species recorded from the northwestern Arabian Sea shelf water during the summer monsoon 2018

Our results revealed that a significant number of coccolithophores (cell density ranged between $0.3–85.6 \times 10^3$ cells/l) with a total of 18 species from 11 genera (Fig. 2) were detected indicating high diversity in the tropical coastal waters. This is interesting that unlike the polar and temperate waters, where Emiliania huxleyi is the dominant coccolithophore, Gephyrocapsa oceanica (Fig. 2) dominates (67% of the total population) the tropical waters and our results are consistent with other studies from the Indian ocean. Besides, species like Florisphaera profunda (11%), Umbilicosphaera sibogae (3.4%), Helicosphaera carteri (3.2%), Calcidiscus leptoporus (2.6%), Calciopappus rigidus (2.0%) and Syracosphaera mediterranea (1.0%) (Fig. 2) were also recorded. The warm oligotrophic water with high salinity prevails in these stations during the summer monsoon and mostly smaller nano and picophytoplankton dominate (Silori et al. 2021) due to their high surface area to volume ratio. Within the mixed layers, nitrate+nitrite levels were quite low (0.47 ± 0.59 µmol/l). The concentrations increased (12.5 to 15.4 µmol/l) below the mixed layers. Dissolved inorganic silicate levels were considerably low within the mixed layers ((0.46 ± 0.2 µmol/l). Nitrate + nitrite concentrations revealed a positive correlation with the total abundance of coccolithophores and are likely to play a role in their distribution patterns within the mixed layers. The smaller phytoplankton without the requirement of dissolved silicate like coccolithophore and cyanobacteria may dominate with decreasing dissolved inorganic silicate levels (Sieracki et al. 1993). The presence of a significant quantity of marker pigments like 19′hexanoyloxyfucoxanthin in these waters already hinted at the possibility of the occurrences of coccolithophore (Silori et al. 2021) and our current study confirmed this trend. We conclude that these nanoplanktonic autotrophic calcifiers make significant contributions to the primary production as well as particle flux of this region.

References

Balch W.M., Drapeau D.T. & Fritz J.J. 2000. Monsoonal forcing of calcification in the Arabian Sea. Deep Sea Research Part II 47: 1301–1337.

Broecker W. & Elizabeth C. 2009. Ratio of coccolith CaCO3 to foraminifera CaCO3 in late Holocene deep sea sediments. Paleoceanography 24, 3.

Guptha M.V.S., Mohan R. & Muralinath A.S. 1995. Living coccolithophorids from the Arabian Sea.Oceanographic Literature Review 42: 992.

Mergulhao L.P., Mohan R., Murty V.S.N., Guptha M.V.S. & Sinha D.K. 2006. Coccolithophores from the central Arabian Sea: sediment trap results. Journal of Earth System Science 115: 415–428.

Poulton, A. J., Adey, T. R., Balch, W. M., & Holligan, P. M. 2007. Relating coccolithophore calcification rates to phytoplankton community dynamics: Regional differences and implications for carbon export. Deep Sea Research Part II: Topical Studies in Oceanography, 54(5-7), 538-557.

Rogalla U. & Andruleit H. 2005. Precessional forcing of coccolithophore assemblages in the northern Arabian Sea: implications for monsoonal dynamics during the last 200,000 years. Marine Geology 217: 31–48.

Sieracki M.E., Verity P.G. & Stoecker D.K. 1993. Plankton community response to sequential silicate and nitrate depletion during the 1989 North Atlantic spring bloom. Deep Sea Research Part II: Topical Studies in Oceanography 40: 213–225.

Silori S., Sharma D., Chowdhury M., Biswas H., Bandyopadhyay D., Shaik A.U.R., Cardinal D., Mandeng-Yogo M. & Narvekar J. 2021. Contrasting phytoplankton and biogeochemical functioning in the eastern Arabian Sea shelf waters recorded by carbon isotopes (SW monsoon). Marine Chemistry 232: 103962.

Taylor A.R., Brownlee C. & Wheeler G. 2017. Coccolithophore cell biology: chalking up progress. Annual Review of Marine Science 9: 283–310.

Young J.R., Geisen M., Cros L., Kleijne A., Sprengel C., Probert I. & Østergaard J. 2003. A guide to extant coccolithophore taxonomy. Journal of Nannoplankton Research 1: 1–132.

Natural Carbon Sequester: The Giant Swimming Trees (Whales) against the Climate Change


Ashish Sahu[1*] and Mahender Singh[2]

[1]PhD Scholar, Faculty of fisheries, Kerala University of Fisheries and Ocean Studies, Panangad, Cochin, Kerala- 682506, India
[2]ICAR-National Bureau of Fish Genetic Resources, PO. Dilkusha Telibag, Lucknow, Uttar Pradesh
[*]Corresponding Author: sahu81862@gmail.com,
Tel. No: +919621091754

Abstract: Carbon in the atmosphere is a significant cause of climate change, which is the greatest threat to all life on Earth as well as an issue of great environmental concern. Global warming mitigation techniques, such as capturing carbon directly from the atmosphere and burying it deep in the earth, are complex, unproven, and pricey, but we have one solution that is whale. There's no doubt that whales are one of the most extraordinary animals in our ocean, but did you know that they're also helping to lighten the load of climate change? The carbon capture potential of whales is truly startling. Whales store a huge amount of carbon in their bodies throughout their long lifetimes, called whale carbon. When whales die of natural causes, they sink to the seafloor called whale falls and each giant whale sequesters 33 tons of CO2, eliminating that carbon from the atmosphere for millennia. Meanwhile, a tree can absorb only up to 48 pounds of CO2 per year. They also fertilize the ocean with their feces and urine, leading to large phytoplankton blooms. Whales bring minerals up to the ocean surface through their vertical movement, called the "whale pump." They are our allies in fighting climate change, and like rainforests, they urgently need our protection. We have to minimize every anthropogenic threat affecting charismatic species through decisive and concerted actions because whales are like giant swimming trees (whales).

Keywords: Whale carbon, Climate change, Global warming, Threats, Whale fall, Whale pump.

Introduction

What is Carbon sequestration? Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide, measured as a rate of carbon uptake per year with the goal of reducing global climate change.

Have you ever heard about "blue carbon"? The answer is most likely no, but you may know more than you realize. What is Blue carbon? Blue carbon is the carbon stored by the ocean, coastal and marine ecosystems such as mangroves, tidal marshes and seagrass meadows. They are sequester and "capture and hold" more carbon per unit area than terrestrial forests acting as something called carbon sink and are now being recognised for their role in mitigating climate change. Eighty three percent of the global carbon cycle is circulated through the ocean. Coastal habitats cover less than 2% of the total ocean area. Coastal habitats account for approximately half of the total carbon sequestered in ocean sediments. However, if the ecosystems are damaged, their carbon sink capacity is lost and the carbon stored is released, resulting in emissions of carbon dioxide (CO2) that contribute to climate change. Dedicated conservation efforts can ensure that coastal ecosystems continue to play their role as long-term carbon sinks.

What is climate change? Climate change refers to long-term shifts in temperatures and weather patterns. Humans and wild animals face new challenges for survival because of climate change. More frequent and intense drought, storms, heat waves, rising sea levels, melting glaciers and warming oceans can directly harm animals, destroy the places they live.

Science has established the urgency of reducing CO2 emissions into the atmosphere. If humans do not reduce greenhouse gas emissions by 45% from 2010 levels in the next nine years and eliminate them completely by 2050, the planet's temperature will rise to 1.5°C. Marine biologists have recently discovered that whales, especially the great whales—play a significant role in capturing carbon from the atmosphere (Roman and others 2014). Whales are sentinel species within the marine ecosystem, playing a vital role in nutrient cycling and are often viewed as an indicator of ecosystem health. Whales are ecosystem engineers because they help maintain the health and stability of the oceans, and even provide services to human society. These marine creatures are at the top of the food chain and play an important role in removing carbon from the atmosphere by accumulating it in their bodies and when they die, they sink to the bottom of the ocean, thereby locking that carbon away for hundreds of years.

Whales are the world's unsung heroes. One whale is worth thousands of trees in carbon capture and their poo is essential for phytoplankton to grow-phytoplankton absorbs more than 4x the Amazon rainforest, and contributes between 50-85% of the world's oxygen.

Whale vs. Tree: According to, the Magazine of the International Monetary Fund (IMF) Report (2019) on average a whale can sequester about 33 tons of CO_2. This is even more than a tree's ability to fight climate change, as a tree can only absorb a maximum of 48 pounds (2.4 tons) of CO_2 in a year. You can call them a Carbon sink.

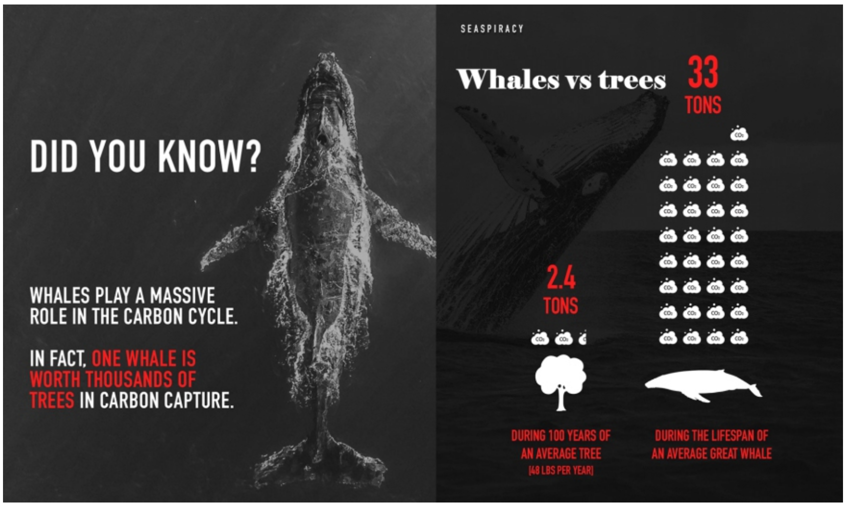

Figure 1. Compare of carbon storage capacity of whale and tree

The whale pump: Whales bring minerals up to the ocean surface through their vertical movement, called the whale pump. These microscopic creatures not only contribute at least 50% of all oxygen to our atmosphere, they do so by capturing about 37 billion metric tons of CO_2, an estimated 40% of all CO_2 produced. This means more phytoplankton means more carbon capture. The International Monetary Fund (IMF) calculates that's the same as the amount captured by 1.7 trillion trees, or four Amazon rainforests' worth. According to IMF, 1% increase in phytoplankton productivity linked to whale activity could mean the capture of hundreds of millions of tons of additional CO_2 a year, equivalent to 2 billion mature trees,

The Whale fall: Whales accumulate carbon in their bodies during their long lives. When they die, they sink to the bottom of the ocean, and their carcasses- known as whale falls- provide a bounty of nutrients for deep sea creatures. Carbon sequestration through whale falls, or carcasses are substantial. More than 145,000 tonnes of carbon are transferred to the ocean floor by the dead bodies of whales each year.

Threats to the whale community: Unfortunately, their slow growth andreproduction rate, as well as human activities such as habitat degradation, vessel stickes, marine pollution, climate and ecosystem change,disturbance from whale watching activities, noise from industrial activities (including oil drilling), reduced prey abundance due to overfishing and most notably, illegal whaling are rapidly pushing this important marine species to extinction.

Conservation management:

There are about 1.3 million great whales in Earth's oceans today. If we could restore them to their pre-commercial whaling numbers—estimated at between 4 and 5 million— the economists' calculations show that great whales could capture about 1.7 billion tons of CO2 each year. Although commercial whaling has been officially banned since 1986, more than 1,000 whales a year are still killed for commercial purposes, according to the World Wildlife Fund (WWF). Our earth needs a healthy ocean and a healthy ocean needs whales. It isn't enough to conserve species, populations and individuals.

In conclusion, whale conservation and protection will not only ensure its population growth and contribute to the health and balance of the marine ecosystem, but also ensure human survival and aid in the Sustainable development goal (SDG) 13 achievements by taking action to combat climate change and its impacts on our environment.

Reference

Herr, D. and E. Landis (2016). Coastal blue carbon ecosystems: Opportunities for Nationally Determined Contributions. Policy Brief. Gland, Switzerland: IUCN and Washington, DC, USA: TNC.

Lavery, T., B. Roudnew, P. Gill, J. Seymour, L. Seuront, G. Johnson, J. Mitchell, and V. Smetacek. 2010. "Iron Defecation by Sperm Whales Stimulates Carbon Export in the Southern Ocean." Proceedings of the Royal Academy 127:3527–31.

Mariani, G., Cheung, W. W., Lyet, A., Sala, E., Mayorga, J., Velez, L., Mouillot, D. (2020). Let more big fish sink: Fisheries prevent blue carbon sequestration — half in unprofitable areas. Science Advances, 6(44).

Roman, J., J. Estes, L. Morissette, C. Smith, D. Costa, J. McCarthy, J. B. Nation, S. Nicol, A. Pershing, and V. Smetacek. 2014. "Whales as Marine Ecosystem Engineers" Frontiers in Ecology and the Environment 12 (2): 377–85.

Roman, J., McCarthy, J. 2010. The whale pump: marine mammals enhance primary productivity in a coastal basin. PLOS ONE.

Smith, C., J. Roman. and J. B. Nation. 2019. "A Metapopulation Model for Whale-Fall Spec2019.ialists: The Largest Whales Are Essential to Prevent Species Extinctions—The Sea." Under review.

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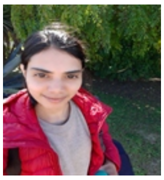
A New Observational Network Design for Indian Ocean Surface pCO_2 Measurements



Vinu Valsala[a], M.G. Sreeush[a,e,f], M. Anju[a,b], P. Sreenivas[a], Y. K.Tiwari[a], K. Chakraborty[c], S. Sijikumar[d].

[a]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, India.
[b]Department of Meteorology and Oceanography, College of Science and Technology, Andhra University, Visakhapatnam
[c]Indian National Centre for Ocean Information Services, Ministry of Earth Sciences, Hyderabad, India
[d]Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, India
[e]Center for Climate Physics, Institute for Basic Science, Busan 46241, Republic of Korea
[f]Pusan National University, Busan 46241, Republic of Korea

This article is based on the following paper.
Vinu Valsala, M.G. Sreeush, M. Anju, Pentakota Sreenivas, Yogesh K. Tiwari, Kunal Chakraborty, S. Sijikumar, An observing system simulation experiment for Indian Ocean surface pCO_2 measurements, Progress in Oceanography, vol.194, 102570, https://doi.org/10.1016/j.pocean.2021.102570, 2021.

Indian Ocean plays a crucial role in mitigating the global climate change by absorbing 16% of the global ocean carbon dioxide sink (Sabine et. al., 2004). There is a large uncertainty exists between the observational and modelling estimates of the Indian Ocean CO_2 sink(Valsala and Maksyutov, 2010, Sarma et. al., 2013). The uncertainty in the various observational estimates of the Indian Ocean sea-to-air CO_2 fluxes mostly arises from the lack of pCO_2 data needed for the CO_2 flux calculations. The Surface Ocean CO_2 Atlas (SOCATv3-2020) database consists of 28 million quality controlled surface ocean pCO_2 measurements available from 1970 to 2019, However Indian Ocean (30oE-130oE, 40oS-30oN) shares only 0.8 million, hardly representing 2.8% of the total quality-controlled global pCO_2 data, especially for north of 30oS (Bakker et al., 2020). The inadequate data coverage of the Indian Ocean hampers the accurate renditions and budgeting of its carbon cycle over seasonal-to-interannual-to-interdecadal variability.

The surface ocean pCO_2 can be measured by instruments mounted to moorings or attached to the hull of ships in case of underway sampling (Takeshita et al., 2018). There has been no effort made to sample pCO_2 by underway sampling using volunteer commercial ships in the Indian Ocean, unlike in the north Pacific and Atlantic Ocean. It leaves a significant data gap in the Indian Ocean, especially north of 30°S (Bakker et al., 2020). Considering the spatiotemporal diversity and the complexity of the Indian Ocean biophysical interactions (Prassana Kumar et al., 2007; Sarma, 2013) and limited availability of resources to make direct observations, This study addresses the following questions (a) Identifying the best existing moorings (RAMA and OMNI moorings) in the Indian Ocean to make pCO_2 measurements most cost-effectively? (b) what is the potential of Bio-Argo floats (including the pH sensors) in replacing moored buoy sensors in the future and (c) which ship-track under the voluntary ship of opportunity programs (SOOP) should be selected for the underway sampling of surface ocean pCO_2 measurements so that the data obtained are optimal to constrain the Indian Ocean sea-to-air CO_2 fluxes in inversion based estimates (Valsala and Maksyutov, 2010; Sreeush et al., 2019).

The study utilizes the Ocean Tracer Transport Model (OTTM; Valsala et al., 2008) coupled with the Ocean Carbon-cycle Model Intercomparison Project (OCMIP-II) biogeochemistry and with a modified biological parameterization for net community compensation depth (Sreeush et al., 2018). To identify the best locations for surface ocean pCO_2 measurements, a Bayesian inversion approach via minimizing the cost function constructed with sea-to-air CO_2 flux errors and mismatches in dissolved inorganic carbon (DIC) between model and observations are used.

$$J=(GS_o-D)^T C_d^{-1}(GS_o-D)+(S-S_o)^T C_{So}^{-1}(S-S_o) \quad (1)$$

Gs_o is the model response vector corresponding to the observation,'D' taken as DIC in the model.CS_o represents prior sea-to-air flux uncertainty of Co_2. C_d contains a combination of both observational (C_{obs}) and model (C_{mod}) errors. S_o and S are the prior and posterior sea-air Co_2 fluxes, respectively. The Bayesian theory states that the above cost function is minimum if the flux vector S_o assumes the optimized form (Tarantola, 2004);

$$S=S_0+ (G^T C_d^{-1} G + C_{So}^{-1})^{-1} G^T C_d^{-1}(D- GS_o) \qquad (2)$$

The posterior flux uncertainty (C_S)) if the observations are available from given locations and for a given prior flux uncertainty of C_{so} is estimated as;

$$C_S= (G^T C_d^{-1} G + C_{So}^{-1})^{-1} \qquad (3)$$

The percentage uncertainty reduction (UR) in the flux estimation at each observational location can be quantified as:

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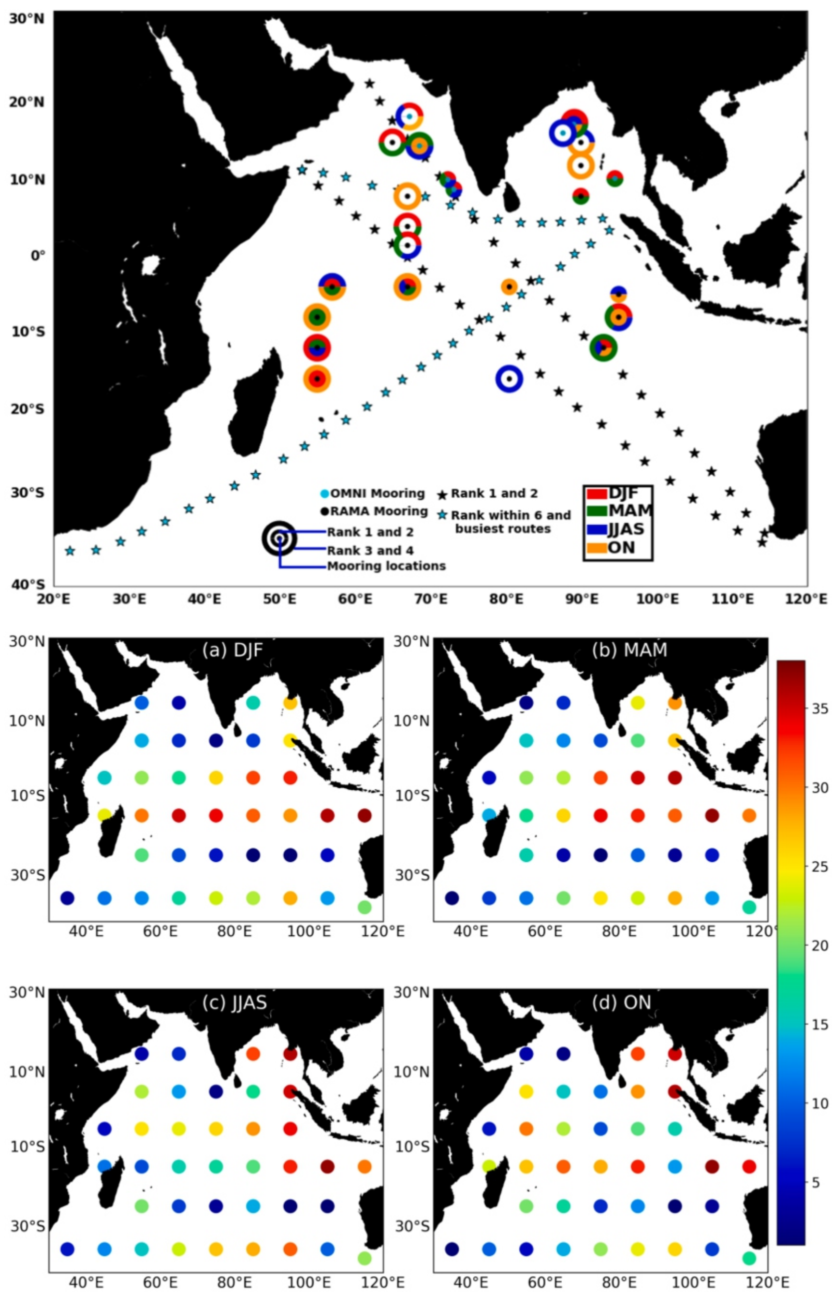

Figure 1. Locations of recommended RAMA + OMNI moorings and SOOP ship tracks (top panel) and the ranks of Bio-Argos for different seasons (bottom panel) by the OSSE for the surface ocean pCO2 measurements.

$$UR = \left[\frac{trace(C_s) - trace(C_{So})}{trace(C_{S_o})} \right] X100 \qquad (4)$$

In order to rank all the moorings of RAMA and OMNI array and to evaluate the potential Bio-Argo floats and Indian Ocean ship tracks for SOOP, an Incremental Optimisation method is utilised (Nalini et. al., 2019). In this study, total of 43 moorings (31 RAMA moorings and 12 OMNI moorings), 38 Bio-Argo floats per every 10ox10o region in the Indian Ocean and 10 SOOP tracks based on satellite data of Tournadre (2014) is evaluated.

References

Sabine, C.L., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L., Wanninkhof, R., Wong, C.S., Wallace, D.W.R.,Tilbrook, B., Millero, Frank J., Peng, T., Kozyr, A., Ono, T., Rios, A.F., 2004. The oceanic sink for anthropogenic CO2. Science 305, 367–371. https://doi.org/10.1126/science.1097403.
Valsala, V., Maksyutov, S., 2010. Simulation and assimilation of global ocean pCO2 and sea-to-air CO2 fluxes using ship observations of surface ocean pCO2 in a simplified biogeochemical offline model. Tellus, Series B: Chem. Phys. Meteorol. 62, 821–840. https://doi.org/10.1111/j.1600-0889.2010.00495.x.
Sarma, V.V.S.S., Lenton, A., Law, R.M., Metzl, N., Patra, P.K., Doney, S., Lima, I.D., Dlugokencky, E., Ramonet, M., Valsala, V., 2013. Sea–air CO2 fluxes in the Indian Ocean between 1990 and 2009. Biogeosciences 10, 7035–7052. https://doi.org/ 10.5194/bg-10-7035-2013.
Bakker, Dorothee C.E., et al., 2020. Surface Ocean CO2 Atlas Database Version 2020 (SOCATv2020) (NCEI Accession 0210711). [indicate subset used]. NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/4xkx-ss49. Accessed [date].
Takeshita, Y., Johnson, K.S., Martz, T.R., Plant, J.N., Sarmiento, J.L., 2018. Assessment of autonomous pH measurements for determining surface seawater partial pressure of CO2. J. Geophys. Res. Oceans 123, 4003–4013. https://doi.org/10.1029/ 2017JC013387.
Prasanna Kumar, S., Nuncio, M., Ramaiah, N., Sardesai, S., Narvekar, J., Fernandes, V., Paul, J.T., 2007. Eddy-mediated biological productivity in the Bay of Bengal during fall and spring intermonsoons. Deep-Sea Res. Part I: Oceanogr. Res. Papers https:// doi.org/10.1016/j.dsr.2007.06.002.
Tarantola, A., 2004. Inverse Problem 498 Theory and Methods for Model Parameter Estimation. Soc. Ind. Appl. Math. ISBN: 978-0-89871-572-9, https://doi.org/ 10.1137/1.9780898717921.
Tournadre, J., 2014. Anthropogenic pressure on the open ocean: The growth of ship traffic revealed by altimeter data analysis. Geophys. Res. Lett. 41, 7924–7932. https://doi.org/10.1002/2014GL061786.
Sreeush, M. G., Valsala, V., Pentakota, S., Prasad, K. V. S. R., and Murtugudde, R.: Biological production in the Indian Ocean upwelling zones –Part 1: refined estimation via the use of a variable compensation depth in ocean carbon models, Biogeosciences, 15, 1895–1918, https://doi.org/10.5194/bg-15-1895-2018, 2018.
Sreeush, M.G., Valsala, V., Halder, S., Pentakota, S., Prasad, K.V.S.R., Naidu, C.V., Murtugudde, R., 2019. Biological production in the Indian Ocean upwelling zones: Part – II: Data based estimates of variable compensation depth for ocean carbon models via cyclo-stationary Bayesian inversion. Deep Sea Res., Pt II, https://doi.org/ 10.1016/j.dsr2.2019.07.007.
Nalini, K., Sijikumar, S., Valsala, V., Tiwari, Y.K., Ramachandran, R., 2019. Designing surface CO2 monitoring network to constrain the Indian Land fluxes. Atmos. Environ. 218, 117003 https://doi.org/10.1016/j.atmosenv.2019.117003.

WORLD OCEANS DAY 2022

On WORLD OCEANS DAY 2022 (8 June 8 2022), Awareness and Beach Cleaning Programmes along all maritime districts of Kerala State was jointly organised by Ocean Society of India – Cochin chapter & National Centre for Coastal Research (NCCR), Chennai with the Co-ordination of Academic and Research Institutions of different districts of Kerala State. Having recognized that the entire coastal areas of Kerala is highly polluted due to various causes and by different agents, Ocean Society of India – Cochin chapter decided to take up this as a challenge to make awareness programmes and beach cleaning activity along the entire stretch by fixing at least one station in each District.

The program was funded by NCCR, Ministry of Earth Sciences, Government of India and was inaugurated by Dr. Jitendra Singh, Hon'ble Union Minister for Earth Sciences. The program was conducted at 1) Varkala – Papanasam, Thiruvananthapuram District, 2) Kollam Beach, Kollam District, 3) Arthunkal Beach, Alappuzha District, 4) Chellanam Beach, Ernakulam District, 5) Nattika Beach, Thrissur District, 6) Ponnani Beach, Malappuram District, 7) Kozhikkode South, Kozhikkode District, 8) Payyambalam Beach, Kannur District, 9) Bekal Beach, Kasargod District.

Prof. K. V. Jayachandran, Chairman, OSI Cochin chapter co-ordinated the activities.

During the World Oceans Day week an awareness brochure was released by Dr. M. Ravichandran, Secretary, MoES, GoI & President, OSI. This was prepared by Dr. Prasad Bhaskaran, Prof. IIT Kharagpur and Joint Secretary, OSI and translated into Malayalam by Dr. Ananathanarayanan, Former Director, NPOL and into Hindi by OSI.

OSI Webinar Series (April-June 2022)

April 2022

Topic: Future Perspective on Coastal Vulnerability and Resilient Infrastructure

Speaker: Dr. Manasa Ranjan Behera, Associate Professor, IIT Bombay, Mumbai

Date & Time: 20 April, 2022; 04:00 PM – 05:00 PM IST

About the Talk:

Coasts across the globe encounter various types of ocean disasters affecting the dense coastal community. IPCC has already established the fact that ocean heat content, sea level, wave height, and ocean extreme events are on the rise. The intensity and frequency of cyclonic events are increasing, emphasizing the need for better preparedness for such events. Overall, the coastal resilient infrastructure needs a wholistic approach starting from assessing the coastal disasters, their impact/loads, and suitable design of coastal infrastructure considering the future scenarios.

Articles/research highlights of general interest to the oceanographic community are invited for the next issue of the Ocean Digest. Contributions may be emailed to **osioceandigest@gmail.com**

Cover Photo: Bioluminescence of Vibrio cultured in a conical flask (top); Pure cultures of Photobacterium (intense luminescence) and Vibrio (dim luminescence) species grown on agar slants (middle) and agar plates (bottom). Image courtesy: Dr. Chatragadda Ramesh, Scientist, CSIR -National Institute of Oceanography, Dona Paula, Goa