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Review

Seaweed Biodiversity of India: Reviewing Current Knowledge to Identify Gaps, Challenges, and Opportunities

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Abstract: Seaweeds are a renewable marine resources and have not yet received considerable attention in the field of taxonomy in India as compared to their terrestrial counterparts, essentially due to the lack of awareness of their economic potential. Although the recent inventory from the Indian region documented the presence of approximately 865 seaweed taxa, of which only a few are taxonomically well characterized, more precise information still awaits with respect to microscopic and molecular examinations of many. Thus far, in terms of spatial extent, probably only a few of the total hospitable seaweed habitats have been explored, and large portions, including island territories and subtidal waters, remain virtually untouched. Surveying those may lead to the reporting of several taxa new to science. Furthermore, more focused efforts are required to understand the endemic and endangered taxa which have high conservation implications. Considering the unprecedented pressures seaweeds are facing, including coastal pollution and human-induced global warming, it is critical to reinforce our knowledge of seaweed biodiversity. In the present communication, we intended to address the status of seaweed biodiversity in India along with the gaps, challenges, and opportunities.

Keywords: biodiversity; conservation; cultivation; India; resource; seaweeds

1. Introduction

Seaweeds are gaining considerable importance in recent times due to the fact of their cosmopolitan distribution, renewable nature, and wide range of applications [1]. Harvests from wild populations coupled with simple cultivation technologies largely evolved in Asian countries which has made it a preferred biomass for emerging commodity goods. Seaweeds also render socio-economic advantages to the maritime rural population in the form of commercial aquaculture. In total, 291 seaweed species are commercially used worldwide across 43 countries [2]. Commercial harvesting of seaweeds has reached new milestone with 31.2 million tonnes year^{-1} production (95% accounts to farming) with a market worth US$ 11.7 billion [3]. Seaweeds, or marine algae, refer to three taxonomic groups that have different pigment composition: Chlorophyta (green algae), Rhodophyta (red algae), and Ochrophyta (brown algae). These groups are non-monophyletic having complex evolutionary life history strategies. The prevalence of cell wall matrix (sulphated polysaccharides) in their tissue makes this resource economically important. Its industrial utility essentially cuts across these high molecular weight polysaccharides also known as phycocolloids and their use as phycosupplement in nutraceutical market.

Biodiversity in a broad sense includes variation among life forms on this planet and is essential for human survival, as it sustains the health of the ecosystem, provides biological resources, besides representing culture and identity. The Convention on Biological Diversity (CBD) defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. Further this includes diversity within species, between species and of ecosystems as well" [4]. Biodiversity essentially enriches the productivity of an ecosystem where every taxa, even the smallest, has an important role to play. The myriad array of species ensures the natural sustainability and health of an ecosystem. Based on the higher taxonomic classification of species, Mora et al. [5] estimated the presence of ~8.7 million species, excluding bacteria and other microorganisms. The Catalogue of Life [6] has listed ~1.8 million species globally as valid and accepted. Whereas, according to World's Register of Marine Species (WORMS), the number of accepted marine species is ~0.23 million [7]. Biodiversity exploration studies have given critical attention in recent times to the steep decline in species, primarily due to the fact of anthropogenic-induced changes. The extinction rate currently is as high as 27,000 taxa per year [8]. Global changes, including human-induced climate change, pollution, overexploitation of natural resources, destruction of natural habitats, and invasive species are the main reasons for biodiversity loss worldwide. Despite impressively rapid growth of protected land and marine areas worldwide, biodiversity is still in peril [9].

India represents only 2%–4% of the world's land area but comprises 7%–8% of total known plant and animal taxa globally [10]. The country enacted the Biological Diversity Act in 2002 with an explicit mandate to encourage conservation of living resources for which the National Biodiversity Authority (NBA) was established in 2003. This was essentially due to the fact that India is the fourth out of thirty-four biodiversity-rich hotspots in the world, indicating a high degree of endemism [11]. The biogeographic zones here encompass an exemplary variation in ecological environments, ranging from grasslands, alpine forests, and desert to wetlands and coastal and marine habitats. The country is bestowed with a long coast-line of approximately 7500 km along with a sizable exclusive economic zone (2.5 million km^2) and a vast shelf area (0.13 million km^2). Seaweed, which is a renewable marine resource, has been underutilized essentially due to the lack of realization of its economic potential. The vast diversity of habitats, including estuarine mangrove vegetation, sandy beaches, rocky shores, deep tide pools, cliffs and caves, coral substrates and artificial offshore structures, provide ample support for diverse seaweed groups to thrive in intertidal and subtidal waters. India has reported the highest number of seaweed taxa compared to all the other nations bordering the Indian Ocean [12].

This current trend reveals that the numbers of species described by taxonomists are increasing worldwide. Recent comprehensive estimates of global algal diversity reported 72,500 taxa of which 44,000 have already been described, although separate figures for marine algae are not available [13]. The most comprehensive estimates for Indian waters reported that there are 841 seaweed species belonging to 216 genera of 68 families present in Indian waters (Table 1) [14]. However, recently Kaliaperumal [15] estimated 871 species from Indian waters. The aim of this review was to consolidate seaweed biodiversity information and identify gaps with recommendations for future research. It may also be noted that the scientific names used in this paper are as per the entitites in AlgaeBase (https://www.algaebase.org/search/species/detail/?species_id=173051) [16].

Table 1. Phylum-wise distribution of seaweed taxa in Indian waters.

Class	Order	Family	Genera	Species + Varieties	Total
Rhodophyta	16	36	136	406 + 28	434
Ochrophyta	6	13	37	159 + 32	191
Chlorophyta	7	19	43	179 + 37	216
Total	29	68	216	746 + 97	841

After Oza and Zaidi [14].

2. Current Knowledge on Seaweeds of India

2.1. History of Seaweed Research in India

Previous records showed that the first seaweed that had been, perhaps, described from the Indian Ocean was a specimen of *Amphiroa* (Rhodophyta) collected by Hermann in 1672 [12]. Linnaeus [17] further recorded *Turbinaria turbinate* (as *Fucus turbinatus*) and *Sargassum granulatum* (as *Fucus granulates*) (Ochrophyta, Phaeophyceae) from Indian waters. The authenticated report on seaweed collections made from Indian shores in 1767 by Köing—who came to this country as a missionary—is available [12]. Subsequently, in the 19th century, several international expeditions, namely, Novara (1857–1859), Challenger (1872–1876), Galathea (1890–1892), Investigator (1890–1892), and Siboga (1899–1900) enriched the seaweed collection in international herbaria. In the early 20th century, seaweeds were collected from Indian waters by various Europeans, but it was not until 1925 that an Indian phycologist, M.O.P. Iyengar, worked on the seaweed flora of Krusadai Island [18]. Fredrik Christian Emil Børgesen, the Danish Prince and a naturalist, visited the coast of the then undivided Hindustan and contributed substantially to describing the Indian seaweed flora [19–26].

Dixit [27] was the first to report a high number of seaweed species in India—411 species. However, this included records from Pakistan and Sri Lanka as well. Krishnamurthy and Joshi [28] provided the first comprehensive information on species distribution for Indian waters. They reported the occurrence of 522 species of seaweeds of which 130 species belong to Chlorophyta, 136 species to Ochrophyta, and 256 species to Rhodophyta. The subsequent checklist by Untawale et al. [29] reported 604 seaweed species of which 156 species belong to Chlorophyta, 141 species to Ochrophyta, and 307 species to Rhodophyta. The revised checklist by Oza and Zaidi [14] indicated the occurrence of 841 species of seaweeds along the Indian coast of which 216 species belong to Chlorophyta, 191 species to Ochrophyta, and 434 species to Rhodophyta. Nevertheless, the most recent floristic work, compiled by the Botanical Survey of India, enumerated the occurrence of 865 taxa from Indian waters of which 212 species belong to Chlorophyta, 211 to Ochrophyta, and 442 to Rhodophyta (Table 2). When compared to data from 1970, there is an increase of approximately 343 species over the last 45 years. Table 2 summarizes the data from five checklists of Indian seaweed flora published so far. The analysis of data very clearly shows that red algae are more diverse than green and brown algae. The abundance of red algal taxa, which inhabits deeper waters, indicates the dominance of subtidal floristics composition along the Indian coast. However, by considering the fact that red algae are dominant globally, more efforts are required to decifer the patterns of seaweed composition in India. Figure 1 represent the common seaweeds of Indian coast.

Table 2. The comparison of seaweed records reported by earlier workers.

Check list	Title	Chlorophyta	Ochrophyta	Rhodophyta	Total
Krishnamurthy and Joshi [28]	Genera	36 (21.56)	33 (19.76)	98 (58.68)	167
	Species	130 (24.90)	136 (26.05)	256 (49.04)	522
Untawale et al. [29]	Genera	44 (21.67)	39 (19.21)	120 (59.11)	203
	Species	156 (25.82)	141 (23.34)	307 (50.82)	604
Oza and Zaidi [14]	Genera	43 (19.90)	37 (17.12)	136 (62.96)	216
	Species	216 (25.68)	191 (22.71)	434 (51.60)	841
Sahoo et al. [12]	Genera	45 (20.36)	38 (17.19)	138 (62.44)	221
	Species	184 (23.89)	166 (21.55)	420 (54.54)	770
Rao and Gupta [30]	Genera	46 (19.65)	50 (21.37)	138 (58.97)	234
	Species	212 (24.51)	211(24.39)	442 (51.1)	865

Values in parenthesis are in percentage (%).

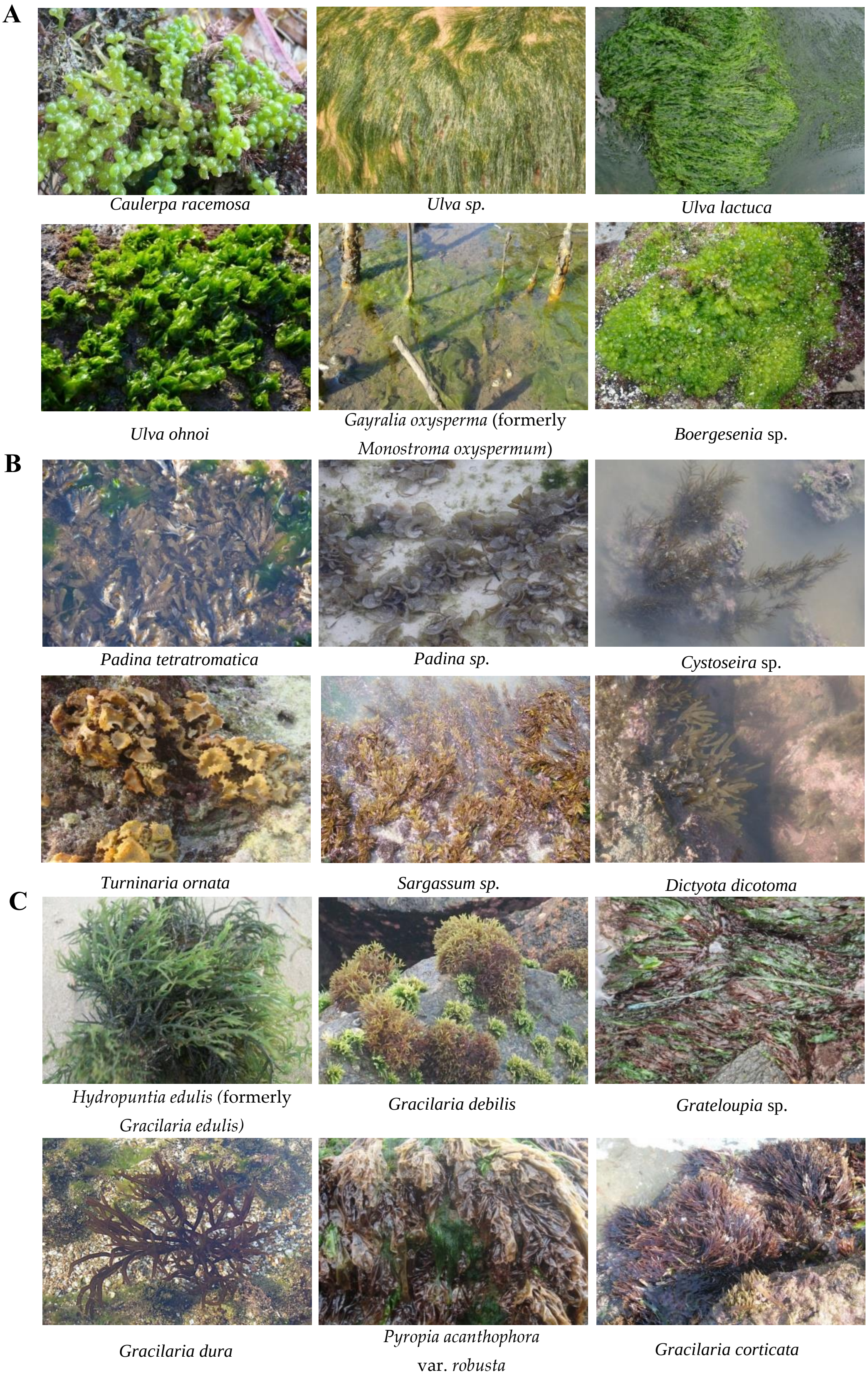

Figure 1. Common seaweeds of Indian coast, (**A**) Chlorophyta, (**B**) Ochrophyta, (**C**) Rhodophyta [Photo credit, Dr. Monica G. Kavale].

The regions of Gujarat and Tamil Nadu harbor the highest seaweed diversity [31]. Gujarat, which is represented by 1600 km coastline, harbours 198 species of which 109 species from 62 genera belong to Rhodophyta, 54 species from 23 genera to Chlorophyta, and 35 species from 16 genera to Ochrophyta [32]. Tamil Nadu has a 1076 km coastline. A recent survey encountered 282 species of which 146 were from Rhodophyta, 80 from Chlorophyta, and 56 from Ochrophyta [31]. A review of the literature revealed that there are several papers published on the taxonomy of seaweeds of the Indian coast, but one cannot claim to have sufficiently covered the entire coastline and to be in a position to compile its seaweed flora. Figure 2 provides decade-wise records on the description of new taxa of seaweeds from Indian waters starting from 1800 to 2019. The analysis revealed that there were two peaks The first, from 1930–1940, can be ascribed to the work carried out by Boergesen. The second peak, from 1980–1990, was due to the extensive floristic research carried out in the "Flora of India Project" funded by the Department of Science and Technology, and particularly by the work of Desikachary, Krishnamurathy, and Balakrishnan. Currently, the rate of new descriptions has decresed considerably, which can be attributed to the lower funding for taxonomic studies. Furthermore, such information for neighboring countries is not available in the public domain for comparison of floristic accounts.

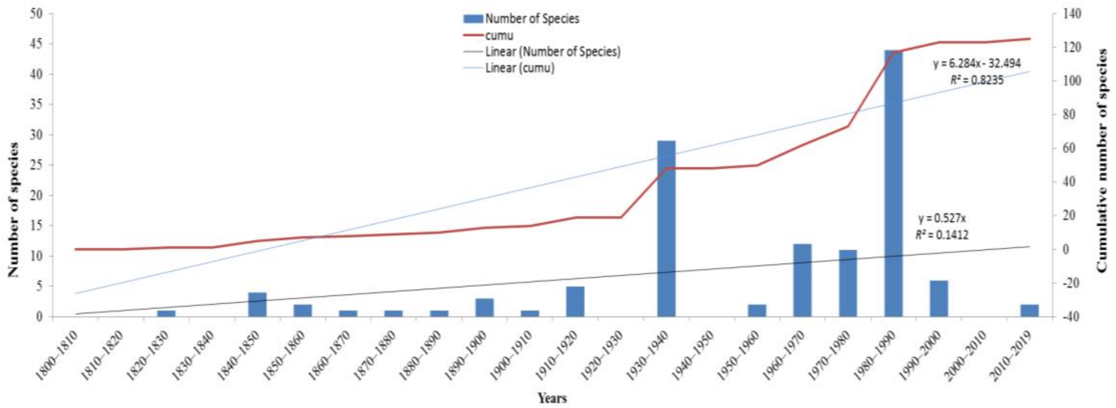

Figure 2. Decade-wise analysis related to the reporting of new taxa from Indian waters.

2.2. Estimates of the Conservation Status of Indian Seaweeds

At least 125 species seem to have a restricted distribution along the Indian coast, as they have never been reported outside the geographical territory of India [14]. These species have been classified as endemic taxa and need a more critical assessment for their taxonomy and conservation status. The species belonging to higher plants have received adequate and focused attention for conservation and, thus, get ample funding. Nevertheless, seaweeds, which are an important renewable marine resource, remain unattended. The lack of interest in these organisms can be well judged from the fact that not a single seaweed species has been included in the Red Data Book of Indian Plants [33]. The recent industrial development in the coastal states of India is already putting this neglected group of marine organisms in peril [34,35]. A recent study carried out by us has shown that the population of *Enteromorpha ovata* (Chlorophyta), occurring along the Gopnath coast, might need immediate conservation attention (authors' own observation). This species, which is endemic to Indian waters, has never been reported outside of its type locality. The Alang ship breaking yard, situated just 30 km north of Gopnath, Gujarat, India (Figure 3), has been exerting ecological pressure on this species, endangering its existence. Similarly, *Ulva beytensis* (Chlorophyta), originally reported in Beyt Dwarka, Gulf of Kutch (Figure 3), has never been encountered from its type locality, although repetitive exploratory surveys have been conducted. Our recent explorations to various islands have confirmed its presence in Kalubhar and Narara Island. The red alga *Claudea multifida* Harvey was discovered recently at depths of 8–10 m in the coral reefs of Mullai Island. An earlier collection of this species from the Indian coast was from Tuticorin, South India [36]. *Claudea multifida*, with its unique coral reef habitat, limited distribution, and rare occurrence, needs focused conservation efforts. However, such species need planned conservation programs. Initiatives from the government, NGOs, and other research institutions and universities should aim to provide more coverage and create awareness regarding such issues. Nevertheless, recent reports suggests that species such as *Cladophora sarcenica*, *Monosporus indicus*, and *Schizoseris bombayensis* (formerly *Myriogramme bombayensis*) (Rhodophyta) are presumably extinct [37]. It is also interesting to note that most common red seaweeds of industrial importance (i.e., *Hydropuntia edulis* (as *Gracilaria edulis*) and *Gelidiella acerosa* (Rhodophyta)) have become locally extinct from some of the islands of the Gulf of Mannar (Figure 3) due to the indiscriminate and unsustainable harvesting, whereas their natural resources existed in plentiful abundance a few decades ago [37]. Although, it is very important to understand how species respond to anthropogenic activities, previous studies were only taxonomic or floristic account (description of species). Ecological parameters, such as abundance, reproduction, distribution, etc., was not provided and, thus, a change in detection was not possible.

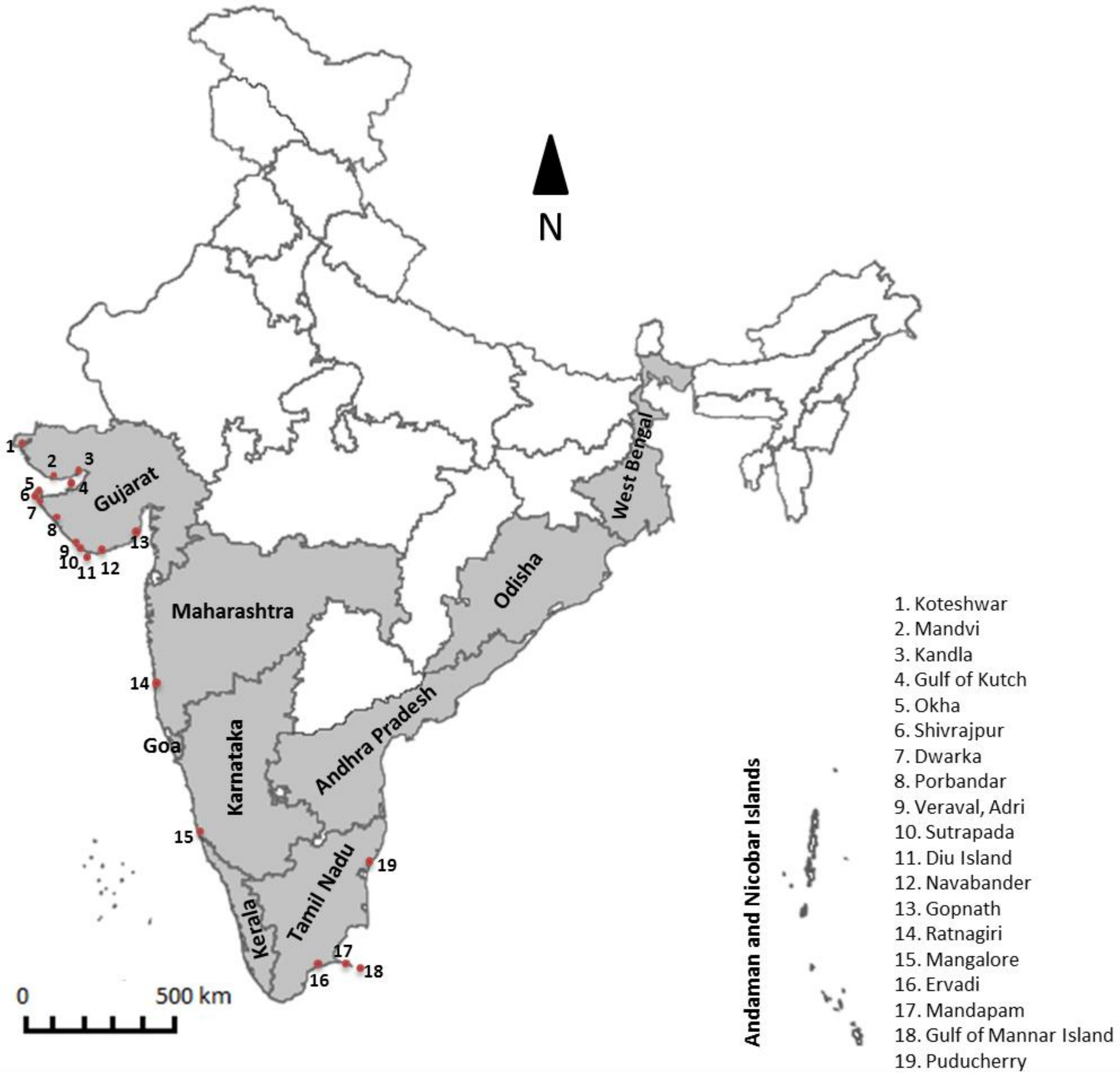

Figure 3. Different coastal states and sites surveyed for seaweed biodiversity in India.

2.3. Estimates of Seaweed Biomass in Indian Waters

The estimation of seaweed biomass is the prerequisite to realizing their economic potential. Several attempts have been made in the past to estimate the standing stock of seaweeds. Hornell [38] was the first to provide estimates of drifting *Sargassum* along the Okha–Mandal coast (Figure 3) of then Baroda state, wherein the presence of a considerable biomass along the Gulf of Kutch (Figure 3) region was reported. Similarly, later Chauhan and Krishnamurthy [39] estimated the fresh weight of *Sargassum* (Ochrophyta) from the same region confirming the availability of this important alginophyte. The earlier estimates (prior to 1962) were based on the regional surveys concentrated to the small pockets adopting spot surveying methods. However, a subsequently larger picture has emerged following the conscious efforts made to survey the entire Indian coast. The distribution of economically important seaweeds—more precisely alginophytes and agarophytes—along the Indian coast was first mapped by Thivy [40]. The more coordinated efforts by CSIR–Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI) along with different state and national agencies have yielded detailed mapping of seaweed resources [41]. The other union territories, namely, Puducherry, Daman, and Diu (Figure 3) remain far from such surveys.

The data for few other surveys for specific purpose are available, such as estimating drift seaweed, seaweeds of deep water submerged banks, and iodinophytes (iodine-rich seaweed). It was reported that a large quantity of seaweed biomass gets stranded and cast ashore during high wind and surf action, indicating the rich potential of seaweed growth along the particular location [41]. The drift seaweeds have shown to be excellent sources of certain phycocolloids and can be used for various other applications including green manuring (ploughing or turning of undecomposed material into the soil). An extensive survey was undertaken by CSIR-CSMCRI along five localities of the Indian coast during 1965–1966. The estimation of resources included Agarophytes, such as *Gracilaria* and *Hypnea*, and Alginophytes such as *Sargassum* and *Turbinaria*. A total standing seaweed biomass from a stretch of 343 km coastline was approximately 1260.18 tons (fresh weight) [42]. Further, drift exhibited marked seasonality in terms of quality and quantity. The study was conducted at Okha coast during May 2004 to April 2005 to document the seasonal variation in floristic composition drifted seaweed taxa and their biomass [43]. The stranded taxa consisted of a total of 62 species that included 26 belonging to Rhodophyta, followed by 22 belonging to Chlorophyta, and 14 belonging to Ochrophyta. The average biomass reported to be 3.10 kg fresh weight/m^2/month while 6.60 kg fresh weight /m^2 was the maximum biomass in April. The taxa from the genus *Sargassum* of Ochrophyta and *Caulerpa* from Chlorophyta were the two conspicuous genera of beach-stranded seaweeds.

Deep water submerged banks have been less explored [44,45]. The Angria bank (off Ratnagiri coast, Maharashtra), Cora Divh, Bassas de-Pedro, and Seassostris (off Mangalore coast, Karnataka) (Figure 3) are the only examples of such studies. The depths at these places range from 20–75 m deep. The calcareous forms, such as *Halimeda*, *Dictyopteris*, *Lobophora*, *Codium*, *Galaxaura*, *Asparagopsis*, *Hildenbrandlia*, and *Anadyomene* were the dominant forms reported from these locations. These seaweeds are a rich source of iodine. The estimates for the iodine-rich seaweed *Asparagopsis taxiformis* (Rhodophyta) have been available from two surveys. One survey was conducted from 1972–1973 at the Boria reef of the Gulf of Kutch as well as at Okha reef which recorded th availability of 12.15 tons (fresh weight) biomass from a 0.067 km^2 area [46]. The other survey was carried out in 1993 encompassing Gulf of Mannar islands (Figure 3), such as Krusadai, Shingle, Pulli–Pullivasal, Putty, Manali, Hare, Mully, and Valai island from which the availability of 61.54 tons (fresh weight) was estimated from a total of 6.23 ha of a potential area [41].

3. Seaweed Biodiversity Research Gaps and Challenges

3.1. Filling Geographic Gaps to Comprehensively Document Species Diversity and Biomass

Although extensive literature exists on the distribution and diversity of seaweeds from Indian coasts starting from the eighteenth century, not much is known about recent changes. A recent checklist has reported the occurrence of 841 taxa; however, much of this knowledge is secondary information coming from various sources published over a vast time period and, therefore, does not confirm taxonomic validity of taxa nor comment on recent advances. Some of the recent surveys reported on the number of species from different maritime states, e.g., Ganesan et al. [28] reported 282 species from Tamil Nadu. Muthuvelan et al. [47] reported 80 species from the Andaman and Nicobar Islands; Mukhopadhyay and Pal [48] reported 14 species from the West Bengal coast; Sahoo et al. [49] reported 14 species from the Odisha coast; Mantri and Subba Rao [50] reported 70 species from Diu island; Jha et al. [32] reported 198 species from the Gujarat coast; Sonali [51] reported 240 species from the Maharashtra coast; Kaladharan et al. [52] reported 78 species from Karnataka; and very recently, Kamboj et al. [53] reported 151 species from the Gulf of Kutch (Gujarat) (Figure 3). A current and precise assessment of the seaweed biodiversity is essential to infer the changes which have taken place in relation to pollution, overexploitation of natural resources, climate change, recent introductions, and bio-invasion. The CSIR-CSMCRI performed a seaweed biodiversity assessment program along the entire Gujarat coast [32]. A total of 15 sampling stations, namely, Gopnath, Navabander, Kotada, Sutrapada, Veraval, Adri, Porbandar, Dwarka, Shivrajpur, Okha, Kandla, Mandvi, Koteswar, and Samiyani Island (Gulf of Kutch) (Figure 3) were selected along the coastal belt. Each station was visited monthly during the lowest spring tide from December 2005 to December 2008. The geographical co-ordinates were recorded while each sampling along with the in situ photographical evidence in its natural habit for each seaweed taxa collected. In all, 198 taxa belonging to 101 genera were reported. Of these, 24 species were new to the Gujarat coast and three, namely, *Solieria chordalis, Ahnfeltia plicata* (Rhodophyta), and *Dictyopteris serrata* (Ochrophyta) were reported from Indian coasts for the first time. The Rhodophycean members outnumbered other groups with a record of 109 species from 62 genera, followed by members of Chlorophyta with 54 species from 23 genera, and Ochrophytawith with 35 species from 16 genera [32]. This survey confirmed the presence of industrially important taxa, namely, *Gelidiella acerosa*, *Gelidium micropterum*, *G. pusillum*, *Ahnfeltia plicata*, *Gracilaria dura*, *G. debilis*, *Gracilariopsis longissima* (formerly *G. verrucosa*), *Hypnea musciformis*, *Meristotheca papulosa*, *Porphyra* sp, *Asparagopsis taxiformis* (Rhodophyta), *Sargassum tenerrimum*, *S. plagiophyllum*, *S. swartzii*, *Turbinaria ornate* (Ochrophyta), *Ulva prolifera* (formerly *Enteromorpha prolifera), Ulva compressa* (formerly *Enteromorpha compressa)*, and *Ulva flexuosa (formerly Enteromorpha tubulosa)* (Chlorophyta) from the coastal waters of Gujarat. This study also confirmed the presence of ecologically important species such as *Caulerpa fastigiata* f. *delicatula*, *Enteromorpha ovata* (Chlorophyta), *Sargassum swartzii*, *Grateloupia indica*, *Helminthocladia clavadosii* f. *indica*, *Odontothalia veravalensis*, and *Predaea feldmannii* var. *indica* (Rhodophyta) which are endemic.

Although much of the data on diversity and distribution of Indian seaweeds has been available, the published records revealed that information is largely based on only a few selected locations. This is apparently due to the bias in selecting these localities either due to the easy access to these place or due to the limited funding avenues to the researchers. The islands and much of the interior portion still need to be explored to comprehensively describe the seaweed biodiversity. The CSIR-CSMCRI initiated the program to document the seaweed biodiversity of Diu Island during April 2002 to March 2004. The survey covered the pre-monsoon, monsoon, and post-monsoon season and recorded 70 different seaweed species from this tiny island. The high potential of seaweed diversity can be seen from the occurrence of 17% of the total seaweed flora of the west coast from this island having only 0.6% coastal land mass [50]. The other unexplored areas are the islands of the Gulf of Kutch for which an extensive survey was undertaken by the CSIR-CSMCRI in 2009. The survey in Kalubhar Island, which is one of the largest islands, representing a 500 ha area, reported the presence of nearly 96 seaweeds, of which 14 were new records to the Indian coast (CSIR-CSMCRI, unpublished data). The most updated data on seaweeds of Gulf of Kutch come from a survey carried out during 2013–2015 by the Gujarat Ecological Education and Research Foundation, Gandhinagar [53]. A total of 151 species belonging to 80 genera and 44 families were identified from 23 intertidal areas. Chlorophyta was represented by 14 families, 18 genera, and 44 species; Ochrophyta by 6 families, 18 genera, and 31 species; and Rhodophyta by 22 families, 44 species, and 76 species [53]. The survey in Samiyani Island which is situated at the mouth of Gulf of Kutch reported the occurrence of 28 seaweed species belonging to 19 genera. The collection has been carried out only during one hour limited exposure, the high species diversity also revealed presence of two new records [54,55]. *Caulerpa lentillifera* (Chlorophyta), a commercially important food algae, has been rediscovered from this island after the gap of half century [55]. A new species of the economically important seaweed *Porphyra indica* (Rhodophyta) has been described from Boriya reef, Gulf of Kutch [56]. These important discoveries pointed out the potential, necessity, and urgent need to intensify the effort to survey the unexplored areas so as to realize the true wealth of our country. Recently, the Gulf of Mannar Bioreserve Trust and Tamil Nadu sponsored the project for CSIR-CSMCRI to decipher and document the seaweed diversity of island of Gulf of Mannar. The work is under progress.

The estimated availability of seaweeds biomass for the entire coast corresponded to 677,308.87 to 682,758.87 tons (fresh weight) which is nearly 3.4% of the global seaweed resource [41]. However, most of the figures mentioned during these studies derived from various surveying methods. Therefore, a new scientific approach to estimate seaweed biomass, such as remote sensing techniques, needs to be applied to arrive at the correct picture. A major networking program needs to be urgently initiated. However, such information from other coastal areas of India is still lacking, and it is crucial to undertake such a survey at the pan-India level but generous funding is required to achieve the task. A project of such magnitude also needs close collaboration of different research organisations with domain expertise. The outcome of such an exercise would not only be helpful in discovering new taxa but would essentially help in developing conservation policies.

3.2. Improving Data Access to the Scientific Community

Each passing day is adding a large pool of information to the existing knowledge on seaweed biodiversity. However, except for international publications, much of the information of national importance is available in the grey literature. The taxonomic work carried out in developing countries is generally published in journals having a domestic scope that are seldom abstracted and, thus, remain inaccessible to peers. The taxonomic revision, validation, and proposed changes in such manuscripts are frequently unrecognized and ignored by the scientific community. The information regarding Indian seaweed research is not yet available in the digital form. Seaweed Research Utilization—the only dedicated research journal where national researchers prefer to publish their findings - can be accessed in print form alone. The benefits from open access publication for authors as well as for the society appear apparent. Authors gain broader recognition for their work among their peers as the online data are freely accessible. The biodiversity informatics is also an emerging science and efforts have already been initiated in such endeavour. Census of Marine Life (CoML) is a global association of researchers encompassing over 80 nations. The researchers are making the information accessible regarding the abundance, diversity, and distribution of marine life forms and subsequent changes over the period of time [57]. Ocean Biogeographic Information System (OBIS) is yet another net-work of researchers from 500 institutions of 56 countries. It is initiated from CoML sponsored Benthic Census Meeting held in 1997 under The Intergovernmental Oceanographic Commission of UNESCO's (IOC-UNESCO) International Oceanographic Data and Information (IODE) programme in 2009 [58]. The first OBIS data base was started from Rutgers University, USA and subsequently in 2001 was linked as an associate participant with Global Biodiversity Information Facility (GBIF). CSIR-NIO has taken the initiative to organize first workshop on coastal and marine biodiversity in December 2003. The participants from countries bordering Indian Ocean region proposed to develop Indian Ocean Gateway to OBIS [59]. Another such proposal endorsed was to develop electronic catalogue of Indian Ocean biota and digitization of marine biological collections. CSIR-NIO has recently initiated such efforts to digitize the seaweed collection housed in their reference center under the program entitled bio search: Marine biodiversity data base of India [60]. Although this initiative is welcome, the information provided along with the digital herbarium is rudimentary and there is need to integrate more information on the distribution, application, utility, diagnostic characters, ecology, conservation status and available published literature. The international effort by Michael Guiry, National University of Ireland, AlgaeBase [16] is worth mentioning. Currently it holds data base of 155,873 species and intraspecific taxa, 21,985 images, 60,250 bibliographic items, 439,687 distributional records. The Ryan Institute, National University of Ireland, Galway, and the Flanders Marine Institute have been continuously developing AlgaeBase as part of a collaborative program. A similar kind of data base needs to be developed for Indian seaweeds that can be linked to AlgaeBase for easy access of regional information to the international seaweed community for better visibility. However, with several institutions involving in the taxonomic research, uniformity has to be maintained while developing the data base. In order to accelerate such efforts to computerize the biological collections in India, CSIR-National Chemical Laboratory (NCL), Pune, has recently developed digitization software SAMPADA [61]. It is cost-efficient, easy to use, and has interoperable tools to digitize seaweed collections located in the institutions across India. Nevertheless, in a recent initiative from Central University of Punjab, Bathinda "DbIndAlgae", a freely accessible on-line database of marine algae of India has been developed [62]. This represents the first initiative of digitizing marine algae database for identification and cataloguing aimed at easy access and effective dissemination. As of 26 July 2019, DBIndAlgae encompasses entries of 51 species of marine algae belonging to 28 genera of Indian records divided into three phyla, namely Ochrophyta (Phaeophyta), Chlorophyta and Rhodophyta. The database gives details regarding unique user ID (UUID), classification, distribution, image, DNA sequence data, and description along with key references [62].

3.3. Expertise Short-Cut and the Need for Capacity-Building and Nationwide Expertise

India is recognized among the 12 mega-biodiversity countries worldwide and, thus, bestowed rich with biological wealth. The loss of biodiversity in the developing countries like India is always associated with infrastructure and development related projects; however, it is equally true that it can be accompanied with a loss of expertise necessary for identifying and inventorying the biota. The retirement of taxonomic specialists, shifts in academic recruitment and reductions in graduate training all contribute to diminish the knowledge that is needed to thrive the fast depleting subject expert.

Marine botany is a long-neglected subject in India and seaweeds as part of it are no exception to this. There are only two universities in our country offering course in phycology at the post-graduate level, although phycology remains the one of the core botany subject taught at many other academy institutions and universities. The meagre funding for full-fledged taxonomy and inventory related projects in phycology also dampen the enthusiasm of researchers. The historical perspectives clearly shows that during 1940–1970 seaweed taxonomy work in India was actively undertaken and several monographic accounts brought out and published by conscious efforts initiated by Indian institutions mainly Indian Council of Agricultural Research (ICAR), New Delhi. The Phaeophyceae in India was published under this initiative [63]. The first Checklist of Indian Marine Algae has been published by CSIR-CSMCRI [28]. The Madras Science Foundation has also brought out two volumes of monographic account of Rhodophyta [64,65]. Recently, a voluminous account of green algae: *Algae of India and neighbouring countries I: Chlorophycota* has been brought by Oxford Publication, New Delhi [66]. However, more recent efforts have shown a reverse trend, with much emphasis on application, two volumes brought out by CSIR-CSMCRI entitled 'Recent advances on applied aspects of Indian marine algae reverberated the need for taxonomy-oriented research [67,68]. A workshop on taxonomy of seaweeds has been jointly organized by CSMCRI-Marine algal Research Station, Mandapam Camp, and Krishnamurthy institute of Algology, Chennai on 17–21 November, 2010 at MARS, Mandapam. 15 participants from different colleges and universities have participated in this workshop. V. Krishnamurthy, Director, Krishnamurthy Institute of Algology, Chennai along with M. Umamaheswara Rao gave various lectures on diversity of seaweeds. The participants were given the hands on training on identification of different algal groups. More recently, Botanical Survey of India, Southern Regional Center has conducted National Workshop entitled 'Advance Trends in Marine Macro Algal Taxonomy, Cultivation and Utilization' during 21–25, October, 2019. 20 participants from several research institutes across the country have taken part in this important event. The initiative was the part of "All India Coordinated Project on Capacity Building in Taxonomy" in the thematic areas by Ministry of Environment, Forest and Climate Change, Government of India. Although such efforts are welcome in addressing the issues of diminishing taxonomy expertise, more such training programs would create awareness on implications of taxonomic studies and encourage young researchers to take up this subject. The participants from several regional institutions and universities would also form a network to achieve more tangible results. Funding in this area is essential for capacity building of the younger generation of researchers.

3.4. Developing Integrated Taxonomy

The taxonomic concepts of each group are evolving quickly with the advent of molecular biology techniques. Several studies are indicative of the fact that classical taxonomic criteria used traditionally for arriving at correct taxonomic identification might not be reliable due to the structural variably. The taxonomy of several seaweeds is challenging because of the simple structures, extraordinary plasticity in morphological features, and great diversity of taxa [69]. Species delineation in many seaweed groups is difficult due to the limitations of distinct morphological, anatomical and reproductive characteristics [70]. The monographic taxonomic treatment has been given to few taxa from Indian waters namely *Ulva* and *Enteromorpha* (later now being considered as synonymous to former), *Caulerpa*, *Sargassum* and *Gracilaria* [71–76]. However, conventional diagnostic characters alone are of limited use to arrive at correctly identifying the species. The use of DNA taxonomy not only helps to unravel classification but also help in elucidating evolutionary relationships between organisms. In India, only a few attempts have been made using molecular techniques to unravel the diversity of seaweeds. Parekh et al. [77] have characterized and established the systematic position and phylogenetic delineation of nine species of *Gracilaria* from Indian waters. The study effectively used different molecular markers belonging to separate genomic regions for inferring the phylogeny such as nucleotide sequences of nuclear-encoded SSU rRNA (i.e., 18S rRNA) gene, mitochondrial *cox*2–3 spacer, and chloroplast-encoded RUBISCO spacer. Kavale et al. [78,79] have studied the genus *Pyropia* from the western coast of India by morphological and molecular approach and reported a new variety, *P. acanthophora* var. *robusta* (Rhodophyta). In another study, identification as well as phylogeny based on molecular data of *Caulerpa* from India was inferred using *tuf*A, *rbc*L, 18S rDNA and ITS rDNA sequences [80,81]. Eleven distinct taxa were identified. Further, datasets supported the sister relationship between *C. veravalensis* and *C. cylindracea* (formerly *C. racemosa* var. *cylindracea*) (Chlorophyta). It was also confirmed that *C. microphysa* (formerly *C. racemosa* var. *microphysa*) and *C. lentillifera* (Chlorophyta) could not be proposed as separate taxa. Two species *C. serrulata* and *C. cupressoides* were successfully resolved using ITS rDNA phylogenetic analysis and 18S rDNA insertion sequence alignment [81]. The study also showed the separate species position for the Indian specimen of *C. peltata* [81]. The DNA taxonomy also helped in identifying two new species of genus *Ulva*, *U. chaugulii* [82] and *U. paschima* [83] from Indian shores. However, *U. paschima* is now regarded as synonym of *U. tepida* [16]. The presence of *U. ohnoi* [82] and *Ulvella leptochaete* [84] in Indian water was also substantiated by molecular analysis. Molecular study of the genus *Ulva* from India (Kazi, 2016) also supported the proposition of *U. fasciata* as junior synonym to *U. lactuca* by O'Kelly et al. [85]. However, these were stand only studies, where a molecular approach was successfully used to address taxonomic problems and more such attempts are required to understand the correct identity of taxa.

4. Opportunities to Develop Seaweed Cultivation and Sustainable Exploitation in India

Seaweeds are the only sources of industrially important thickening agents and gels such as, agar, carrageenan and alginates, which are of wide commercial value. They are also a source of fine chemicals such as natural pigments, manitol, iodine and cosmetic and therapeutically active products. While giving the growing emphasis on utilization of natural materials and the squeeze for land, the demand for seaweeds will probably increase in the coming years. The seas around India have not been used for economic gains to the extent possible except for fishing. The marine capture fisheries in India have been rapidly depleting due to over exploitation and threatening the very livelihood of more than 6 million fishers in India. The CSIR-CSMCRI has considerable expertise on bio-prospecting of Indian seaweeds since the 1960s. The added value work coupled with development of improved cultivation technologies has opened up renewed employment opportunities in the seaweed based industries in India in recent years.

The studies have shown that protoplast (cell devoid of cell wall) and tissue culture of seaweed are the two important micro-propagation techniques employed for multiplication of elite germplasm (having desired agronomic or economical traits). These techniques are routinely highlighted as the means to develop elite clones and seedling production strategy for seaweed aquaculture. It would be rather prudent to develop a seed bank utilising these methods for long term maintenance of some of these species catering need of elite germplasm for commercial farming. Furthermore, these techniques will be helpful for immediate conservation attention, such as *Gelidiella acerosa* which has been locally become extinct due to high demand [86]. The successful cultivation from tissue culture progeny has been achieved very recently [86].

Seaweeds are globally being used for the production of phycocolloids. In India, about 46 seaweed based industries—21 agar and 25 alginate—form the phycocolloid business [41]. The limited potential of Indian seaweed industry is partly due to the non-availability of elite germplasm and the absence of refined cultivation technologies. However, several recent innovative technologies have been developed by CSIR-CSMCRI of which worth mentioning is the bio-prospecting of Indian agarophytes. The agarose having gel strength >1900 g/cm^2 in 1% gel from *Gracilaria dura* has been developed by an eco-friendly method [87,88]. Simultaneously, the method of mass cultivation from vegetative fragments as well as spores has also been developed for this algae, by identifying the fast growing tetrasporophytes with high yield [89,90]. It is also noteworthy that the cultivation method neither requires any irrigation water nor any fertilizer. It also helps oxygenate the seawater and functions as a CO_2 sink.

4.1. Cultivation of Ulva flexuosa Wulfen *and* U. lactuca Linnaeus

Cultivation of these species under laboratory, outdoor and field conditions have been established at Okha (Figure 3) by using swarmers (those attached to nylon threads) cultured in enriched seawater [91,92]. A biomass of 996–1350 g (fresh weight)/m^2 area of pool was obtained, while 21.6%–26.5%/day growth rate was recorded for a period of 33–38 days (Table 3). The technology enables the cultivation practice to be carried out throughout the year but the optimum temperature shall be in the range of 17–32 °C. Approximately10–12 harvests per year can be obtained with a combined yield of 12.38 tons dry weight harvests per year [91].

The studies on the swarmer production and cultivation of *U. fasciata* (Now *U. lactuca* after Kazi, et al. [82]) along Okha coast were attempted by Oza et al. [93]. The profuse swarmer production was observed near new and full moon periods. The cultivation was attempted on the fishing nets at the 0 to 2.2 m seawater level in the intertidal region. The biomass production ranged between 829.9 g (fresh weight) m^{-2} to 404.2 g (fresh weight) m^{-2} during the 11 week growth experiments [93]. In another experiment, which was carried out along the Diu coast (Figure 3) during winter/spring months of 1995–1996. The biomass yield varied from 183 to 1040 g (fresh weight) m^{-2} [94]. However, these experiments required sexually mature plants for seeding and their unavailability in the field is a major impediment for expanding the experimental cultivation to commercial scale. Mantri, et al. [95] have developed a technique wherein induction of zoospore can be achieved by tinkering salinity and temperature. The optimum salinity and temperature requirement for zoospores induction was found to be 15 psu and 25 °C respectively. The optimum regeneration (78.53% ± 10.05%) was recorded at 25 °C temperature and salinity of 30 psu. The maximum daily growth rate (16.1% ± 0.28%) was recorded at 25 °C under 30 psu salinity (Figure 4A).

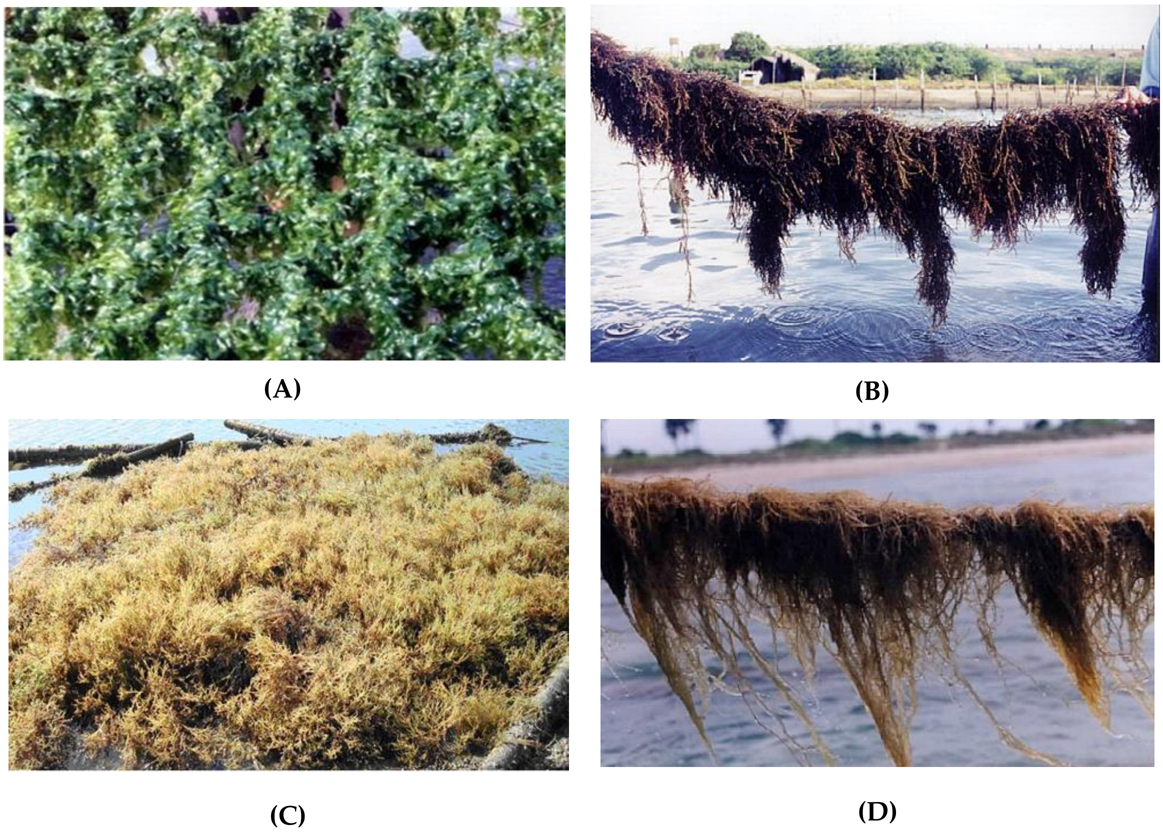

Figure 4. Cultivation of seaweeds. (**A**) Cultivation of *Ulva* on net. (Photo credit: R.M. Oza) (**B**) Cultivation of *Hydropuntia edulis* by long line rope method. (Photo credit: M. Ganesan) (**C**) Cultivation of *Hydropuntia edulis* by raft method. (Photo credit: M. Ganesan) (**D**) Cultivation of *Hypnea* by long line rope method. (Photo credit: M. Ganesan).

4.2. Cultivation of Hydropuntia edulis (as Gracilaria edulis)

Hydropuntia edulis is one of the important agarophytes of Indian coast commercially being exploited in the southern coast. Ganesan et al. [96] have reported the overexploitation of this seaweed from the Tamil Nadu coast, which ultimately might result in denudation of this natural resource. *H. edulis* along with *Gelidiella acerosa* have been commercially harvested and processed for extraction of agar in India. The high demand of raw material for industrial utilisation has prompted CSIR-CSMCRI to develop cultivation technologies for this seaweed. Initially two methods, namely the long-line rope method [96,97] (Figure 4B) and single-rope floating raft techniques (SRFT) [98] were suggested for the cultivation of *H. edulis* in open waters and shallow lagoons. In these methods, apical vegetative fragments, approximately 3–4 cm. long, are used as seed material for planting on coir/polypropylene rope. The biomass yield from the long line, rope method had been reported to be 20 tons dry weight. $ha^{-1}y^{-1}$ in 3 harvests and 30 tons dry weight from SRFT method in 4 harvests [98]. Ganesan et al. [96] had tried floating raft technique to improve biomass production in *G. edulis* along the Tamil Nadu coast. The biomass yield ranged between 1.5 to 2.6 kg fresh weight. m^{-2} while daily growth rate ranged from 2.6% to 7.4%/day during January–February. The experiments in subtidal waters have produced significantly higher biomass (12.5 ± 0.9 kg fresh weight. m^{-2}) and daily growth rate (DGR) (7.4% ± 0.4%/day) compared to the intertidal region (Figure 4C).

4.3. Cultivation of Gelidiella acerosa (Forsskål) G. Feldmann et Hamel

Various methods namely coral block, cement block, raft, and bottom net have been evaluated for the culture of *Gelidiella acerosa* in the open sea. The long line method had yielded about 3.13 g (fresh weight) m^{-2} in 130 days of the cultivation experiments carried out during 1972–1973 [99].

While in single rope floating raft technique, an average crop yield of 58 g (fresh weight) m^{-2} was recorded. The average crop yield of 210 g (fresh weight) m^{-2} $year^{-1}$ in two harvests was reported in net culture method. For experiments conducted during the year 2000 at the CSIR-MARS farm in Erwadi (Figure 3) using dead coral stones (natural substrata) and solid cement stones, an average crop yield of 1735 g (fresh weight) m^{-1} and 1955 g (fresh weight) m^{-1} respectively was reported [100]. The highest yield of 367 ± 45 g (fresh weight) m^{-2} was reported in 180 days of cultivation at southeastern coast of India through the bamboo raft method [101]. Furthermore, an innovative suspended stone (SS) method was developed by Ganesan et al. [101] for achieving higher biomass yield. The biomass production was steadily augmented from the first to subsequent harvests which ranged from 528 to 3645 g (fresh weight) m^{-2}. The daily growth rate was increased exponentially from 1.33% to 2.62% in four harvest recordings. The frequency distribution of the weight of an individual plant in the SS method was improved continuously in subsequent crops and 5% of the plantings, in the fourth harvest the biomass increased to 200–250 g fresh weight. Thus in situ propagation using the SS technique could be a feasible choice for preservation and large-scale cultivation in the sea.

Table 3. Economical important seaweeds and their cultivation in India.

Name of Marine Algae	Use	Method of Cultivation	Place of Cultivation	Year	DGR/ Day (%)	Biomass Yield in g (Fresh Weight) m^{-2}	Reference
Ulva flexuosa	Antibacterial activity	In Plastic pools (attached to nylon threads)	Okha	1981	21.6–26.5	996–1350	[91]
Ulva lactuca	Food	Seeding of spore suspension on nets	Okha	1983	-	829.9	[93]
Ulva lactuca	Food, Antiviral activity	Seeding of swarmer suspension on nets	Diu	1995–1996	-	183–1040	[94]
Hydropuntia edulis	Food grade agar	Long-line rope method	Ervadi, southeast coast of India	2006–2009	2.6–7.4	1500–2600	[96]
Hydropuntia edulis	Food grade agar	Long-line rope method	Krusadai Island	1967–1968	-	25.5–30.0	[97]
Hydropuntia edulis	Food grade agar	Single rope floating raft technique	Krusadai Island	1988–1989	4–5	-	[98]
Gelidiella acerosa	Bacteriological grade agar	Coral stone	Ervadi	1979	-	3.13	[99]
Gelidiella acerosa	Bacteriological grade agar	Suspended stone method	Ervadi	2004–2006	1.33–2.62	367 ± 45	[101]
Hypnea musciformis	Carrageenan	Single Raft Floating Technique		2001–2003	7.6–10.9	403	[102]

4.4. Cultivation of *Hypnea musciformis* (Wulfen) Lamouroux

Cultivation of this indigenous carrageenophyte has been attempted along the southeast coast of India for 21 months from June 2001 to February 2003 [102]. The polypropylene and coir ropes were used as cultivation substrata and the effect of seedling density, depth of water and duration of culture period was registered. The highest biomass yield of 403 g (fresh weight) m^{-2} was recorded in August, while the increasing trend in biomass yield was observed along with an increase in seedling density. The surface water was found to stimulate growth more than the deeper water while duration of the cultivation period was not a limiting factor in *H. musciformis*. The biomass yield and DGR were consistently higher on coir rope compared to the polypropylene rope during all culture months (Figure 4D).

4.5. Issue related to *Kappaphycus* cultivation in India

Seaweed harvest worldwide through intervention of farming technologies has augmented from 2 million fresh weight t in 2000 (21% accounts for production by farming) to close-to 9 million fresh weight t in 2010 (47%). However, business centric farming in tropical waters has resulted in enhanced production of *Kappaphycus* and *Eucheuma* from 0.94 million fresh weight. t in 2000 (48% of total red seaweed cultivation) to 5.6 million fresh weight t in 2010 (63%) [103]. India is among the largest importers of carrageenan in the world and thus should take the advantage of its warm waters to cultivate tropical carrageenophytes like *Kappaphycus*. The entire farmed biomass today in India has emanated from a small piece of *K. alvarezii* (then known as *K. striatum*), of Philippines origin, acquired from Japan by CSIR-CSMCRI in 1984. It may be noted that all the procedures regarding to introduction and quarantine were followed. During the laboratory acclimatization and culture, the alga has produced asexual propagules [104]. Although the mother plant died, the plants have germinated from these propagules in laboratory cultures, which have been then introduced in the sea in confined conditions following the FAO guidelines employing perforated polythene bag method in Okha, Gujarat [105,106] and later in Mandapam, Tamil Nadu [107–109]. This method has been then dispensed with as the alga had, by then, been reported from Indian waters the Red Skin Island, South Andaman (Figure 3) [110]. Domestic growth was impressive (489% increase), from over 20 t dry weight in 2001 to about 1490 t in 2013 with concomitant purchase value of < 4.5–35 Rs./kg(dry) [110]. Currently bamboo raft method, tube net method and monoline or long line method are adopted for commercial cultivation of this alga along the South east and Gujarat coast. India is fast emerging as an important production center in Southeast Asia for *K. alvarezii* production with estimated 765,000 man-days of employment, having an annual turnover of around Rs. 2 billion [111].

Recently, new technologies have been developed including integrated method for production of carrageenan and liquid fertilizer from fresh *Kappaphycus* biomass [112], low sodium salt of botanic origin [113], process of preparation of biodegradable films from semi refined kappa-carrageenan [114] and a process for integral production of ethanol and seaweed sap from *Kappaphycus alvarezii* [115]. This has given much needed impetus and promotion of seaweed cultivation industry in India in recent years. There are about 1000 fishermen undertaking seaweed farming along Tamil Nadu and growing 2000 tons of seaweed. Globally, the environmental impacts of *Kappaphycus* and *Eucheuma* introductions have been studied only in five instances - three at Hawaii and one each at Fiji and Venezuela [116]. As a technology provider, CSIR-CSMCRI carried out the first rapid EIA study in 2002, two years after starting the commercial faming, to understand the environmental implications at Mandapam coast. The evidences concerning environmental issues of *K. alvarezii* cultivation have not been reported, but subsequently apprehension of its likely expansion in the Gulf of Mannar has been expressed [117]. Chandrasekaran et al. [118] have further reported the bioinvasion of *K. alvarezii* on the corals of Krusadai Island, Gulf of Mannar marine biosphere reserve to which concerns have been expressed [119]. In view of this; elaborate efforts were made to survey the island between May–August 2008 and again in July 2009. The aim was to ascertain status of alleged invasion *K. alvarezii* occurrence at Krusadai and additionally at two other adjoining islands of Gulf of Mannar including selected locations of mainland coast of Palk Bay where large cultivation farms of SHGs exists. This study briefly appraises the results of field surveys conducted to (1) ascertain the present status of *K. alvarezii* occurrence on *Acropora* sp. at Krusadai Island; (2) determine the situation at neighbouring islands and (3) evaluate the changes in its growth and distribution after the first report of its localization in August 2007. As reported by Chandrasekaran et al. [118] this study also recognized the establishment of the alga over two small patches (40 m × 40 m and 18 m × 17 m) on *Acropora muricata* corals in the south eastern part of the island. Additionally third minute spot (8 m × 9 m) was also identified at the nearby area. The real spread occurred in approximately 7 m^2 area, which was far less (0.0005%) than entire coral reef of the island. It may be noted that there was no lateral spread reported. Further it was found that common seaweed flora thrived unhindered and all entire habitat was free from any of the establishment by *K. alvarezii*. No evidence of algal invasion was found from other two islands, namely, Pulli and Pullivassal islands, as well as the commercial cultivation grounds of main land coast of Palk Bay. It was concluded that absence of functional reproduction, little fertility, low spore vitality, complete absence phases of microscopic nature in the life history along with presence of herbivores was responsible for no further spread in the Krusadai Island [120]. It was well evident that copious quantities of algal drift tend to scatter due to farm maintenance operations. Those drifted trashes tend to die subsequently. The study was undertaken to test the efficacy of drifted pieces categories under three groups namely live, semi-bleached, and bleached. They were subjected to different salinity (20%, 25%, 30%, 35%, and 40‰) and temperature (15, 20, 25, 30, and 35 °C) regimes. Their survival and daily growth rate (DGR) were recorded in this experiment and $NO^{3-}N$, $PO^{4-}P$, and $SiO^{3-}Si$ uptake was studied. This study confirmed that conducive temperature and salinity, along with survival efficiency due to bioavailability of required nutrients and regeneration capacity of drifting fragments, play crucial role in establishment of *K. alvarezii* population in the wild and drift mitigation is critical management practice to avoid establishment of non-farm population [121].

Ask et al. [122] have reported that there are practically no reports of bioinvasion of *K. alvarezii* from countries where it has been introduced for cultivation purposes and the cultivation practices are still going on providing income for thousands of families. The reported association of *Kappaphycus* on *Acropora* corals at Krusadai Island could have been merely due to the fact of their prevailing dominance over other coral species in the southeastern part of Krusadai Island. The absence of *Kappaphycus* on other coral species has been attributed to their lack of suitable settling surfaces for drifting fragments. It could be thus perceived that besides settling surfaces, there are many factors like abundance and density of receiving organisms, prevalence of grazers, morphology of invading algae and other ecological and environmental conditions which may regulate and determine the algal establishment. Ganesan et al. [123] had shown that a substantial amount of biomass of *K. alvarezii* was consumed by herbivores animals at Krusadai Island. More recently, Bindu [124] reported that 30% of the cultivated biomass is lost to herbivore. She further stated in her review entitled '*The commercial red seaweed Kappaphycus alvarezii—an overview on farming and environment*' that based on literature, it is clear that the introduction to new localities for commercial profit is likely to continue in the foreseeable. It may also be noted that National Academy of Agricultural Sciences, India in its "Seaweed Cltivation and Utilization Policy Paper" (2003) [] recommended this domain as national priority. As rural employment annually is growing at the slow pace of 0.58% corresponding to higher population growth at 1.7%, this activity could certainly rejuvenate the rural economy.

5. Conclusions

Tropical Indian waters harbor a diversity of habitats which provide excellent support for a myriad of species. Although the first report of seaweed from India was made in 1672, taxonomy of this group is neglected. The initial knowledge regarding to diversity of Indian seaweeds came through the efforts of European Missionaries and naturalists. It may be noted that utilisation aspect has come much latter, especially during the second world war when the government made serious efforts to use this neglected renewable marine resource. In reason of the decreasing number of active taxonomists, seaweed taxonomy has become very rare in the new literature of the last two decades, and there is therefore an urgent need to strengthen this subject. This review is the first serious effort to synthetically gather information on seaweed biodiversity of India, as well as to identify gaps and opportunities. The challenging task of compiling all the relevant information which is currently scattered and not easily accessible to the research community shall not only help in drawing comprehensive research program but also aid in policy formulation. Our review clearly highlights the urgent need of mapping biodiversity at the pan-Indian level by using the latest techniques of remote sensing and geographic information system. An appropriate collaborative research is absolutely essential to avoid duplication and to achieve focused reliable goals for tangible outcome. With only ~10% share in global seaweed diversity and ~0.01% in farming, India still assume significant importance, as more than 20% of its coastline is occupied by two island territories namely Andaman & Nicobar and Lakshadweep and largely unexplored for its seaweed diversity. It may also be noted that, establishment of 100 marine protected areas located in islands and costal union territories of India, coupled with identification of nine critical habitats provide strong legal frameworks for protection and conservation of this economically important resource. Subtidal habitats are also important because they can support seaweed farming activities. Commercial seaweed farming techniques are simple and easy to adopt. Thus, more focus has been given by government departments on implementing seaweed farming under rural employment schemes for rejuvenating coastal economy. Seaweed farming that has been successful in Tamil Nadu and most recently Gujarat it is likely to attract attention by other maritime states due to the fact of nil agricultural inputs, farmland requirements, and fresh water needed.

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