Coastal sand dunes are hips and strips formed by sand particles which are eroded and ground rock, derived from terrestrial and oceanic sources. This is considered as a specialized ecosystem characterized by conditions which are hostile for life forms like high salt, low moisture, and low organic matter content. However, dunes are also inhabited by diverse groups of flora, fauna, and microorganisms specifically adapted to these situations. Microbial groups like fungi, bacteria, and actinobacteria are quite abundant in the rhizosphere, phyllosphere, and inside plants which are very much essential for the integration of dunes. Microorganisms in this ecosystem have been found to produce a number of bioactive metabolites which are of great importance to agriculture and industries. Many species of arbuscular mycorrhizal fungi and Rhizobia associated with the roots of dune flora are prolific producers of plant growth promoting biochemistry like indole acetic acid. In addition to that bacteria belonging to *Pseudomonas* sp., *Gammaproteobacteria* have been found to have antagonistic activity towards plant pathogens like *Rhizoctonia solani*, *Pythium ultimum*, *Fusarium oxysporum*, and *Botrytis cinerea*. Many neutrophilic and alkaliphilic eubacterial species, endophytic fungi from dunes have proved their ability for the production of extracellular enzymes like cellulase, pectinase, amylase, protease, tannase, chitinase, etc., which are of great importance to various industries. In this context, it is relevant to observe that the state of Odisha in India has a 480km long coast having numerous sand dunes. These dunes are rich in floral and faunal diversity. However, a comprehensive study is yet to be taken up to explore the microbial diversity and their bioactive potential in this region. The current review sheds light on the enormous potential of sand dune microorganisms in the coast and surfaced the idea and need for such exploration in the state of Odisha, India.

1. Introduction

Coastal sand dunes are described as mounds and narrow strips of sand with distinct boundaries determined by the sea and landward limits of sand transport. Sand dunes are widely distributed across the globe, covering $6 \times 10^6 \text{ km}^2$ of its land surface. This specialized ecosystem is considered to be unique and different from inland dunes due to the effect of sea [1–3]. These are natural barriers against the wave action of the sea, protecting the shoreline and natural habitats or developed areas inland [4]. These structures are also the basis of important ecosystems, supporting valuable communities of plants and animals. As such, they provide resources and shelter for aboriginal people, generating cultural values that remain important today. Sand dunes are now recognised as integral parts of our beach systems with intrinsic biodiversity values [5]. The ecosystem of sand dunes is too hostile for the establishment of normal life forms and also does not support dense and very diverse vegetation. However, due to unusual circumstances, this environment harbours atypical floral, faunal, and microbial diversity [6]. Coastal dunes have been reported to contain a larger diversity of agriculturally, industrially, and pharmaceutically important bacteria, fungi, actinomycetes, and other groups of microbes [7–15]. Despite these facts, unlike desert dunes, coastal dunes have generally been neglected and attracted little attention from investigators for study on their biodiversity. Particularly, the potential of microbial diversity has not been exploited much in India. In Odisha, the area has still remained untouched despite of having a coast line of about 480km. Hence, it has become very important to highlight the bioefficacy of such novel microbial diversity and their potential role in various fields.
with a context to Odisha. Further, with the mandate of the “Convention on Biological Diversity,” the Biological Diversity Act 2002 implemented by the Government of India u/s 41 also puts provision for the documentation of microbial resources along with flora, fauna, and associated traditional knowledge. It has, therefore, become very much essential to explore microbial potential in unattended ecosystems like the coastal sand dunes in Odisha. The current review sheds light on such issues in a concise way.

2. The Extraordinary Ecosystem and Microbial Relevance

The main composition of coastal sand dunes is permeable sand materials which act as biocatalytic filters for various types of materials advected by currents and winds, including dissolved and particulate organic matter derived from living and dead biomass of terrestrial or marine origin [16]. These are dynamic and disturbance prone habitats which undergo continuous alteration in topography by sand movement as well as physicochemical features mainly due to strong wind and wave action. These are generally characterized by infertile soil along with saline mist, salt spray, dryness, lack of water holding capacity, desiccation, high light intensity, nutrient deficiency, sand erosion, sand accretion, and other transitional factors [17]. Such environmental stresses not only affect the pattern of vegetation and faunal diversity, but also the dynamics and composition of microbial community.

Diversity of microorganisms in the dune ecosystem may be viewed from two angles, bulk sand and plant associated. In sand dune ecosystems, lack of abundant vegetation cover constrains the soil carbon availability [18] and, hence, affects the microbial biomass [19]. Subtidal sands harbor rich microbial diversity due to the accumulation of both organic and inorganic materials. In contrary to this, supratidal sands which include sand dunes have low organic matter content and concentrations of other reactive substances required to support biological processes, therefore, having less diversity of microbial communities. Microbial biomasses like carbon and nitrogen are higher in the humic layer than the underlying soil layer in sand dune forest soil [20]. However, Probandt et al. [21] estimated that a single sand grain may contain $10^4$ to $10^5$ microbial cells. Predominant population of Acidobacteria and Proteobacteria have been isolated from humic soils of upland and lowland Casuarina and lowland Hibiscus successional forests in a coastal sand dune ecosystem of Taiwan, where Bradyrhizobium related clones were abundant in Casuarina forest soils [22]. The composition of the dune soil microbial community also varies with abiotic stresses, especially soil salinity [19]. The overall interaction in the habitat may impact hydrological, sedimentological, and biogeochemical processes that occur throughout the whole beach system. Though the dynamic environmental parameters in coastal sands pose a challenge to many microbial communities, still a rich bacterial community is supported by the high diversity of niches where few but tolerant and well-adapted resident types are naturally selected [23]. Gobet et al. [24] found only 3 to 5% of all bacterial types were present at all the seasons in a given depth zone of sand soil, but 50-80% of them belonged to the most abundant types. Sridharan et al. [25] isolated 24 fungal species belonging to Zygomycetes, Ascomycetes, and Deuteromycetes from the dune soils of Tamil Nadu coast.

3. Microorganisms Associated with Root and Rhizosphere

Plantations present on coastal sand dunes vary in structure and composition and these variations may alter soil microbial communities [26]. Rhizosphere is the thin soil layer immediately surrounding plant roots and microorganisms which are coexisting in the rhizosphere are known as rhizospheric microorganisms. Plants in dunes and in general have specific rhizospheric microflora which depends on the influx of mineral nutrients to roots and the abundance, density, composition, and diversity of plant-derived exudates. Interactions with microbes like Arbuscular mycorrhizal fungi in the roots appear crucial in obtaining inorganic nutrients or growth-influencing substances. Plant-associated bacteria increase the ability of plants to utilize nutrients from the soil by increasing root development, nitrate uptake, or solubilizing phosphorus and to control soilborne pathogens. Successful restoration of plants like Amnophila arenaria in nutrient-poor saline dunes even depended on plant-microbe symbiosis like nitrogen-fixing bacteria [27].

Some perennial shrubs like Artemisia monosperma and Retama raetam have created favorable niches for microorganisms where the rhizospheric microbial mass was found to be 234.6 and 173.1 $\mu$Cg $^{-1}$ dry soil [17]. Rhizospheric soil of Calystegia soldanella (beach morning glory) and Elymus mollis (wild rye) found in South Korean dunes have been found to be enriched with 27 different established genera of bacteria [27]. A total of 47 rhizobacterial strains (including 22 fluorescent Pseudomonads) could be isolated from 5 rhizosphere soil samples collected from the coastal sand dunes in Uthandi Beach, Chennai [7]. Abundant population of siderophores producing bacteria belonging to Bacillus spp., Streptomyces spp., Pseudomonas spp., Renibacterium spp., Corynebacterium, Azotobacter spp., Kurthia spp., Brochothrix spp., etc. could be isolated from rhizosphere of sand dune creeper Ipomoea pes caprae found in Miramar, Goa, located on the west coast of India [2]. Extreme halo-tolerant novel bacterial species named as Halomonas malpeensis sp. nov. has been recently isolated from the rhizosphere sand of a coastal sand dune plant which could grow in the presence of 0.5 to 5% (w/v) NaCl (growth up to 20% NaCl) and had a wide range of growth conditions [28].

4. Prevalence of Arbuscular Mycorrhizal Fungi (AMF)

Establishment of vegetation in stressed environments like sand dunes have been promoted by Arbuscular mycorrhizal fungi (AMF), a special group of fungi which can enhance uptake of plant nutrient and water and protect plants from root herbivores and pathogens. Particularly, this microbial
group plays an important role in stabilization and rehabilitation of dunes by a way of producing glomalain and development of a vast network of hyphae which ultimately prevent soil erosion by the formation of wind-resistant soil aggregates. The AMF belong to the phylum Glomeromycota, which includes about 270 described species. These fungi are an important link in the soil-plant interface because they form a mutualistic symbiosis with plant roots of over 80% of vascular plants and act as efficient facilitators for the absorption of nutrients by their host plants, including most inaccessible nutrients (e.g., phosphorous), increase in the complementarities of nutritional resources, ensure greater tolerance to biotic and abiotic stresses, and contribute to the stabilization of soils due to the formation of stable soil aggregates [29].

Unvegetated sites in dunes generally lack propagules of AMF, but when culms of plants (carrying propagules of AMF) like A. breviligulata transplanted in such area, the roots became mycorrhizal in less than a year after planting. The province lands area of Cape Cod National Seashore, Massachusetts, is such as it were early and later sporulating 

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was evenly distributed in those dunes having more than 40 species [45].

6. Macrofungi in Coastal Dunes of India

Macrofungi constitute important natural resource owing to their major role in decomposition, nutrient cycling, mutualistic association, and other advantages (nutrition, medicine, and metabolites). In spite of saline conditions and disturbances, coastal sand dunes may consist of 29% of macrofungi. Sand dunes of Karnataka coast are especially rich in the diversity of macrofungi harbouring some eminent species like Coprinus plicatilis, Crepidotus uber, Dacryopinax spathularia, Ganoderma lucidum, Hexagonia tenuis, Lentinus squarrosulus, Lycoperdon utriforme, Marasmius kisangensis, Microporus xanthopus and Thelephora palmate, Amanita spp., Collybia dryophila var. extuberans, etc. [46, 47]. Spatial and temporal analysis carried out by Ghatre and Sridhar [48] yielded 64 species of macrofungi belonging to 34 genera in five coastal sand dunes (CSDs) of southwest India, where Marasmius was the major genus (7 spp.) followed by Agaricus (5 spp.), Lentinus (4 spp.), and Lepiota (4 spp.).

7. Diversity of the Indispensable Endophytic Microorganisms

This group of microorganisms asymptomatically lives inside the plant body and generally impart beneficial effects to the plant such as growth promotion, protection from biotic and abiotic stress, etc. [49, 50]. Tropical endophytic fungal inventory is turning to be an important component of fungal diversity estimation. Other than AMFs, the coastal sand dune vegetation might depend on endophytic fungi assemblage to cope with extreme conditions. Both bacterial and fungal endophytes have been isolated from roots, vegetative parts, and propagules of plants thriving in coastal sand dunes. Studies conducted in the Korean dunes have enumerated a great diversity of bacterial endophytes, where as many as 21 different bacterial genera could be isolated alone from the roots of two plants viz. soldanella (beach morning glory) and Elymus mollis (wild rye) [27]. Bacterial species belonging to Pseudomonas, Chryseobacterium, Microbacterium, Paenibacillus, Acinetobacter, and Lysobacter were found to form the majority of the root endophytic bacteria. The dune flora also inhabited by diverse fungal groups where Penicillium and Fusarium were found to be dominant species [10]. Fungal strains belonging to thirteen orders viz. Capnidioldae, Eurotiidae, Glomereidae, Helotiales, Hypocreales, Mortierellales, Onygenales, Ophostomalales, Pleosporales, Polyporales, Russulales, Saccharomycetales, and Xylariacea could be isolated from coastal sand dune plants like Argusia sibrica, Calystegia soldanella, Elymus mollis, Lithospermum zollingeri, Raphanus sativus, Salsola collina, Zoysia macrostachya, and Zoysia sinica [51].

Plants in the southern and west coast sand dunes of India are found to be abundantly associated with endophytic microorganisms. The common sand binder Ipomoea spp. in this region was found to be mutually associated with 46 morphologically different bacterial strains some of them having Plant Growth Promoting (PGPR) property [8]. Ipomoea pes-caprae along with Launaea sarmentosa and Polycarpaea corymbosa were also associated with dominant root endophytic fungi like Chaetomium globosum and Torula caligans. In a pilot trial by Beena et al. [37, 38], Acremonium was found to be the dominant endophyte having no negative impact on the arbuscular mycorrhizal fungal colonisation and reproduction. Forty-six fungal taxa comprising 6 ascomycetes, 33 mitosporic fungi, 2 zygomycetes, and 5 sterile morpho species could be recovered from 3 age classes (seeds, seedlings, and mature plants) and 5 tissue classes (cotyledons, seed coats, roots, stems, and leaves) of coastal sand dune legumes Canavalia cathartica and Canavalia maritima. The most dominant endophyte, Chaetomium globosum, colonized over 50% of the root, stem, and leaf segments of C. maritima and over 50% of the root segments of C. cathartica [52].

8. A Brief Pause on the Role of Microbes for the Integration of Dune Ecosystem

In the foregoing sections, it has been established by fact that despite being a stringent environment, coastal sand dunes have a rich microbial diversity as the integral part of that ecosystem. As mentioned in these discussions, the various groups of fungi and bacteria are responsible for the successful succession and establishment of vegetation and subsequently fauna in the dunes. Microorganisms are fundamental components of any terrestrial ecosystem due to their key role in organic matter decomposition, nutrient cycling, and the development of soil structure, especially in sand dune environments [3]. The increase in number and diversity of microorganisms is supposed to be responsible for the formation of stable aggregates in unstable to stable dunes. One of the multiple reasons for this may be due to the secretion of extracellular complex polysaccharides by certain group of bacteria in response to mycorrhizal activity and another may be the formation of mucilage by Nostoc spp. which binds the sand particles to help other microorganisms [6]. The AM fungi themselves are known to improve the soil structure as well as stability due to the formation of sand aggregates [53]. They are responsible for three distinct phases of aggregates: (a) hyphae entangle the soil particles; (b) roots and hyphae create conditions congenial to form microaggregates in soil; and (c) roots and hyphae enmesh and bind the microaggregates to larger macroaggregates [54]. Polysaccharide secretions of AM fungi firmly adhere to the microaggregates [55]. Other than stabilizing the dune structure, microorganisms like Bacillus and Pseudomonas spp. produce low-molecular-weight, high-affinity iron chelators termed siderophores which reduce the formation of Fe³⁺ ions which in turn reduces the chances of iron deficiency in the rhizosphere [2].

9. Beneficial Biopotential of Sand Dune Microbes

The environmental conditions prevailing in the sand dune ecosystems make the microorganisms and other living forms
more competent and may have good potential of bioactivity. So bioprospecting of coastal sand dune microorganisms is a worthy one [7]. The proven ability to produce numerous secondary metabolites by various groups of microorganisms inhabiting coastal sand dunes has already shown the path to be exploited for use in agriculture, industries, and pharmaceuticals.

9.1. Agricultural Importance. Diverse group of Plant Growth Promoting Rhizobacteria (PGPR) has been isolated from sand dunes in Chennai coast which were found to produce extracellular plant growth hormone indole acetic acid (IAA). These bacteria have demonstrated for their remarkable ability to increase seedling length and seedling weight of wheat, green gram, mustard, black gram, and kidney bean through seedling growth chamber studies [7, 8]. Rhizobia isolated from wild legumes growing in sand dunes of West coast India not only increased nodulation and nitrogen fixation, but also induced higher root and shoot mass when inoculated in cowpea (Vigna unguiculata), green gram (Vigna radiata), black gram (Vigna mungo), and horse gram (Macrotyloma uniflorum) [9]. Gibberellins also produced by Gibberella fujikuroi from 9 sand dunes of Korea could increase root shoot length of Waito-c rice [10, 11]. Shin et al. [14] found Gammaproteobacteria constituting 65.9% and members of Pseudomonas constituted 49.5% of the total isolates which were endophytic to sand dune plants like Lathyrus japonica, Vitex rotundifolia, Carex kobomugi, Artemisia fukudo, Messerschmidia sibirica, Glehnia littoralis, etc. Among them, seven strains were shown to produce indole acetic acid (IAA), 33 to produce siderophores, 23 to produce protease, 37 to produce pectinase, and 38 to produce chitinase. Growth promoting fungi may constitute more than 85% of total fungal population in particular sand dunes. Enhancement of root and shoot length, root and shoot weight of maize plant could be achieved by treatment of extract of endophytic Phoma species isolated from Tinospora cordifolia and Calotropis procera [12]. Similarly, growth of Waito-c rice has been enhanced by Penicillium citrinum isolated from Exser repens which extracellularly produced active gibberellins, GA1, GA3, GA4, and GA7 (1.95 ng/ml, 3.83 ng/ml, 6.03 ng/ml, and 2.35 ng/ml, respectively).

Other than the production of growth enhancing phytohormones, microorganisms associated with roots can protect plant growth through the biological control of plant pathogens or they can do both. There are 20 different biocontrol PGPR strains commercially available in the market at present. Many strains of Pseudomonas spp. and Gammaproteobacteria having such broad spectrum activity have been isolated by Shin et al. [14], among which 25 strains were antagonistic towards Rhizoctonia solani, 57 strains were antagonistic towards Pythium ultimum, 53 strains were antagonistic towards Fusarium oxysporum, and 41 strains were antagonistic towards Botrytis cinerea. Pseudomonas spp. AMET 6007 specifically exhibited 32% control over Sheath blight pathogen (Rhizoctonia solani) of rice by their antagonistic mechanisms such as competition for iron (production of siderophores), production of volatile (hydrogen cyanide, HCN) and diffusible metabolites in addition to their ability to produce IAA [56]. Similar dual property has been exhibited by rhizobacteria obtained from plants growing in the coastal sand dunes located along East Coast of Korea. Out of 1330 rhizobacteria screened from 11 different plants from this area, 23 strains were able to produce auxin and had spectrum of antagonism toward various phytopathogenic microbes [57]. Not only that, obligate endospore-forming parasitic bacterial strains like Pasteuria penetrans isolated from European fore dune flora Ammophila arenaria showed the potential to control aggressive nematode like Meloidogyne spp. [4]. Sangeetha [13] isolated 70 actinobacterial strains, most of them which exhibited PGP activity and inhibited the mycelia growth of Rhizoctonia solani, Fusarium oxysporum, and Sclerotium rolfsii. Strain AMET053 which was identified as Streptomyces rochei produced highest zone of inhibition of 9mm and protected tomato plant against Fusarium wilt disease in green house.

9.2. Production of Industrial Enzymes. Microorganisms mainly bacteria, fungi, and actinomycetes are active producers of many extracellular enzymes like cellulase, pectinase, amyrase, protease, tannase, chitinase, etc. These enzymes are gold mines to be used in various industries for the conversion of biological waste residues like agrowaste to useful products. A large number of such microorganisms have been isolated from marine and coastal environment. There are also few reports of collection of such microbial strains from coastal sand dunes which could produce these enzymes in vitro and showed the potential for industrial use. Many neutrophilic and alkaliphilic eubacterial species from rhizosphere Ipomoea pes-caprae and Spinifex littoreus are having special capabilities of producing multiple hydrolytic enzymes as mentioned above. The majority of such neutrophilic bacteria belonged to Bacillus sp., while alkaliphilic bacteria were gram-positive irregular rods belonging to Brevibacterium, Brochothrix, Cellulomonas, and Microbacterium. These bacterial populations are higher during premonsoon period due to the process of degradation of shredded foliages [58]. Many endophytic bacteria isolated from Tae-An area (Baramarae, Sambong, Shindu, and Hagam), Chungnam Province of Korea produced important commercial enzymes like protease, pectinase, and chitinase. These bacteria belonged to Pseudomonas spp., Rahnella spp., Rhizobium spp., Xanthomonas spp., Pantoea sp., Erwinia spp., Chryseobacterium spp., Bacillus spp., and Acinetobacter spp. [14]. Penicillium spp. strain IS-07 isolated from dunes of Brazilian coast could produce cellulase enzymes (Carboxymethyl-cellulase 2274 U/L and Filter-paperase 128 U/L) by using sugarcane wastes in a fermentation process [15]. Another Brazilian strain Trichoderma spp. IS-05 from the dune soil of Guaíba beach produced 564.0 UL⁻¹ of cellulase, obtained after 2 days by fermentation of wheat bran [59]. Other than fungi and bacteria, Actinobacteria from the sand dune rhizospheric soil of Chennai coast of India were screened by Sangeetha [13] for the production of lytic enzymes. Out of 70 morphologically distinct strains, 34 strains produced amyrase, 11 strains produced tannase, 30 strains produced chitinase, 61 produced gelatinase, 51 produced caseinase, and 24 produced pectinase. The
extraordinary capability of sand dune microbes for the production of such important enzymes can be harnessed in specific industries and commercial scale production of such enzymes may be carried out through fermentation process.

10. Coast, Coastal Dunes and Its Microflora in Odisha

The state of Odisha is situated in the eastern part of India and is one of the four maritime states bordering the Bay of Bengal. The state has a coastline of about 480 km constituting 8% of the Indian coastline which stretches from the Udaipur village (21° 31’ N; 87° 34’ E) bordering West Bengal in the north to the marshes of Ichapuram and Bahuda estuary bordering Andhra Pradesh in the south (19° 02’ N; 84° 47’ E). This includes the luxuriant Bhitarkanika mangrove vegetation, Mahanadi delta, and the coastal Chilika Lake. There are seven coastal districts, namely, Ganjam, Puri, Khordha, Jagatsinghpur, Kendrapara, Bhadrak, and Balasore, consisting of approximately 250 coastal fishing villages and about 25 fish landing centres along the coast of Odisha. This coast is bestowed with a variety of habitats, such as sand dunes, tidal creeks, backwaters, brackish water lagoons, estuaries, mangroves, mudflats, and salt marshes. The Exclusive Economic Zone (EEZ) of the state has been estimated at 172,000 km² ([60]; http://iomenvis.nic.in).

Although there has been no specific investigations carried out to study the biodiversity of the sand dunes of Odisha coast, few reports have certainly indicated the existence of rich diversity of flora, fauna, and microbial resources in this specialized ecosystem. The floristic composition in the coastal line was dominated by some of the larger plant families including Asteraceae, Fabaceae, Poaceae, and Convulvaceae [61]. Particularly in the dunes, at least 55 species of medicinal plants having ethno-botanical use have been identified by Pattanaik et al. [62]. This much is enough to indicate the existence of rich microbial diversity associated either with the rhizosphere or present as endophytic mode. As far as microbial diversity is concerned, novel fungal and bacterial strains have been isolated from various coastal habitats of Odisha like Bhitarkanika mangrove area [63]. Even arbuscular mycorrhizal (AM) fungi belonging to genera Glomus, Acaulospora, Gigaspora, Scutellospora, and Entrophospora were recorded from different salinity zones of Bhitarkanika mangrove ecosystem [64]. However, Panda et al. [43] have conducted a study particularly in the dunes of southern coast of Odisha in Anacardium and Casuarina plantation area. Fungal community in sand dunes with Anacardium plantation was found to be of 45 genera & 114 species on surface and 41 genera & 93 species on subsurface. Sand dune with Casuarina plantation was having 36 genera & 78 species of fungi on surface and 38 genera & 85 species on subsurface. Barren sand dune possessed 54 genera & 91 species on surface and 46 genera and 80 species on subsurface. Considering a vast coast line and diversity of dunes in Odisha, a large gap can be clearly observed regarding the exploration of microbial diversity particularly in sand dunes. Specific efforts need to be initiated to explore numerous possibilities in this unattended ecosystem.

11. Conclusion

Current discussions have brought out the enormous potential of coastal sand dunes in terms of having useful microbial diversity. Such hostile habitats around the world have been explored and numerous useful microorganisms have been isolated and identified which possessed the ability to produce many important biochemicals. Particularly, the Arbuscular Mycorrhizal Fungal (AMF) group has been predominant in association with plants which could be exploited and applied in the agricultural field. The state of Odisha in spite of having such a long and biodiversity rich coast still needs to be explored for such novel microorganisms. More than 60% population of Odisha is dependent on agriculture. Most of the farmers use chemical fertilizers and pesticides during agricultural operations which are of higher cost and sometimes those are beyond the buying capability of farmers. In this regard, the discovery of novel microorganisms (fungi, bacteria, and actinobacteria) from this ecosystem in Odisha having plant growth promotion and biological control properties could do wonders towards the idea of sustainable agriculture in the whole state. The extraction of an array of industrial enzymes might lead to the establishment of relevant industries like bioethanol, detergent plats, etc. which may generate jobs in addition to use of agrowaste and other byproducts.

Furthermore, useful and efficient microorganisms could be protected from biopiracy and financial benefits could be generated through patent rights by constitution of Biodiversity Management Committees (BMCs) as per provisions mentioned U/S 41 of the Biological Diversity Act 2002 of Government of India. Section 41(1) of the Act says, “Every local body shall constitute a Biodiversity Management Committee within its area for the purpose of promoting conservation, sustainable use and documentation of biological diversity including preservation of habitats, conservation of land races, folk varieties and cultivars, domesticated stocks and breeds of animals and microorganisms and chronicling of knowledge relating to biological diversity.” In accordance with “Nagoya Protocol,” to which India is also a party, Government of India has notified “Guidelines on Access to Biological Resources and Associated Knowledge and Benefits Sharing Regulations, 2014.” Along the strength of these guidelines, the BMCs have to get the benefit sharing from the utilisation of any such microbial resources from the coastal sand dunes. As microorganisms cannot be viewed with naked eye, scientific investigations need to be carried out to explore the microbial diversity and preserve useful ones for their utility for specific purpose. Hence, a comprehensive effort is required for the enumeration of microbial diversity in coastal sand dunes of Odisha and the bioactive potential need to be exploited for various applications. The Forest Department of Odisha State has recently initiated efforts for such study through Odisha Biodiversity Board, Bhubaneswar. A project has been sanctioned for a comprehensive study on the flora, fauna, and microorganisms in the coastal sand dunes of Odisha. The outcome of the project may be utilized in the management plan of coasts by the State Government of Odisha.
Refereences

[1] P. A. Hesp, “Ecological processes and plant adaptations on coastal dunes,” *Journal of Arid Environments*, vol. 21, no. 2, pp. 165–191, 1991.

[2] T. Gaonkar, P. K. Nayak, S. Garg, and S. Bhosle, “Siderophore-producing bacteria from a sand dune ecosystem and the effect of sodium benzoate on siderophore production by a potential isolate,” *The Scientific World Journal*, vol. 2012, Article ID 857249, 8 pages, 2012.

[3] H. Wasserstrom, S. Kublik, R. Wasserstrom, S. Schulz, M. Schloter, and Y. Steinberger, “Bacterial community composition in coastal dunes of the Mediterranean along a gradient from the sea shore to the inland,” *Scientific Reports*, vol. 7, no. 1, Article 40266, 2017.

[4] S. R. Costa, B. R. Kerry, R. D. Bardgett, and K. G. Davies, “Interactions between nematodes and their microbial enemies in coastal sand dunes,” *Oecologia*, vol. 170, no. 4, pp. 1053–1066, 2012.

[5] C. García-Lozano and J. Pintó, “Current status and future restoration of coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea),” *Journal of Coastal Conservation*, vol. 22, no. 3, pp. 319–332, 2018.

[6] K. R. Sridhar and A. B. Arun, “Coastal sand dune vegetation and microbial resources: benefits, threats and safeguards,” in *Potential Macroorganisms for Sustainable Agriculture: A Techno-Commercial Perspective*, D. K. Maheshwari and R. C. Dubey, Eds., pp. 463–475, I.K. International Publishing House Pvt. Ltd., New Delhi.

[7] M. Jayaprakashvel, V. K. Kumar, J. Abideen, S. Swarnakala, M. Venkatramani, and A. J. Hussain, “Production of indole acetic acid and plant growth promotion by rhizobacteria from a less studied marine ecosystem,” *Biosciences, Biotechnology Research Asia*, vol. 11, pp. 179–185, 2014.

[8] R. Muthezhila, B. S. Sindhuja, A. J. Jaffar Hussain, and M. Jayaprakas, “Efficiency of plant growth promoting rhizobacteria isolated from sand dunes of Chennai coastal area,” *Pakistan Journal of Biological Sciences*, vol. 15, no. 16, pp. 795–799, 2012.

[9] A. B. Arun and K. R. Sridhar, “Symbiotic performance of fast-growing rhizobia isolated from the coastal sand dune legumes of west coast of India,” *Biology and Fertility of Soils*, vol. 40, no. 6, pp. 435–439, 2004.

[10] S. A. Khan, M. Hamayun, H. Yoon et al., “Plant growth promotion and *Penicillium citrinum*,” *BMC Microbiology*, vol. 8, no. 1, p. 231, 2008.

[11] S. A. Khan, M. Hamayun, A. L. Khan, I.-J. Lee, Z. K. Shinwari, and J.-G. Kim, “Isolation of plant growth promoting endophytic fungi from dicots inhabiting coastal sand dunes of korea,” *Pakistan Journal of Botany*, vol. 44, no. 4, pp. 1453–1460, 2012.

[12] A. Kedar, D. Rathod, A. Yadav, G. Agarkar, and M. Rai, “Endophytic *Phoma sp.* isolated from medicinal plants promote the growth of *Zea mays*,” *Nusantara Bioscience*, vol. 6, no. 2, pp. 132–139, 2014.

[13] S. Sangeetha, A. Jaffar Hussain, and M. Jayaprakashvel, “Antagonistic activity of salt tolerant actinobacteria against phytopathogens,” in *Abstracts of National Conference on Marine Environmental Challenges and Coastal Zone Management Strategy*, V. Manoharan, Ed., p. 12, Bharathidasan University Press, Trichirappalli, India, 2012.

[14] D.-S. Shin, M. S. Park, S. Jung et al., “Plant growth-promoting potential of endophytic bacteria isolated from roots of coastal sand dune plants,” *Journal of Microbiology and Biotechnology*, vol. 17, no. 8, pp. 1361–1368, 2007.

[15] M. A. Ferreira, J. P. Andrade, J. C. Santos, G. G. Lira, and R. P. Nascimento, “Cellulase production by *Penicillium* sp. strain IS-07 using agro-industrial by-products,” in *Microbes In Applied Research: Current Advances and Challenges*, A. Méndez-Vilas, Ed., pp. 372–376, World Scientific.

[16] D. De Beer, F. Wenzhöfer, T. G. Ferdeman et al., “Transport and mineralization rates in North Sea sandy intertidal sediments, Sylt-Rømø Basin, Wadden Sea,” *Limnology and Oceanography*, vol. 50, no. 1, pp. 113–127, 2005.

[17] S. Sarig, A. Fliessbach, and Y. Steinberger, “Soil Microbial Biomass Under the Canopy of Coastal Sand Dune Shrubs,” *Arid Land Research and Management*, vol. 13, no. 1, pp. 75–80, 1999.

[18] Y. Su, H. Zhao, Y. Li, and J. Cui, “Carbon mineralization potential in soils of different habitats in the semi-arid horqin sandy land: a laboratory experiment,” *Arid Land Research and Management*, vol. 18, no. 1, pp. 39–50, 2004.

[19] T. Rajaniemi and V. Allison, “Abiotic conditions and plant cover differentially affect microbial biomass and community composition on dune gradients,” *Soil Biology & Biochemistry*, vol. 41, no. 1, pp. 102–109, 2009.

[20] T. Chen, C. Chiu, and G. Tian, “Seasonal dynamics of soil microbial biomass in coastal sand dune forest,” *Pedobiologia*, vol. 49, no. 6, pp. 645–653, 2005.

[21] D. Probandt, T. Eickhorst, A. Ellrott, R. Amann, and K. Knittel, “Microbial life on a sand grain: from bulk sediment to single grains,” *The ISME Journal*, vol. 12, no. 2, pp. 623–633, 2018.

[22] Y. Lin, W. B. Whitman, D. C. Coleman, T. Chen, and C. Chiu, “Composition of bacterial communities in sand dunes of subtropical coastal forests,” *Biology and Fertility of Soils*, vol. 50, no. 5, pp. 809–814, 2014.

[23] E. Gaidos, A. Rusch, and M. Ilardo, “Ribosomal tag pyrosequencing of DNA and RNA from benthic coral reef microbiota: Community spatial structure, rare members and nitrogen-cycling guilds,” *Environmental Microbiology*, vol. 13, no. 5, pp. 1138–1152, 2011.

[24] A. Gobet, S. I. Böer, S. M. Huse et al., “Diversity and dynamics of rare and of resident bacterial populations in coastal sands,” *The ISME Journal*, vol. 6, no. 3, pp. 542–553, 2012.

[25] S. Sridharan, P. Madhanraj, S. Manorajan, and N. Nadimuthu, “An investigation of the mycoflora in the sand dune soils of Tamilnadu coast, India,” *Advances in Applied Science Research*, vol. 1, no. 3, pp. 160–167, 2010.

[26] M. W. Warren and X. Zou, “Soil macrofauna and litter nutrients in three tropical tree plantations on a disturbed site in Puerto Rico,” *Forest Ecology and Management*, vol. 170, no. 1-3, pp. 161–171, 2002.

[27] M. S. Park, S. R. Jung, M. S. Lee et al., “Isolation and characterization of bacteria associated with two sand dune plant species, Calystegia soldanella and Elymus mollis,” *The Journal of Microbiology*, vol. 43, no. 3, pp. 219–227, 2005.
[28] P. Kämpfer, P. D. Rekha, H. Busse, A. B. Arun, P. Priyanka, and S. P. Glaser, “Halomonas malpeensis sp. nov., isolated from rhizosphere sand of a coastal sand dune plant,” International Journal of Systematic and Evolutionary Microbiology, vol. 68, no. 4, pp. 1037–1046, 2018.

[29] S. E. Smith and D. J. Read, Mycorrhizal Symbiosis, Academic Press, San Diego, USA, 3rd edition, 2008.

[30] R. E. Koske and J. N. Gemma, “Mycorrhizae and succession in plantings of beachgrass in sand dunes,” American Journal of Botany, vol. 84, no. 1, pp. 118–130, 1997.

[31] L. Corkidi and E. Rincón, “Arbuscular mycorrhizal fungi in a tropical sand dune ecosystem on the Gulf of Mexico,” Mycorrhiza, vol. 7, no. 1, pp. 9–15, 1997.

[32] S. Rodriguez-Echenevéria and H. Freitas, “Diversity of AMF associated with Ammophila arenaria ssp. arundinacea in Portuguese sand dunes,” Mycorrhiza, vol. 16, no. 8, pp. 543–552, 2006.

[33] J. Blaszkowski and B. Czerwińska, “Arbuscular mycorrhizal fungi (Glomeromycota) associated with roots of Ammophila arenaria growing in maritime dunes of Bornholm (Denmark),” Acta Societatis Botanicorum Polonicae, vol. 80, no. 1, pp. 63–76, 2011.

[34] S. L. Stürmer, R. Stürmer, and D. Pasqualini, “Taxonomic diversity and community structure of arbuscular mycorrhizal fungi (Phylum Glomeromycota) in three maritime sand dunes in Santa Catarina state, south Brazil,” Fungal Ecology, vol. 6, no. 1, pp. 27–36, 2013.

[35] D. K. da Silva, C. M. Pereira, R. G. de Souza, G. A. da Silva, F. Oehl, and L. C. Maia, “Diversity of arbuscular mycorrhizal fungi in restinga and dunes areas in Brazilian Northeast,” Biodiversity and Conservation, vol. 21, no. 9, pp. 2361–2373, 2012.

[36] D. K. da Silva, R. G. de Souza, B. A. Velez, G. A. da Silva, F. Oehl, and L. C. Maia, “Communities of arbuscular mycorrhizal fungi on a vegetation gradient in tropical coastal dunes,” Applied Soil Ecology, vol. 96, pp. 7–17, 2015.

[37] K. R. Beena, K. Ananda, and K. R. Sridhar, “Fungal endophytes of three sand dune plant species of west coast of India,” Sydowia, vol. 52, no. 1, pp. 1–9, 2000.

[38] K. R. Beena, N. S. Raviraja, A. B. Arun, and K. R. Sridhar, “Diversity of arbuscular mycorrhizal fungi on the coastal sand dunes of the west coast of India,” Current Science, vol. 79, no. 10, pp. 1459–1466, 2000.

[39] V. R. Kamble, D. G. Agre, and G. B. Dixit, “Incidence of arbuscular mycorrhizal fungi in Indian Squill: Drimia indica from coastal sand dunes of Konkan, India,” Journal of Pharmaceutical and Biological, vol. 4, no. 3, pp. 31–36, 2012.

[40] B. Sadhana, “Arbuscular mycorrhizal fungal diversity in coastal region of manapadu near tiruchendur, tamil nadu,” International Journal of Pure & Applied Bioscience, vol. 3, no. 6, pp. 226–236, 2015.

[41] G. J. F. Pugh and G. E. Mathison, “Studies on Fungi in Coastal soils: III. An ecological survey of keratinophilic fungi,” Transactions of the British Mycological Society, vol. 45, no. 4, pp. 567–572, 1962.

[42] I. Gonzalez Gonzalez, Molecular fungal diversity and its ecological function in sand-dune soils [Doctoral dissertation], University of Manchester, 2015, https://www.research.manchester.ac.uk.

[43] T. Panda, P. K. Pani, N. Mishra, and R. B. Mohanty, “A comparative account of the diversity and distribution of fungi in tropical forest soils and sand dunes of Orissa, India,” Journal of Biodiversity, vol. 1, no. 1, pp. 27–41, 2017.

[44] T. Panda, “Some sugar fungi in coastal sand dunes of Orissa, India,” Journal of Yeast and Fungal Research, vol. 1, no. 5, pp. 73–80, 2010.

[45] T. Panda, “Penicillium abundance and diversity patterns associated with cashew plantations in coastal sand dunes, Odisha, India,” India. Of Ecology and the Natural Environment, vol. 3, no. 6, pp. 221–227, 2011.

[46] S. Ghate, K. Sridhar, and N. Karun, “Macrofungi on the coastal sand dunes of south-western India,” Mycosphere, vol. 5, no. 1, pp. 144–151, 2014.

[47] K. R. Sridhar, “Highlights on the macrofungi of south west coast of karnataka, India,” International Journal of Life Sciences, vol. A9, pp. 37–42, 2018.

[48] S. Ghate and K. R. Sridhar, “Spatiotemporal diversity of macrofungi in the coastal sand dunes of Southwestern India,” Mycosphere, vol. 7, no. 4, pp. 458–472, 2016.

[49] D. Wilson, “Endophyte: the evolution of a term, and clarification of its use and definition,” Oikos, vol. 73, no. 2, pp. 274–276, 1995.

[50] J. L. Azevedo, W. Maccheroni Jr., J. O. Pereira, and W. L. De Araújo, “Endophytic microorganisms: a review on insect control and recent advances on tropical plants,” Electronic Journal of Biotechnology, vol. 3, no. 1, pp. 15–16, 2000.

[51] Y. H. You, Y. Seo, H. Yoon et al., “Endophytic fungal diversity associated with the roots of coastal sand-dune plants in the sindu-ri coastal sand dune, Korea,” Journal of Microbiology and Biotechnology, vol. 41, no. 3, pp. 300–310, 2013.

[52] S. Seena and K. R. Sridhar, “Endophytic fungal diversity of 2 sand dune wild legumes from the southwest coast of India,” Canadian Journal of Microbiology, vol. 50, no. 12, pp. 1015–1021, 2004.

[53] I. Jakobsen, “Research approaches to study the functioning of vesicular-arbuscular mycorrhizas in the field,” Plant and Soil, vol. 159, no. 1, pp. 141–147, 1994.

[54] R. M. Miller and J. D. Jastrow, “Hierarchy of root and mycorrhizal fungal interactions with soil aggregation,” Soil Biology & Biochemistry, vol. 22, no. 5, pp. 579–584, 1990.

[55] J. M. Tisdall, “Fungal hyphae and structural stability of soil,” Australian Journal of Soil Research, vol. 29, no. 6, pp. 729–743, 1991.

[56] M. Jayaprakashvel, R. Priyima, and A. J. Hussain, “In Vitro biocontrol traits of rhizobacteria isolated from the coastal sand dune plants in Chennai, India,” International Journal of Advanced Research in Engineering and Applied Sciences, vol. 5, no. 2, pp. 1–11, 2016.

[57] J.-H. Lim, J.-G. Kim, and S.-D. Kim, “Selection of the auxin and ACC deaminase producing plant growth promoting rhizobacteria from the coastal sand dune plants,” Journal of Microbiology and Biotechnology, vol. 36, no. 4, pp. 268–275, 2008.

[58] T. Gaonkar, “Eubacterial siderophores and factors modulating their production,” in Bioprospects of coastal Eubacteria, S. Borkar, Ed., pp. 25–38, Springer, Cham, Switzerland, 2015.

[59] J. P. Andrade, A. S. D. R. Bispo, P. A. S. Marbach, and R. P. Do Nascimento, “Production and partial characterization of cellulases from Trichoderma sp. IS-05 isolated from Sandy Coastal plains of Northeast Brazil,” Enzyme Research, vol. 2011, Article ID 167248, 7 pages, 2011.

[60] S. Behera and B. Tripathy, “Review of current developmental activities and their possible impact on olive ridley sea turtles along the Odisha Coast of India,” Testudo, vol. 8, no. 1, pp. 38–55, 2014.
[61] T. Chakraborty, A. K. Mondal, and S. M. Parui, "Studies on the prospects and some problems of sand dune vegetation at the fragile coastal zones of West Bengal and Orissa, in Eastern India," *African Journal of Plant Science*, vol. 6, no. 2, pp. 48–56, 2012.

[62] C. Pattanaik, C. S. Reddy, and N. K. Dhal, "Phytomedicinal study of coastal sand dune species of Orissa," *Indian Journal of Traditional Knowledge*, vol. 7, no. 2, pp. 263–268, 2008.

[63] H. N. Thatoi, B. C. Behera, T. K. Dangar, and R. R. Mishra, "Microbial biodiversity in mangrove soil of Bhitarakanika, Odisha, India," *International Journal of Environmental Biology*, vol. 2, no. 2, pp. 50–58, 2012.

[64] N. Gupta, K. M. Bihari, and I. Sengupta, "Diversity of arbuscular mycorrhizal fungi in different salinity of mangrove ecosystem of Odisha, India," *Advances in Plant and Agricultural Research*, vol. 3, no. 1, p. 85, 2016.