Insights on marine fungal research in India

Rohit Sharma[1], Belle Damodara Shenoy[2], Kandikere Ramaiah Sridhar[3]

[1]Centre for Biodiversity Exploration and Conservation, Tilhari, Mandla Road, Jabalpur 482021, Madhya Pradesh, India, Email: rsfungus@gmail.com, [2]CSIR-National Institute of Oceanography, Regional Centre, 176, Lawson's Bay Colony, Visakhapatnam 530017, Andhra Pradesh, India, Email: shenoynio@gmail.com, [3]Department of Biosciences, Mangalore University, Mangalore, Mangalagangotri, Karnataka, India, Email: kandikeremanasa@gmail.com

Abstract
In this article, we present our insights on the ecological roles and biotechnological potential of marine fungi along India's diverse coastline. Our aim is to shed light on existing research gaps and underscore the pressing need for further exploration in this domain. We advocate for interdisciplinary research, heightened conservation endeavours, and enhanced public and policy awareness to harness the yet untapped potential of marine fungi for sustainable development and ecological well-being. Furthermore, we present a ten-point program aimed at catalysing future research efforts and fostering collaboration within the field of marine mycology in India. It is important to note that while our article offers valuable insights, it is not intended to serve as a comprehensive review paper.

Keywords: Biodiversity, Deep Ocean Mission, Coastal biodiversity, Marine biotechnology, Matsya 6000

Citation: Sharma R, Shenoy BD, Sridhar KR (2024) Insights on marine fungal research in India. MycoIndia 2024/04.

Received: 26.03.2024 | **Accepted**: 30.03.2024 | **Published**: 30.03.2024 | **Handling Editor**: Dr. K. Manjusha

1. Introduction

At a time when the equilibrium between nature and human activities is increasingly fragile, it is vital to acknowledge that oceans cover approximately 71% of Earth's surface, leaving just 29% as land. The distribution of Earth's waters is led by the Pacific Ocean at 52%, followed by the Atlantic at 25%, and the Indian Ocean at 20%. Additionally, ice, groundwater, and surface waters like rivers and lakes hold smaller fractions of the total water (Webb 2024). It is believed that life on Earth originated in the ocean's high-pressure depths around 3 billion years ago (Isabelle et al. 2006).

The ocean's stratification includes the epipelagic (euphotic) zone, where sunlight supports photosynthesis; the mesopelagic (dysphotic) zone with limited light, inhibiting photosynthesis; and aphotic zones (bathypelagic, abyssopelagic, and hadopelagic), devoid of light and characterized by extreme pressure, supporting specially adapted organisms (Webb 2024). Although the euphotic zone has been the most accessible and has been extensively studied, the depths of the aphotic zone hold many unexplored mysteries (Koslow 2007).

Marine ecosystems are known for their vast biodiversity, with an estimated 2.2 million species that remain largely unexplored and undocumented (Mora et al. 2011). Fungi, notably, have carved out a niche within these habitats, appearing in a multitude of forms, including mycelial microfungi, single-celled yeasts, zoosporic fungi of Chytridiomycota, and even lichens. This diversity greatly enhances our understanding of the complexity and breadth of marine life (Cunliffe 2023).

2. Marine fungi

Marine fungi are grouped into two main types: obligate, which complete their life cycle exclusively in marine settings and often require salt to thrive, and facultative, which are versatile enough to grow in both saltwater and freshwater environments, as well as on land. The facultative fungi, in particular, are noted for their adaptability, inhabiting a range of terrestrial and aquatic niches. Some workers prefer a different terminology, marine-derived fungi that grow or sporulate, live symbiotically, or are adapted to survive in marine habitats (Pang et al. 2016).

Marine fungi play versatile ecological roles, serving as parasites that infect phytoplankton, saprobes that decompose organic material, and participants in symbiotic relationships, notably with seaweeds. Their pivotal contribution to marine ecosystems influences the populations of phytoplankton, zooplankton, and marine animals, alongside the biochemical dynamics of marine sediments (Kohlmeyer and Kohlmeyer 1979, Damare et al. 2006). Climate change is linked to increased disease prevalence, where environmental fungi, including marine varieties, are increasingly identified as pathogenic. A notable case is *Candida auris*, a recently recognized multi-drug resistant fungus, originally found in the marine environment off the Andaman Islands before its pathogenic properties were understood (Arora et al. 2021).

Marine fungi thrive on diverse organic substrates, from sponges to zooplankton, affected by oceanic salinity levels. However, research has traditionally focused on brackish waters and shorelines, limiting our grasp of their broader distribution. Recently, Calabon et al. (2023) have shown a significantly greater diversity within marine fungi, especially in the Ascomycota group, than previously known. Furthermore, mangrove decomposition has proven to be a vital substrate, supporting a rich fungal community that, in some cases, surpasses diversity found on driftwood (Hyde and Pointing 2000, Sarma and Devadatha 2020, Devadatha et al. 2017-2019, 2021a, b).

3. Historical perspective

The foundational work on the taxonomy of marine fungi by Sutherland (1915) and Sparrow (1936) laid the groundwork for future explorations in this field. A landmark achievement came with Roth et al. (1964), who were the pioneers in isolating deep-sea fungi from extraordinary depths of up to 4,450 meters. Building on this, Kohlmeyer and Kohlmeyer (1979) extended the research by successfully isolating marine fungi from submerged wood located between 500 and 3,000 meters beneath the sea surface. Initially focused on temperate regions, the scope of marine fungal research broadened significantly to include tropical areas across the Atlantic, Pacific, and Indian Oceans, thanks largely to the influential contributions of Kohlmeyer and Kohlmeyer (1979).

The 1990s witnessed significant advancements, with Lorenz and Molitoris (1992) and Raghukumar and Raghukumar (1998) furthering the exploration of marine fungi through deep-sea sampling and cultivation under high-pressure conditions. Additionally, Damare et al. (2006) conducted a comprehensive study on culturable fungi from deep-sea sediments in the Central Indian Ocean Basin, enriching our understanding of marine fungal diversity and ecological roles.

4. Marine fungal research in India

India's extensive coastline, stretching approximately 7,516 km across both the East and West Coasts, features a diverse range of habitats including estuaries, lagoons, mangroves, backwaters, salt marshes, rocky and sandy coasts, and coral reefs. This rich tapestry of marine ecosystems supports a wide variety of life forms, from algae and phytoplankton to zooplankton and coral reefs, forming a dynamic marine environment. Prominent Indian researchers such as B. D. Borse, T. S. Suryanarayanan, K. R. Sridhar (the third author), V. V. Sarma, Seshagiri Raghukumar, Chandralata Raghukumar, and P. Manimohan have made significant contributions to the study of marine fungi, uncovering its complex interactions within these ecosystems. Recent efforts by researchers of CSIR-National Institute of Oceanography have further expanded our knowledge through detailed studies of deep-sea sediments and tarballs (Damare et al. 2006, Shenoy et al. 2024), highlighting the ongoing research into marine mycology.

Varada Samir Damare of Goa University is at the forefront of exploring thraustochytrids, a group of fungoid protists (Damare and Raghukumar 2006), marking an important area of study within marine biology. Additionally, the CSIR-National Institute of Oceanography, with its headquarters in Goa and regional centres in Mumbai, Kochi, and Visakhapatnam, plays a crucial role in marine research. Its vessels, CRV Sindhu Sankalp and RV Sindhu Sadhana, are instrumental in conducting deep-sea expeditions and collecting samples, further advancing our understanding of India's marine fungal diversity.

Marine fungal research in India has significantly progressed from early studies on basic substrates like marine water and driftwood (Raghukumar 1973, Prasannarai and Sridhar 2001, 2003) to exploring diverse environments such as mangroves and hydrothermal vents, incorporating advanced techniques like molecular phylogeny and bioprospecting (Reverter et al. 2020, Hosseini et al. 2022). Historical overviews by Sarma (2021), Borse and Sarma (2021), and Pang et al. (2023) trace these advancements. Early taxonomic studies identified species from fishing boats (Becker and Kohlmeyer 1958, Kohlmeyer 1959, Kohlmeyer et al. 1967, Jones 1968), while recent studies highlight the ecological importance of mangroves (Kohlmeyer and Vittal 1986, Ravikumar and Vittal 1991, Sarma and Vittal 1998-1999, 2000-2004, Sridhar 2013). Research on solar salterns demonstrates the prevalence of *Aspergillus*, highlighting the industrial significance of halotolerant fungi (Suryanarayanan et al. 1996, Thirunavukkarasu et al. 2017, Suryanarayanan and Ravishankar 2023). Additionally, novel genera and species discovered by V. V. Sarma and B. Devadatha (Dayarathne et al. 2017, 2020a, b) have enriched our understanding of marine fungal diversity, ecology and their biotechnological applications.

5. The focal issues

5.1 Deep-sea fungi

The deep sea, with its low temperatures, high pressure, darkness, and scarcity of nutrients, poses an extreme yet fascinating environment for scientific exploration, especially in the study of marine fungi with unique survival strategies and potential for bioprospecting. In the Central Indian Basin, research by Damare et al. (2006) has successfully isolated various fungal species under these harsh conditions, yet *Alisea longicolla* stands out as the sole reported deep-sea endemic fungus (Nagano et al. 2019). The study of deep-sea sediments reveals significant insights into evolutionary timelines, although challenges such as limited sampling resources hinder research progress. Collaborations with institutions like the CSIR-National Institute of Oceanography and innovative approaches to sampling are critical for advancing this field.

5.2 Marine fungal cultures

Marine fungal studies typically begin with isolating fungi from seawater and other samples, and transferring them to high-salt media to mimic their habitats. Understanding the nutrient compositions of marine waters is vital for growth media, crucial for fungal preservation and research. Maintaining live cultures for physiology, biochemistry, and industrial applications faces challenges like viability loss during storage and diminished bioactivity (Nakagiri 2012). Research into preservation methods, cryoprotectants, and novel isolation media is essential. Establishing a national culture collection dedicated to marine fungi could aid in their conservation, taxonomy, and bioprospecting.

5.3 Embracing NGS tools

Recent studies leveraging next-generation sequencing (NGS) have unveiled the presence of pathogenic fungi, such as *Candida tropicalis* and *Aspergillus penicillioides*, on Indian beaches, highlighting the predominance of Ascomycota in these coastal ecosystems. Chopra et al. (2024) identified these species at Ramakrishna Beach in Visakhapatnam, while Shenoy et al. (2024) explored fungal diversity within tarballs at tourist beaches in Goa, uncovering a significant presence of *Aspergillus* species. Tarballs, resulting from oil spills and posing health and ecological risks, suggest that these fungi may play important roles in crude oil bioremediation, underscoring the necessity of ongoing research and environmental monitoring.

5.4 Fungi in marine biotechnology

Marine fungi are pivotal in synthesizing secondary metabolites like steroids, alkaloids, and terpenoids, which are crucial for their anti-tumor, anti-cancer, and antimicrobial properties (Devi and Thakur 2022, Kamat et al. 2020). These fungi, thriving under extreme conditions such as high salinity and pollution, exhibit diverse bioactivities, including antioxidative and anti-inflammatory effects (Simmons et al. 2005, Leman-Loubière et al. 2017). Studies have shown that over 1000 natural secondary metabolites from marine-derived fungi have been examined, yet only a fraction from obligate marine fungi have been explored for their potential (Overy et al. 2014, 2019). Thraustochytrids, for example, are exploited for omega-3 PUFA production, which is beneficial for both health and aquaculture (Raghukumar 2008). Marine fungi also contribute to emerging fields like plastic degradation and cosmeceuticals (Zeghal et al. 2021, Agrawal et al. 2018a, b). Despite the extensive marine ecosystem, the full potential of marine fungi, particularly in bioprospecting and pharmaceutical applications, remains largely untapped (Sarma, 2019, Sarma and Jeewon 2019).

6. Future directions

Sustained coastal research in India holds paramount importance for healthcare, conservation, and industrial advancements. The Deep Ocean Mission, spearheaded by India’s Ministry of Earth Sciences, endeavours to unlock the mysteries of the deep sea through initiatives such as Samudrayaan and Matsya 6000, thereby significantly contributing to the exploration of marine fungal biodiversity. Despite the immense expanse of the marine environment, the identification of marine fungal species remains limited, underscoring the need for intensified exploration efforts. Notably, marine fungi present a wealth of biotechnological potential, with the capability to yield bioactive compounds crucial for healthcare and various industrial applications.

Effective collaboration among mycologists, biochemists, and bioinformaticians holds the key to expediting the discovery of natural products derived from marine fungi. To this end, we advocate for a comprehensive ten-point program aimed at advancing marine fungal research in India (Table 1). By implementing these strategic initiatives, we hope for ground-breaking opportunities in marine mycology, particularly for aspiring young scientists.

Acknowledgment

The authors thank Dr. K. Manjusha, Dr. Sunil K. Deshmukh, Dr. Rajesh Jeewon, Prof. T. S. Suryanarayanan, Prof. D. Jayarama Bhat, Prof. V. V. Sarma, Dr. Patricia Vélez Aguilar, Dr. K. C. Rajeshkumar, Dr. Varada Samir Damare, and Dr. B. Devadatha for their constructive criticism, which greatly improved the manuscript.

Table 1: A ten-point program for advancing marine fungal research in India

Theme	Description
Infrastructure development for marine mycology	Enhance existing research facilities to support advanced studies in marine mycology, including the acquisition of state-of-the-art equipment for deep-sea sampling, high-pressure culturing, and molecular analysis.
National repository and database	Establish a comprehensive national repository and database for marine fungi, which would catalog and provide access to information on species discovered, their genetic data, metabolites, and ecological importance.
Research funding and grants	Secure increased funding and grant opportunities specifically earmarked for marine fungal research to support exploration, biodiversity studies, and the development of biotechnological applications.
Collaborative research programs	Foster interdisciplinary and international collaborations to leverage diverse expertise in taxonomy, ecology, molecular biology, and biotechnology, aiming to address complex questions and applications in marine mycology.
Capacity building and training	Develop specialized training programs and workshops to equip early-career scientists and researchers with skills in modern techniques such as next-generation sequencing, bioinformatics, and culturing under extreme conditions.
Public-private partnerships	Encourage collaborative projects between academic institutions and industries to drive the applied research and commercialization of marine fungal discoveries, particularly in pharmaceuticals, agriculture, and bioremediation.
Exploration and biodiversity studies	Dedicate efforts to explore less studied marine habitats along the Indian coastline, including deep-sea environments, mangroves, and coral reefs, to discover new fungal species and understand their roles in marine ecosystems.
Innovative preservation techniques	Innovate and improve methods for the preservation of marine fungi to ensure the long-term viability of cultures for research and biotechnological exploitation, exploring new cryopreservation techniques and growth media.
Biotechnological and pharmaceutical research	Intensify the bioprospecting of marine fungi for novel secondary metabolites with potential applications in medicine, agriculture, and various industries, focusing on antimicrobial, anticancer, and anti-inflammatory compounds, as well as industrially relevant enzymes.
Environmental and conservation initiatives	Integrate marine fungal research into broader environmental monitoring and conservation strategies, recognizing the critical role of fungi in marine ecosystems. This includes assessing the impact of climate change on marine fungal diversity and the potential of fungi in ecosystem restoration and pollution mitigation.

References

Agrawal S, Adholeya A, Barrow CJ, Deshmukh SK (2018a) In-vitro evaluation of marine derived fungi against *Cutibacterium acnes*. Anaerobe 49:5–13. DOI: 10.1016/j.anaerobe.2017.10.010

Agrawal S, Adholeya A, Barrow CJ, Deshmukh SK (2018b) Marine fungi: An untapped bioresource for future cosmeceuticals. Phytochemistry Letters 23:15–20. https://doi.org/10.1016/j.phytol.2017.11.003

Arora P, Singh P, Wang Y, Yadav A, Pawar K, et al. (2021) Environmental isolation of *Candida auris* from the coastal wetlands of Andaman Islands, India. mBio 12:10.1128/mbio.03181-20. https://doi.org/10.1128/mbio.03181-20

Becker G, Kohlmeyer J (1958) Deterioration of wood by marine fungi in India and its special significance for fishing crafts. Journal of the Timber Dryers' and Preservers' Association of India 4:1–10.

Borse BD, Sarma VV (2021) History of marine mycology in India. In: Satyanarayana T, Deshmukh SK, Deshpande MV (eds), Progress of mycology: An Indian perspective. Springer-Nature. Doi:10.1007/978-981-16-23 50-9_2

Calabon MS, Jones EBG, Pang KL, Abdel-Wahab MA, Jin J, et al. (2023) Updates on the classification and numbers of marine fungi. Botanica Marina 66:213–238. https://doi.org/10.1515/bot-2023-0032

Chopra M, Behera S, Jagadeesan L, Rachuri V, Shenoy BD (2024) Exploring fungal diversity and their ecological roles in the coastal waters of Ramakrishna Beach, Visakhapatnam, India. MycoAsia 2024/01. https://doi.org/10.59265/mycoasia.2024-01

Cunliffe M (2023) Who are the marine fungi? Environmental Microbiology 25:131–134. DOI: 10.1111/1462-2920.16240

Damare S, Raghukumar C, Raghukumar S (2006) Fungi in deep-sea sediments of the Central Indian Basin. Deep Sea Research Part I: Oceanographic Research Papers 53:14–27. https://doi.org/10. 1016/j.dsr.2005.09.005

Damare V, Raghukumar S (2006) Morphology and physiology of the marine straminipilan fungi, the aplanochytrids isolated from the equatorial Indian Ocean. Indian Journal of Geo-Marine Sciences 35:326–340.

Dayarathne MC, Abeywickrama P, Jones EBG, Bhat DJ, Chomnunti P, Hyde KD (2017) Multi-gene phylogeny of *Jattaea bruguierae*, a novel asexual morph from *Bruguiera cylindrica*. Studies in Fungi 2:235–245. Doi: 10.5943/sif/2/1/27

Dayarathne M, Jones EBG, Maharachchikumbura S, Devadatha B, Khongphinitbunjong K, et al. (2020a) Morpho-molecular characterization of microfungi associated with marine based habitats. Mycosphere 11:1–188. Doi: 10.5943/mycosphere/11/1/1

Dayarathne MC, Wanasinghe DN, Devadatha B, Abeywickrama P, Jones EBG, et al. (2020b) Modern taxonomic approaches to identifying diatrypaceous fungi from marine habitats, with a novel genus *Halocryptovalsa* Dayarathne et K.D. Hyde, gen. nov. Cryptogamie Mycologie 41:21–67. https://doi.org/10.5252/cryptogamie-mycologie2020v41a3

Devadatha B, Jones EBG, Ghate SD, Sarma VV (2021a) Biodiversity of marine fungi in mangroves with reference to Muthupet mangroves, Tamil Nadu, east coast of India. Marine Biodiversity 51:88. https://doi.org/10.1007/s12526-021-01214-8

Devadatha B, Jones EBG, Pang KL, Abdel-Wahab MA, Hyde KD, et al. (2021b) Occurrence and geographical distribution of mangrove fungi. Fungal Diversity 106:137–227. https://doi.org/10.1007/s13225-020-00468-0

Devadatha B, Mehta N, Wanasinghe DN, Baghela A, Sarma VV (2019) *Vittaliana mangrovei*, gen. nov., sp. nov. Phaeosphaeriaceae from mangroves near Pondicherry India, based on morphology and multigene phylogeny. Cryptogamie Mycologie 40:117–132. https://doi.org/10.5252/cryptogamie-mycologie2019 v40a7

Devadatha B, Sarma VV, Ariyawansa A, Jones EBG (2018) *Deniquelata vittalii* sp. nov., a novel Indian saprobic marine fungus on *Suaeda monoica* and two new records of marine fungi from Muthupet mangroves, East coast of India. Mycosphere 9:565–582. Doi: 10.5943/mycosphere/9/3/8

Devadatha B, Sarma VV, Wanasinghe DN, Hyde KD, Jones EBG (2017) Introducing the new Indian mangrove species, *Vaginatispora microarmatispora* (Lophiostomataceae) based on morphology and multigene phylogenetic analysis. Phytotaxa 329:139–149. DOI: 10.11646/PHYTOTAXA.329.2.4

Devi P, Thakur N (2021) Bioprospecting of marine fungi. In: Satyanarayana T, Deshmukh SK, Deshpande MV (eds) Progress in Mycology. Springer, Singapore. https://doi.org/10.1007/978-981-16-3307-2_18

Hosseini H, Al-Jabri HM, Moheimani NR, Siddiqui SA, Saadaoui I (2022) Marine microbial bioprospecting: Exploitation of marine biodiversity towards biotechnological applications - a review. Journal of Basic

Microbiology 62:1030–1043. DOI: 10.1002/jobm.202100504

Hyde KD, Pointing SB (2000) Marine mycology- A practical approach. Fungal Diversity Press, Hong Kong.

Isabelle D, Philippe O, Roland W (2006) Origins of life and biochemistry under high-pressure conditions. Chemical Society Reviews 35:858–875. DOI: 10.1039/B517766A

Jones EBG (1968) Marine fungi. Current Science 37:378–379.

Kamat S, Kumari M, Taritla S, Jayabaskaran C (2020) Endophytic fungi of marine alga from Konkan coast, India—a rich source of bioactive material. Frontiers in Marine Science 7:31. https://doi.org/10.3389/fmars.2020.00031

Kohlmeyer J (1959) Neufunde hazberrede Inder meerspilze. Nova Hedwigia 1:77–99.

Kohlmeyer J Vittal BPR (1986) *Lophiostoma mangrovis*, a new marine ascomycete from the tropics. Mycologia 78:485–489

Kohlmeyer J, Kohlmeyer E (1979) Marine mycology: The higher fungi. London: Academic Press.

Kohlmeyer J, Schmidt I, Nair NB (1967) Eine neue *Corollospora* (Ascomycetes) aus dem Indischen Ozean and der Ostsee. Berichte der Deutschen Botanischen Gesellschaft 80:98–102.

Koslow TL (2007) The Silent Deep: The Discovery, ecology, and conservation of the deep sea. The University of Chicago Press.

Leman-Loubière C, Goffg L, Debitus C, Ouazzani J (2017) Sporochartines A–E, a new family of natural products from the marine fungus *Hypoxylon monticulosum* isolated from a Sphaerocladina sponge. Frontiers in Marine Science 4:1–9. doi: 10.3389/fmars.2017.00399

Lorenz R, Molitoris HP (1992) Combined influence of salinity and temperature (Phoma-pattern) on growth of marine fungi. Canadian Journal of Botany 70:2111–2115.

Mora C, Tittensor DP, Adl S, Simpson AGB, Worm B (2011) How many species are there on earth and in the ocean? PLoS Biololgy 9(8):e1001127. https://doi.org/10.1371/journal.pbio.1001127

Nagano Y, Fujiwara Y, Nishimoto A, Haga T, Fujikura K (2019) Deep-sea endemic fungi? The discovery of *Alisea longicolla* from artificially immersed wood in deep sea off the Nansei Islands, Japan. Mycoscience 60:228–231. https://doi.org/10.1016/j.myc.2019.03.004

Nakagiri A (2012) Culture collections and maintenance of marine fungi. In: Jones EBG and Pang KL (eds) Marine fungi. De Gruyter, Boston-Berlin. pp. 501–507. https://doi.org/10.1515/9783110264067.501

Overy DP, Bayman P, Kerr RG, Bills GF (2014) An assessment of natural product discovery from marine (*sensu stricto*) and marine-derived fungi. Mycology 5:145–167. https://doi.org/10.1080/21501203.2014.931308

Overy DP, Rämä T, Oosterhuis R, Walker AK, Pang KL (2019) The neglected marine fungi, *sensu stricto*, and their isolation for natural products' discovery. Marine Drugs 17:42. doi: 10.3390/md17010042

Pang KL, Jones EG, Abdel-Wahab MA, Adams SJ, Alves A, et al. (2023) Recent progress in marine mycological research in different countries, and prospects for future developments worldwide. Botanica Marina 66:239–269. https://doi.org/10.1515/bot-2023-0015

Pang KL, Overy DP, Jones EBG, Calado ML, Burgaud G, et al. (2016) 'Marine fungi' and 'marine-derived fungi' in natural product chemistry research: Toward a new consensual definition, Fungal Biology Reviews 30:163–175. https://doi.org/10.1016/j.fbr.2016.08.001

Prasannarai K, Sridhar KR (2001) Diversity and abundance of higher marine fungi on woody substrates along the west coast of India. Current Science 81:304–311.

Prasannarai K, Sridhar KR (2003) Abundance and diversity of marine fungi on intertidal woody litter of the west coast of India on prolonged incubation. Fungal Diversity 14:127–141.

Raghukumar S (1973) Marine lignicolous fungi from India. Kavaka 1:73–85.

Raghukumar S (2008) Thraustochytrid marine protists: production of PUFAs and other emerging technologies. Marine Biotechnology 10:631–640. DOI: 10.1007/s10126-008-9135-4

Raghukumar C, Raghukumar S (1998) Barotolerance of fungi isolated from deep-sea sediments of the Indian Ocean. Aquatic Microbial Ecology 15:153–163.

Ravikumar DR, Vittal BPR (1991) A new species of *Bathyascus* from Indian mangroves. Mycological Research 95:370–371. https://doi.org/10.1016/S0953-7562(09)81250-1

Reverter M, Rohde S, Parchemin C, Tapissier-Bontemps N, Schupp PJ (2020) Metabolomics and marine biotechnology: coupling metabolite profiling and organism biology for the discovery of new compounds. Frontiers in Marine Science 7:613471. https://doi.org/10.3389/fmars.2020.613471

Roth Jr FJ, Orpurt PA, Ahearn DG (1964) Occurrence and distribution of fungi in a subtropical marine environment. Canadian Journal of Botany 42:375–383. https://doi.org/10.1139/b64-037

Sarma VV (2019) Marine fungal diversity – Present status and future perspectives. In: Satyanarayana T, Das SK, Johri BN (eds) Microbial diversity in ecosystem sustainability and biotechnological applications. Springer Nature, Singapore. https://doi.org/10.1007/978-981-13-8315-1_9.

Sarma VV (2021) Historical developments in Indian mycology. In: Satyanarayana T, Deshmukh SK, Deshpande MV (eds) Progress of mycology: An Indian perspective. Springer – Nature. Doi.10.1007/978-981-16-23509_1.

Sarma VV, Devadatha B (2020) Fungal diversity in mangroves of India and a note on their medicinal potential. Elsevier. In: Patra JK, RR Mishra RR, Thatoi H (eds) Biotechnological utilization of mangrove resources. Academic Press, Elsevier.

Sarma VV, Jeewon R (2019) Marine fungal ecology in the molecular era. In: Satyanarayana T, Deshmukh SK, Deshpande MV (eds) Advancing frontiers in mycology and mycotechnology. Springer, Singapore. DOI: 10.1007/978-981-13-9349-5.

Sarma VV, Vittal BPR (1998–1999) Ecological studies on manglicolous fungi from Godavari and Krishna deltas, East coast of India. Observations on the seasonal occurrence. Kavaka 26–27:105–120.

Sarma VV, Vittal BPR (2000) Biodiversity of mangrove fungi on different substrata of *Rhizophora apiculata* and *Avicennia* sp. from Godavari and Krishna deltas, East coast of India. Fungal Diversity 5:23–41.

Sarma VV, Vittal BPR (2001) Biodiversity of manglicolous fungi on selected plants in the Godavari and Krishna deltas, East Coast of India. Fungal Diversity 6:115–130.

Sarma VV, Vittal BPR (2002) A preliminary study on vertical distribution of manglicolous fungi on prop roots of *Rhizophora apiculata* Blume at Krishna delta, East coast of India. Kavaka 30:21–29.

Sarma VV, Vittal BPR (2004) Manglicolous fungi recorded from Godavary and Krishna deltas, A. P., East coast of India along with dichotomous key and notes on some taxa. Kavaka 32:65–111.

Shenoy BD, Khandeparker RDS, Fernandes P, Amberkar U (2024) Fungal diversity associated with Goa's tarballs: Insights from ITS region amplicon sequencing. Fungal Biology 128:1751–1757. https://doi.org/10.1016/j.funbio.2024.03.001

Simmons TL, Andrianasolo E, McPhail K, Flatt P, Gerwick WH (2005) Marine natural products as anticancer drugs. Molecular Cancer Therapeutics 4:333–342.

Sparrow FK (1936) Biological observations of marine fungi. Biological Bulletin 70:236–263.

Sridhar KR (2013) Mangrove fungal diversity of west coast of India. In: Bhat JR, Sanjappa SM, Ramadevi OK, Nilaratna BP, Venkataraman K (eds) Mangroves of India - Their biology and uses. Zoological Survey of India, Kolkata, pp. 161–182.

Suryanarayanan TS, Muruganandam V, Rajagopal K, Girivasan KP (1996) Soil mycoflora of a commercially operated solar saltern. Kavaka 24:11–13.

Suryanarayanan TS, Ravishankar JP (2023) They too serve who tolerate and survive: the need to study halotolerant fungi to appreciate their role in saline ecosystems. Fungal Biology Reviews 46:100328. https://doi.org/10.1016/j.fbr.2023.100328

Sutherland GK (1915) New marine fungi on *Pelvetia*. New Phytologist 14:33–42.

Thirunavukkarasu N, Suryanarayanan TS, Rajamani T, Rajulu MG (2017) Diversity and technological potential of fungi from solar salterns of southern India. Kavaka 48:26–32.

Webb P (2024) Introduction to oceanography. Accessed from http://rwu.pressbooks.pub/webboceanography

Zeghal E, Vaksmaa A, Vielfaure H, Boekhout T, Niemann H (2021) The potential role of marine fungi in plastic degradation – A review. Frontiers in Marine Science 8:738877. doi: 10.3389/fmars.2021.738877