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Review Article

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A review on the economic potential of seaweeds in India

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Abstract

'Seaweeds' are the marine macro algae, adapted to survive exclusively in the marine ecosystems. They are among the most potential marine living resources and play significant role in sustainability of the marine ecosystems. India, endowed with a coastline of c .7500 km, exhibits unique marine habitats and support good diversity of seaweeds. Globally, c.11,000 taxa of seaweeds are reported. Among them, c. 221 taxa have been recognized as economically important in various forms. Presently, the Indian coastline harbours c. 865 taxa of marine macro algae, comprising of 442 taxa of Rhodophyceae, 212 taxa of Chlorophyceae and 211 taxa of Phaeophyceae. Among these, c. 94 taxa (42 Rhodophyceae, 35 Chlorophyceae and 17 Phaeophyceae) are recognized as economically important and used in various forms. Among these, 43 seaweeds are edible, while 19 are used as fodder, 41 as industrially important, 37 as medicinal and 13 as manure (SLF). The paper highlights the economic potential of these promising resources for the welfare of the mankind.

Keywords: Chlorophyceae, Economical potential, Indian coast, Phaeophycea, Rhodophyceae, Seaweeds.

Introduction

Seaweeds are not the *weeds*, rather they are the marine macro algae and constitute important components of the marine floral diversity along with other groups of plants like mangroves and seagrasses. Seaweeds are adapted to survive exclusively in marine ecosystems and grow predominantly on rocky substrata, coralline beds, reefs, pebbles, shells, dead corals and also as epiphytes on other marine plants in the intertidal shallow sub-tidal and deep sea waters. In plant kingdom, seaweeds, including other diverse groups of algae, are the primitive, simple, chlorophyll bearing, photosynthetic, non-vascular and aquatic plants and considered as ancestors of the higher plants. Seaweeds are broadly divided into three groups, *viz.* Chlorophyceae (green algae), Phaeophyceae or Heterokontophyceae (brown algae) and Rhodophyceae (red algae), based upon the photosynthetic pigments, colours, and reserve food materials.

India (8°-37° N & 68°-97° E), being a peninsular country, is endowed with *c.* 7500 km of length including those of islands of Andaman & Nicobar and Lakshadweep (Figure 1). The mainland coastline of India is broadly divided into the East coast (*c.* 2652 km long) and the West coast (*c.* 3216 km long) and the Islands constitute *c.* 1620 km length (Rao & Mantri, 2006). It has an Exclusive Economic Zone (EEZ) of around 2.5 million sq km. The country has 97 major estuaries, 34 major lagoons, 31 mangroves areas, 5 coral reefs, 31 Marine Protected Areas or MPAs (Singh, 2003). These diverse habitats form unique habitats, support wide range of marine biological diversity and constitute integral part of the floral diversity of the country.

Fig. 1: Map showing the coastlines of India

Materials and Methods

This study is mainly a review study and based on the study literature related to seaweed study in general and economic aspects of seaweeds in particular. All the relevant literature were scrutinised and the economic potentials of seaweeds in respect to Indian scenario were analysed.

Results and Discussion

Seaweeds diversity in Indian coast

Globally, there are *c.* 11,000 taxa of seaweeds, which include *c.* 7,200 taxa of Rhodophyceae, 2,000 taxa of Phaeophyceae and 1,800 taxa of Chlorophyceae (http://www.seaweed.ie). The Indian coastlines exhibit very diverse coastal habitats and support 865 taxa of seaweeds (Rao & Gupta, 2015),comprising 442 taxa of Rhodophyceae under 151 genera, 212 taxa of Chlorophyceae under 46 genera and 211 taxa of Phaeophyceae under 50 genera as shown in Figure 2.

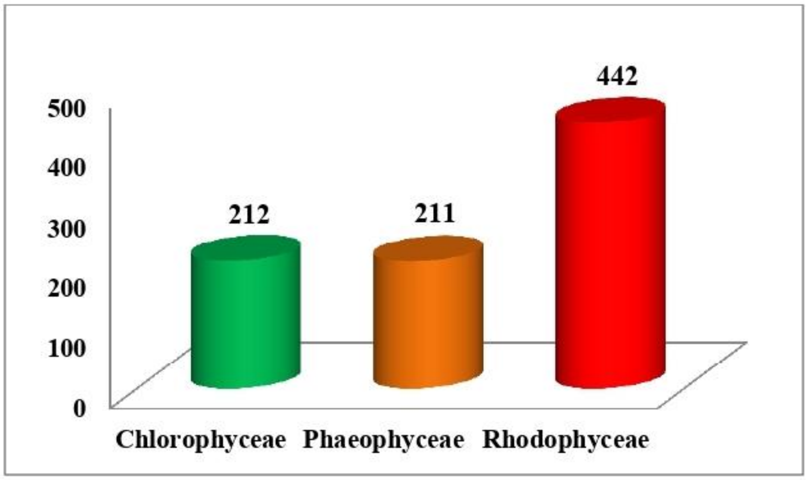

Fig. 2: Graph showing seaweeds diversity in India

Perusal of literature pertaining to the works carried on Indian seaweeds reveals that among various maritime states, Tamil Nadu coast shows the highest diversity of seaweeds with 282 species (Anon.2012; Ganesan & al., 2019), followed by Maharashtra coast with 240 species Piwalatkar, 2010), Gujarat coast with 198 species (Jha & al., 2009), Kerala with 147 taxa (Palanisamy & Yadav, 2015), Karnataka with 105 taxa (Yadav & Palanisamy, 2020), Goa with 90 taxa of seaweeds (Palanisamy & Yadav, 2019), Andaman & Nicobar islands with 80 species (Muthuvlan & al., 2001), Diu island with 70 species (Mantri &Rao, 2005), Andhra Pradesh with 65 species (Anon., 1984), West Bengal with 14 species (Mukhopadhyay & al., 2002) and Odisha with 14 species (Sahoo & al., 2003). More interestingly, the Indian coastline also harbours around 125 species of seaweeds endemic to India (Oza & Zaidi, 2001). Recently, Mantri & al. (2019) pointed out the gradual increase in diversity of seaweeds from the Indian waters (Mantri & al., 2019), based on the checklists published so far, starting from 167 species in 1970 (Krishnamurthy & Joshi, 1970) to 865 in 2015 (Rao & Gupta, 2015) and the number of new seaweed taxa reported during 1800 to 2019 and opined that there were two major peaks, the first from 1930-1940 and the second, from 1980-1990, during which maximum new records were added to the Indian seaweed flora. Moreover, many new records of seaweeds have been added in the recent years by various researchers (Bast & al., 2014, 2015; Rani & Bast, 2019) to the Indian seaweed flora. Even now also, many of the remote localities of the Indian coastline are under explored or unexplored and therefore, the actual number of seaweed species may upsurge. Therefore, the Indian coastline exhibits significant diversity of seaweeds.

Economical potential of seaweeds

Seaweeds are economically one of the most important marine natural resources and used by human beings in various forms such as food and fodder as early as 2500 years ago in Chinese literature (Tseng, 2004). Globally, *c.* 7.5 – 8 million tons of wet seaweeds are being produced every year (McHugh, 2003). In India, the algal research got momentum only during the end of 19th century by Prof. M.O.P. Iyengar (1886–1966), *the Father of Indian Algology*, during 1927 (Iyengar, 1927). However, as far as the research on economic aspects of seaweeds is concerned, Thivy (1960) made the first attempt to study the distribution of few economically important seaweeds. Thereafter, various other workers also made significant contributions and reported on various aspects of seaweeds from different parts of the Indian coast.

Globally, around 42 countries in the world are actively involved in the commercial utilization of seaweed resources. Among them, China ranks first, followed by North Korea, South Korea, Japan, Philippines, Chile, Norway, Indonesia, USA and India. These top ten countries contribute up to 95% of the world's commercial seaweed utilization (Khan & Satam, 2003). China and Japan are the two major seaweed harvesting countries, where more than 70 species of seaweeds are edible and consumed as salads directly or after cooked. About 400,000 tonnes of seaweeds of economic importance such as *Porphyra* (for Nori), *Laminaria* (for Kombu), Undaria (for Wakame) are harvested annually throughout the world (Braune & Guiry, 2011). In Japan, China and Korea, green seaweeds constitute around 5 % of human diets

(Dawes, 1998). Globally, *c.* 221 species of seaweeds are economically utilized in various forms, which include 145 species for food and 110 species for phycocolloid production (Chennubhotla & al., 2013; Nedumaran & Arulbalachandran, 2014).

The scrutiny of literature reveals that the Indian coastlines support significant diversity of economically important seaweeds. However, information available on the economic aspects of this promising natural resources are usually sporadic and locality specific. Therefore, an attempt has been made here to present a comprehensive account on the economic potential of these seaweeds. The study reveals that out of total recorded 865 taxa of seaweeds from India, *c.* 94 taxa are economically important in various forms and have great application perspectives. These include 42 Rhodophyceae, 35 Chlorophyceae and 17 Phaeophyceae (Figure 3, Table 1).The analysis also reveals that among these, 43 seaweeds are edible in nature and used as food, 19 as fodder, 41 as industrially important, 37 as medicinal and 13 as manure or seaweed Liquid Fertilizer (SLF) and have been represented in Table 2 and 3. Most of the edible seaweeds aregreen (chlorophyceae) as they contain starch as reserve food materials.

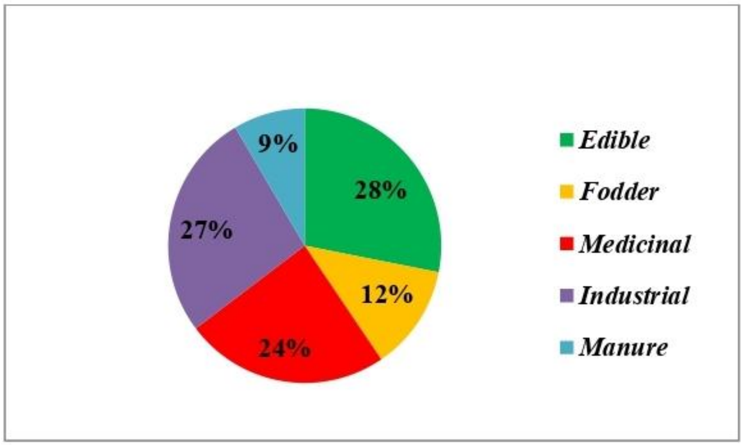

Fig. 3: Pie chart showing economical potential of seaweeds in various forms

Table 1: Seaweed diversity in India and its economic potential

Class	No. of taxa	No. of taxa with Economic potential
Chlorophyceae	212	35
Phaeophyceae	211	17
Rhodophyceae	442	42
Total	**865**	**94**

Likewise, most of the industrially important seaweeds belong to red (Rhodophyceae) and brown seaweeds (Phaeophyceae) as they contain more secondary metabolites and phycocololloids. The economic potentials of these seaweeds may be dealt under the following major heads:

1. Seaweeds in food industry

The uses of Seaweeds in the form of food are well known in many Indo-Pacific countries since long ago. Many of the South East Asian countries like China, Japan, Thailand, Korea etc. have started large scale utilization of seaweeds for food industry. Seaweeds are rich in both minerals and trace elements (Chapman, 1970) and contain good quantity of fibres and minerals which help in improving the mineral content. In addition, uses of seaweeds or their extracts to food products will help in reducing the utilization of chemical preservatives (Chapman & Chapman, 1980). However, in Indian perspective, around 30 % of the population lives close to coasts, the uses of seaweeds in the form of food are still very limited. India's traditional food systems are different from other Asian countries. Therefore, seaweed eating has not become habituated in the Indian food systems at large scale (Ganesan & al., 2019). As the population is increasing rapidly and the agricultural lands are shrinking, the cultivation of seaweeds in coastal vicinity on large scale, may serve as an additional source in our food system. Globally, *c.* 145 species of seaweeds are edible and used as food mainly in the form of *recipes*, *salads*, *soups*, *jellies* and *vinegar dishes*. They mostly belong to green seaweeds. From India, a list of 43 edible seaweeds, enumerated based on references, are provided in Table 3.

The common edible seaweeds found along the Indian coast are *Ulva*, *Cladophora*, *Brypsis*, *Caulerpa*, *Sargassum*, *Hydroclathrus*, *Porphyra*, *Gracilaria*, *Gelidium*, *Grateloupia*, *Hypnea*, *Rhodymenia etc.*

Table 2: Uses of the economically important seaweeds in various forms

Uses of seaweeds	No. of taxa
Edible (Food)	43
Fodder	19
Medicinal	37
Industrial	41
Manure (SLF)	13

Table 3: List of the economically important seaweeds occurring in the Indian coast*

Sl. No.	Name of the taxa	Economic potential of seaweeds	References
1.	**CHLOROPHYCEAE** *Ulvella lens* P. Crouan & H. Crouan	Fodder (Aquaculture)	Hannon & al., 2014
2.	MONOSTROMATACEAE *Monostroma latissimum* Wittr.	Edible	Jha & al., 2009
3.	ULVACEAE *Ulva compressa* L.	Edible, Fodder, Medicinal (Antioxidant Activity)	Kaliaperumal & al.,1995
4.	*Ulva conglobata* Kjellman	Edible	Jha & al., 2009
5.	*Ulva flexuosa* Wulfen	Edible, Fodder	Jha & al., 2009
6.	*Ulva intestinalis* L.	Edible, Fodder	Jha & al., 2009
7.	*Ulva linza* (L.) J. Agardh	Fodder	Jha & al., 2009
8.	*Ulva prolifera* O.F. Muell.	Edible, Medicinal, Industrial (cosmetics)	Zhao & al., 2016
9.	*Ulva fasciata* Delile	Edible, Fodder, Medicinal	Sobha & al., 2008; Shynu & al., 2014
10.	*Ulva lactuca* L.	Edible, Fodder, Medicinal, Manure	Shynu & al., 2014
11.	*Ulva reticulata* Forssk.	Edible, Medicinal	Sobha & al., 2008; Kaliaperumal & al., 1995
12.	*Ulva rigida* C.Agardh	Edible, Fodder, Medicinal	Kaliaperumal & al., 1995; Shynu & al., 2014
13.	*Ulva quilonensis* Sindhu & Panikkar	Edible, Fodder, Medicinal	Kaliaperumal & al., 1995; Shynu & al., 2014
14.	ACROSIPHONIACEAE *Acrosiphonia orientalis* (J. Agardh) P.C. Silva	Medicinal	Manilal & al., 2012

15.	CLADOPHORACEAE *Chaetomorpha antennina* (Bory) Kuetz.	Medicinal, Paper industry	Jha & al., 2009; Abhishek & al., 2018
16.	*Chaetomorpha crassa* (C. Agardh) Kuetz.	Medicinal, Paper industry	Jha & al., 2009
17.	*Chaetomorph linum* (O.F. Muell.) Kuetz.	Medicinal (Antibacterial activity)	Stabili & al., 2019;
18.	*Chaetomorpha litorea* Harv.	Industrial (Biogas production)	Sangeetha & al., 2011; Haniya & al., 2015
19.	*Cladophora prolifera* (Roth) Kutz.	Edible, Fodder	Shynu & al., 2014
20.	*Cladophora albida* (Nees) Kuetz.	Medicinal (Anticancerous activity)	Awad & al., (2009)
21.	*Cladophora glomerata* (L.) Kuetz.	Edible, Medicinal Industrial (Bioethanol production)	Munir & al., 2019; Surayot & al., 2016.
22.	*Cladophora vagabunda* (L.) C. Hoek [*C. fascicularis* (G. Mertens ex C.Agardh) Kutz.]	Edible, Fodder Industrial (Bioethanol production)	Kaliaperumal & al., 1995; Munir & al., 2019. Sharmila & al., 2012.
23.	SIPHONOCLADACEAE *Boergesenia forbesii* (Harv.) Feldmann	Industrial (Salt production)	Jha & al., 2009
24.	*Valoniopsis pachynema* (G. Martens) Boergesen	Industrial (Biopesticides)	Manilal & al., 2009
25.	BRYOPSIDACEAE *Bryopsis pennata* J.V. Lamour.	Medicinal (Kahalalide F, as antiviral, antimicrobial and anti-tumorous)	Manilal & al., 2010; Contreras & al., 2019
26.	*Bryopsis plumosa* (Huds.) C. Agardh	Edible, Fodder, Manure Medicinal (Antibacterial)	Shynu & al., 2014; Contreras & al., 2019
27.	CAULERPACEAE *Caulerpa lentillifera* J.Agardh	Edible	Mary & al., 2009.
28.	*Caulerpa peltata* J.V. Lamour.	Edible, Fodder, Manure	Mintardjo (1990). Shynu & al., 2014
29.	*Caulerpa racemosa* (Forssk.) J. Agardh	Edible	Kaliaperumal & al., 1995; Sobha & al., 2008
30.	*Caulerpa sertularioides* (S.G. Gmel.) M. Howe	Edible, Fodder, Manure	Kaliaperumal & al., 1995; Shynu & al., 2014
31.	*Caulerpa scalpelliformis* (R. Br. ex Turner) C. Agardh	Medicinal (Antibacterial activity)	Kotteswari & al., 2015.
32.	*Caulerpa taxifolia* (Vahl) C. Agardh	Edible, Fodder, Manure	Shynu & al., 2014
33.	CODIACEAE *Codium dwarkense* Boergesen	Medicinal (Anticoagulant property)	Siddhanta & al., 1999; Shanmugam & al., 2002
34.	*Codium tomentosum* Stack.	Medicinal (Anticoagulant property)	Shanmugam & al., 2002
35.	*Codium decorticatum* (Woodward) M.Howe	Edible, Medicinal	Jha & al., 2009

36.	**PHAEOPHYCEAE** DICTYOTACEAE *Dictyopteris bartayresiana* J.V. Lamour.	Edible, Fodder, Medicinal, Manure	Shynu & al., 2014
37.	*Dictyota dichotoma* (Huds.) J.V. Lamour.	Industrial (Biopesticides)	Manilal & al., 2009
38.	*Lobophora variegata* (J.V. Lamour.) Womersley ex E.C. Oliveira	Industrial	Shynu & al., 2014
39.	*Padina gymnospora* (Kutz.) Sond.	Edible, Fodder, Industrial, Manure	Shynu & al., 2014
40.	*Padina tetrastromatica* Hauck	Edible, Fodder, Industrial, Manure	Sobha & al., 2008; Shynu & al., 2014
41.	*Spatoglossum asperum* J. Agardh	Manure (Seaweed Liquid Fertilizer), Antifungal activity	Chennubhotla & al., 2013
42.	*Stoechospermum marginatum* (C.Agardh) Kuetz.	Medicinal (Antibacterial activity)	Esmaeili and Khakpoor 2012
43.	*Chnoospora bicanaliculata* V. Krishnam. & P.C. Thomas	Industrial (Biopesticides)	Manilal & al., 2009
44.	SCYTOSIPHONACEAE *Hydroclathrus clathratus* (C.Agardh) M.Howe	Edible, Fertilizer (SLF)	Jha & al., 2009
45.	SARGASSACEAE *Sargassum cinereum* J. Agardh	Industrial	Pati & al., 2016
46.	*Sargassum myriocystum* J. Agardh	Edible, Manure, Industrial (Algin)	Kaliaperumal & al., 1995; Shynu & al., 2014
47.	*Sargassum polycystum* C. Agardh	Industrial (Cosmetics)	Chan & al., 2011
48.	*Sargassum ilicifolium* (Turner) J. Agardh	Medicinal (Immuno modulatory activities)	Simpi & al., 2013
49.	*Sargassum tenerrimum* J. Agardh	Edible, Manure, Industrial (Agaroid)	Kaliaperumal & al., 1995
50.	*Sargassum wightii* Grev.	Edible, Fodder, Industrial (Algin)	Kaliaperumal & al., 1995; Sobha & al., 2008
51.	*Turbinaria conoides* (J. Agardh) Kutz.	Industrial (Algin)	Kaliaperumal & al., 1995
52.	*Turbinaria ornata* (Turner) J. Agardh	Edible, Industrial (Agaroid)	Kaliaperumal & al., 1995
53.	**RHODOPHYCEAE** BANGIACEAE *Porphyra indica* V. Krishnam. & Baluswami	Edible	Kaliaperumal & al., 1995
54.	*Porphyra kanyakumariensis* V. Krishnam. & Baluswami	Edible	Shynu & al., 2014
55.	*Porphyra vietnamensis* Tak. Tanaka & P.H. Ho	Edible (Proteins, Polyunsaturated fatty acids)	Kavale & al., 2018
56.	LIAGORACEAE *Dermonema virens* (J.Agardh) Pedroche & Avila	Edible	Jha & al., 2009
57.	GELIDIACEAE *Gelidium micropterum* Kutz.	Edible, Industrial (Agar)	Kaliaperumal & al., 1995; Shynu & al., 2014

58.	*Gelidium pusillum* (Stackhouse) Le Jolis	Industrial (Agar)	Kaliaperumal & al., 1995
59.	*Gelidiella acerosa* (Forssk.) J. Feldmann & G. Hamel	Industrial (Agar)	Kaliaperumal & al., 1995
60.	GRACILARIACEAE *Gracilaria corticata* (J. Agardh) J. Agardh	Industrial (Agar)	Kaliaperumal & al., 1995; Sobha & al., 2008; Shynu & al., 2014
61.	*Gracilaria corticata* (J. Agardh) J. Agardh var. *cylindrica* M.U. Rao	Industrial (Agar)	Kaliaperumal & al., 1995
62.	*Gracilaria dura* (C.Agardh) J.Agardh	Industrial (Agar & Agarose source)	Jha & al., 2009
63.	*Gracilaria edulis* (S.G.Gmel.) P.C.Silva	Edible, Industrial (Agar)	Kaliaperumal & al., 1995
64.	*Gracilaria foliifera* (Forssk.) Borgesen	Industrial	Shynu & al., 2014
65.	*Gracilaria verrucosa* (Hudson) Papenf.	Manure, Industrial (Agar)	Kaliaperumal & al., 1995; Shynu & al., 2014
66.	BONNEMAISONIACEAE *Asparagopsis taxiformis* (Delile) Trevis.	Edible, Industrial (Antifouling agent)	Kaliaperumal & al., 1995; Manilal & al., 2010
67.	HALYMENIACEAE *Grateloupia filicina* (J.V. Lamour.) C.Agardh	Edible, Industrial (Carrageenan)	Shynu & al., 2014
68.	*Grateloupia lithophila* Boergesen	Medicinal (Antibacterial activity)	Priya & al., 2018
69.	*Halymenia dilatata* Zanardini	Industrial (minerals, polysaccharides, pigments)	Fantonalgo 2018
70.	CORALLINACEAE *Amphiroa anceps* (Lam.) Desce.	Medicinal (Antibacterial activity)	Roy & Anantharaman 2018
71.	*Amphiroa fragilissima* Harv.	Manure (Seaweed Liquid Fertilizer)	Pati & al., 2016
72.	*Corallina officinalis* L.	Medicinal (Antibacterial activity)	Taskin & al., 2007
73.	*Jania adherens* J.V.Lamour.	Industrial	Shynu & al., 2014
74.	*Jania rubens* (L.) J.V. Lamour.	Medicinal (antioxidant activity)	Chakraborty & al., 2015
75.	CAULACANTHACEAE *Catenella impudica* (Mont.) J. Agardh	Industrial (Carrageenan source)	Jha & al., 2009
76.	GIGARTINACEAE *Chondracanthus acicularis* (Roth) Fredericq	Industrial importance (Carrageenan)	Pereira 2013.
77.	HYPNEACEAE *Hypnea musciformis* (Wulf.) J.V. Lamour.	Edible, Medicinal (antioxidant activity), Industrial (Carageenan)	Kaliaperumal & al., 1995; Chakraborty & al., 2015
78.	*Hypnea spinella* (C.Agardh) Kuetz.	Medicinal (antiviral activity)	Li & al., 2018
79.	*Hypnea valentiae* (Turner) Montagne	Edible, Medicinal (antioxidant activity), Industrial (Carageenan)	Kaliaperumal & al., 1995; Chakraborty & al., 2015

80.	SOLIERIACEAE *Kappaphycus alvarezii* (Doty) Doty ex P.C.Silva	Industrial (Carrageenan, Biodiesel, Fertilizer)	Jha & al., 2009; Khambhaty & al., 2012
81.	*Meristotheca papulosa* (Mont.) J. Agardh	Edible	Jha & al., 2009; Lideman & al., 2011
82.	CHAMPIACEAE *Champia compressa* Harv.	Industrial (Agar-Agar)	Shahnaz & al., 2019.
83.	LOMANTARIACEAE *Gelidiopsis intricata* (C. Agardh) Vickers	Industrial	Shynu & al., 2014
84.	*Gelidiopsis repens* (Kuetz.) Weber Bosse	Edible, Medicinal	Jha & al., 2009
85.	*Gelidiopsis variabilis* (J. Agardh) F. Schmitz	Industrial (Agaroid)	Chennubhotla & al., ,1987
86.	CERAMIACEAE *Centroceras clavulatum* (C. Agardh) Mont.	Medicinal (Dominic and Kainik acid are anthelminthin and insecticidal activities)	Smit 2004
87.	*Ceramium cruciatum* Collins & Herv.	Edible, Industrial (Phycocolloid)	Jha & al., 2009
88.	*Spyridia filamentosa* (Wulfen) Harv.	Medicinal (Antibacterial activity)	Centeno & al., 1996
89.	*Spyridia hypnoides* (Bory) Papenf.	Medicinal (Antibacterial activity)	Centeno & al., 1996
90.	RHODOMELACEAE *Acanthophora spicifera* (Vahl.) Borgesen	Edible, Industrial (Agaroid)	Chennubhotla & al.,1987
91.	*Chondria armata* (Kuetz.) Okamura	Medicinal (Dominic and Kainik acid)	Smit, 2004
92.	*Digenea simplex* (Wulfen) C. Agardh	Medicinal (Anthelminthic)	Jha & al., 2009
93.	*Bostrychia tenella* (J.V. Lamour.) J. Agardh	Medicinal (Antibacterial and antifungal activities)	Felício & al., 2015
94.	*Palisada perforata* (Bory) K.W.Nam [*Laurencia papillosa* (C. Agardh) Grev.]	Medicinal (Dominic and Kainik acid)	Smit, 2004

**based on literature*

2. Seaweeds as fodder

Seaweeds have been used historically in Agriculture since long time. Today, it is being used as animal feed on large scale in a number of countries like Iceland, Norway, France, UK, USA and many other European countries. There are many seaweed based factories in these countries to dry and grind it into the form of cattle feed. In Iceland, fresh seaweeds are commonly used as fodder for sheep, cattle and horses. Seaweeds are the rich and sustainable source of macronutrients (particularly dietary fiber and micronutrients and used to enhance the nutritional quality of animal feed (Michalak & Mahrose, 2020). Some of the common seaweeds, suitable as fodder and found along the Indian coast are *Monostroma, Ulva, Cladophora, Bryopsis, Caulerpa, Dictyopteris, Padina, Sargassum etc.*

3. Seaweeds in Industries

Seaweeds are the natural sources of raw materials for many of the industries. They are the only sources of thickening agents and gels (phycocolloides) like agar-agar, algin, carrageenans etc. and widely used in various biochemical industries (Mantri & al., 2019). The three major phycocolloids are Agar-Agar, Alginates and Carrageenan.

Agar, Agarose and Carrageenan are mainly extracted from the red seaweeds like species of *Gelidium*, *Gelidiella*, *Gracilaria* etc. Similarly, *Alginate*, also known as *Algin* or *Alginic acid* is a polysaccharide and is mainly extracted from the brown seaweeds like species of *Sargassum*, *Turbinaria*, *Cystoceira*, *Dictyota*, *Padina*, *Hormophysa*, *Colpomenia*, *Spatoglossum*, *Stoechospermum* etc (Anantharaman & Balasubramanian, 2010).

In addition, seaweeds are also widely used in Pharmaceutical and nutraceutical industries. Plants serve as reliable source of medication for nearly 60% of the world's population (Chennubhotla & al., 2013). Many species of seaweeds contain secondary metabolites which are of high pharmaceutical potential and used in making medicines. For instance, *Chondria armata*, a red seaweed, is known to have chemical components like Domoic acid and Kainic acid, useful in neurological treatment and also have anthelminthic and insecticidal properties (Smit, 2004). Similarly, sulphated polysaccharides extracted from *Cladophora glomerata* are known to be useful in cancer treatment (Surayot & al., 2016; Kaeffer & al., 1999). Based on references, 37 medicinally important seaweeds, reported from India, are provided in Table 3.

4. Seaweeds as Fertilizer (SLF) and Manure

In recent years, uses of seaweeds as liquid fertilizers by farmers, horticulturists, gardeners etc. have got attention and now widely used in many of the European countries. The successful applications of SLF on various crops have been reported recently by various workers (Rani & al., 2011; Sujatha & al., 2011; Usha & al., 2013). Some of the commonly used seaweeds for SLF are *Dictyopteris*, *Padina*, *Sargassum* etc.

5. Seaweeds in Biofuel production

With the continuous increase in human population, the pressure on the requirements of energy has increased many folds. In such a situation, bioethanol is being considered as a potential and alternative source due to limited quantity natural resources (Masami & al., 2008). Many species of seaweeds have great potentials for the production of biofuels. The production of bioethanol from algae involves three major steps *i.e.* pretreatment of biomass (maceration), enzymatic hydrolysis (reducing sugar) and fermentation using microbial agents. From Indian coast, many seaweeds like species of *Gelidium*, *Gracilaria*, *Kappaphycus*, *Ulva*, *Sargassum* etc. have been assessed for ethanol production using various microbes (Ramachandra & Deepthi, 2016). Similarly, species of green seaweed *Cladophora* particularly C. *glomerata*, *C. vagabunda* etc. possess substantial biomass and considered as suitable biofuel feedstock (Sharmila & Rebecca, 2012; Munir & al., 2019; Boonprab & Matsui, 2018). Recently, the red alga *Kappaphycus alvarezii* has been used to produce biodiesel and run a petrol vehicle at experimental level successfully (Khambhaty & al., 2012). Therefore, seaweeds have great potential to serve as an additional source of biodiesel production in future.

Conclusion

Seaweeds are the potential marine living resources and integral part of the biodiversity. In addition to ecological and biological importance's, seaweeds have also immense economic potential in the form of food, fodder and also serve as raw materials for various industries. Therefore, its proper documentation and identification is prerequisite for its proper utilisation.

The large scale cultivation of economically important seaweeds and proper industrial supports can play crucial role in socio-economic dimensions in coastal areas and may serve as additional source of income and boom the livelihood of the local people. There has been an estimate that seaweed resources in India can provide employment to more than 20,000 fishers in harvesting and an equal number of jobs in post-harvesting activities, provided stocks are managed rationally (Krishnan & Kumar, 2010). However, due to the lack of the proper awareness, infrastructure and practical applications, these marine natural resources are still potentially unexplored. Therefore, this is one of the thrust areas and need more research in order to sustainably utilize the potentiality of these promising resources to its full extent.

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References

Abhishek D, Jyoti P, Savan D, Sumitra C.2018. Pharmacognostic standardization of *Chaetomorpha antennina* and *Ulva lactuca*, green seaweeds from Gujarat coast. *J. Pharmacogn. Phytochem*. 7(2): 3863-3870.

Anantharaman P, Balasubramanian T. 2010. Seaweeds and their potential values. In: *Souv. Nat. Symp. Mar. plants*. 29-44.

Anonymous. 2012. Final Report, Council of scientific and industrial research. Ministry of Science & Technology, Rafi Marg, New Delhi. 2012; 1–30.

Anonymous, 1984. A Report on the Survey of Marine Algal Resources of Andhra Pradesh. 1978–1982. CSMCRI, Bhavnagar. 1–30.

Awad N, Ibrahim N, Matloub A. 2009. Phycochemical and cytotoxic activity of some marine algae. *Plant Med.* 75. PE73.

Bast F, John AA, Bhushan S. 2015. *Cladophora goensis* sp. nov. (Cladophorales, Ulvophyceae) –a bloom forming marine algae from Goa, India. *Indian J. Mar. Sci*. 44 (12): 1874–1879.

Bast F, John AA, Bhushan S. 2014. Strong Endemism of Bloom-Forming Tubular *Ulva* in Indian West Coast, with Description of *Ulva paschima* Sp. Nov. (Ulvales, Chlorophyta). *PLoSONE* 9 (10): e109295. doi:10.1371/journal.pone.0109295.

Boonprab K, Matsui K. Use of *Monascus* sp. NP1 for bioethanol production from *Cladophora glomerata*, J. Appl. Phycol. 2018; 1–8.

Braune W, Guiry MD2011. Seaweeds, A colour guide to common benthic green, brown and red algae of the world's oceans. A.R.G. Gantner Verlag K.G., Ruggell, Liechtenstein, Germany, 601.

Centeno POR, Ballantine DL and Gerwick WH. 1996. Dynamics of antibacterial activity in three species of Caribbean marine algae as a function of habitat and life history. *Hydrobiologia* 326, 457–462. https://doi.org/10.1007/BF00047846.

Chakraborty K, Joseph D, Praveen NK. 2015. Antioxidant activities and phenolic contents of three red seaweeds (Division: Rhodophyta) harvested from the Gulf of Mannar of Peninsular India. *J Food Sci Technol*.52 (4):1924-1935.

Chan YY, Kim KH, Cheah SH. 2011. Inhibitory effects of *Sargassum polycystum* on tyrosinase activity and melanin formation in B16F10 murine melanoma cells. *J Ethnopharmacol*.137:1183–8.

Chapman VJ, Chapman DJ. 1980.Seaweed as Animal Fodder, Manure and for Energy. In: Seaweeds and their Uses. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-5806-7_2

Chapman VJ. 1970. Seaweeds and Their Uses. Chapman & Hall. London, 334.

Chennubhotla VSK, Kaliaperumal N. and Kalimuthu S. 1987. Economically important seaweeds. In P.S.B.R. James (ed.), SRUA. CMFRI, Bulletin, 41: 3- 18.

Chennubhotla VSK, Rao MU, Rao KS. 2013. Commercial importance of marine macro algae. *Seaweed Res. Utiln.*35 (1&2): 118-128.

Chennubhotla VSK, Rao MU, Rao KS.2013. Exploitation of marine algae in Indo-Pacific region. *Seaweed Res. Utiln.*35 (1&2): 1-7.

Chennubhotla, VSK, Rao M U, Rao KS. 2013. Commercial importance of marine macro algae. *Seaweed Res. Utiln.*,35 (1&2): 118-128.

Contreras N, Alvíz A, Torres J, Uribe S. 2019. *Bryopsis* spp.: Generalities, Chemical and Biological Activities. *Pharmacog Rev*. 13(26):63-70.

Dawes CJ. 1998. Marine Botany, John Wiley & Sons.

Esmaeili A, Khakpoor M. 2012. Biological activities and chemical composition of solvent extracts of *Stoechospermum marginatum* (C. Agardh). *Acta Biochimica Polonica* 59 (4): 581–585.

Fantonalgo R N. 2018. Preliminary Study on Biogeography and Diversity of Red Alga *Halymenia* in Manila Bay, Philippines. *Annal. Geograph. Stud.*1 (1): 1-10.

Felício, Rafael de, Pavão, Gabriel B., Oliveira, Ana Lígia L. de, Erbert, Cíntia, Conti, Raphael, Pupo, Monica T., Furtado, Niege A.J.C., Ferreira, Elthon G., Costa-Lotufo, Letícia V., Young, Maria Cláudia M., Yokoya, Nair S., Debonsi, Hosana M. 2015. Antibacterial, antifungal and cytotoxic activities exhibited by endophytic fungi from the Brazilian marine red alga *Bostrychia tenella* (Ceramiales). *Rev. bras. farmacogn.* 25(6), 641-650. https://doi.org/10.1016/j.bjp.2015.08.003.

Ganesan M, Trivedi N, Gupta V, Madhav S, Reddy CRK, Levine IA. 2019. Seaweed resources in India – current status of diversity and cultivation: prospects and challenges, *Bot. Mar.* 62(5), 463-482. Doi: https://doi.org/10.1515/bot-2018-0056

Haniya, AMK, Sweety F Y, Kothari S, Mahalakshmi K. 2015. Antibacterial activity of *Chaetomorpha litorea* (Harvey) against isolated fish bacteria. *Indian J. Mar. Sci*. 44 (3): 416-420.

Hannon C, Officer RA, Dorven JL, Chamberlain J. 2014. Culture methods of live algal feeds for European aquaculture: optimising culture conditions for *Ulvellalens*. *Aquacult Int*. DOI 10.1007/s10499-014-9784-4.

http://www.seaweed.ie/ The Seaweed Site: information on marine algae.

Iyengar MOP.1927. Krusadai Island Flora. *Bull. Madras Govt. Mus. N.S. Nat. Hist. Sect*. 1(1): 185–188.

Jha B, Reddy CRK, Thakur MK, Rao MU. 2009. *Seaweeds of India: The Diversity and Distribution of Seaweeds in Gujarat Coast*. CSMCRI, Bhavnagar.1-215.

Kaeffer B, C. Bénard, M. Lahaye, H.M. Blottière, C. Cherbut. 1999. Biological properties of ulvan, a new source of green seaweed sulfated polysaccharides, on cultured normal and cancerous colonic epithelial cells, *Plant Med*. 65: 527–531.

Kaliaperumal N, Kaliamuthu S, Ramalingam J R. 1995. *Economically Important Seaweeds*. CMFRI special publication 62: 1–35.

Kavale MG, Kazi M A, Bagal P U, Singh VV, Behera D P. 2018. Food value of *Pyropia vietnamensis* (Bangiales, Rhodophyta) from India. *Indian J. Mar. Sci*. 47 (2): 402–408.

Khambhaty Y, Mody K, Gandhi MR, Thampy S, Maiti P, Bhrahmbhatt H, Eswaran K, Ghosh PK. 2012. *Kappaphycus alvarezii* as a source of bioethanol. *Biores. Techn.* 103 (1): 180–185.

Khan SI, Satam SB. 2003. Seaweed Mariculture: scope and potential in India. Aquaculture Asia, 4 (4): 26-28.

Kotteswari M, Shanthi N, Elamvaluthi M, Murugesan S. 2015. Antibacterial activities of *Caulerpa scalpelliformis* (R. Brown ex Turner) C.Agardh from the Gulf of Mannar south east coast of India.*European J. Pharm. Med. Research 2(4), 900-907.*

Krishnamurthy VK, Joshi HV. 1970. A Check-List of Indian Marine Algae. Central Salt and Marine Chemicals Research Institute: Bhavnagar, India; 1-36.

Krishnan M, Kumar RN.2010. Socio-economic dimensions of Seaweed Farming in India. Central Marine Fisheries Research Institute. CMFRI Special Publication No. 104.

Li Y, Siqi S, Xiaowei P, Yuzhe Y, Fei Z, Shouyu Z, Nianjun X. 2018. Evaluation of Antimicrobial Activities of Seaweed Resources from Zhejiang Coast, China. Sustainability10, 2158; doi:10.3390/su10072158

Lideman G, Nishihara N, Tadahide N, Terada R. 2011. *In Vitro* Growth and Photosynthesis of Three Edible Seaweeds, *Betaphycus gelatinus*, *Eucheuma serra* and *Meristotheca papulosa* (Solieriaceae, Rhodophyta). *Aquaculture Sci.* 59 (4): 563-571.

Manilal A, Sujith S, Selvin J, Kiran G S, Shakir C. 2009. In vivo Antiviral activity of Polysaccharide from the Indian Green Alga, *Acrosiphonia orientalis* (J. Agardh): Potential Implication in Shrimp Disease Management. *World J. Fish Mar. Sci*. 1(4): 278–282.

Manilal A, Selvin J, Sujith S, Panikkar MVN. 2012. Evaluation of therapeutic efficacy of Indian Green Alga, *Acrosiphonia orientalis* (J. Agardh) in the treatment of vibriosis in *Penaeus monodon*. *Thalassas*, 28 (1): 33-46.

Manilal A, Sujith S, Subarathnam B, Kiran G S, Selvin J, Shakir C, Lipton A P. 2010. Bioactivity of the Red algae *Asparagopsis taxiformis* collected from the south western coast of Kerala. *Brazilian J. Ocean.* 58 (2): 93–100.

Mantri VA, Kavale MG, Kazi MA. 2019. Seaweed Biodiversity of India: Reviewing Current Knowledge to Identify Gaps, Challenges, and Opportunities. Diversity, 12(1): 13. doi:10.3390/d12010013

Mantri VA, Rao PVS. 2005. Diu Island: A paradise for tourists and seaweed biologists. *Curr. Sci.* 89: 1795–1797.

Mary A, Mary V, Lorella A, Matias JR. 2009. Rediscovery of naturally *Caulerpa lentillifera* occurring seagrape from the Gulf of Mannar and its mariculture. *Curr. Sci.* 97:1418–1420.

Masami GO, Usui IY, Urano N. 2008. Ethanol production from the water hyacinth *Eichhornia crassipes* by yeast isolated from various hydrospheres. *Afr. J. Microbiol. Res*. 2, 110–113.

McHugh DJ. 2003. A guide to the seaweed industry. FAO Fisheries Tech. Paper: 441, 105.

Michalak I, Mahrose K. 2020. Seaweeds, Intact and Processed, as a Valuable Component of Poultry Feeds. *J. Marine Sci. Eng.* 8(8): 620.

Mintardjo K. 1990. Status of production and utilization of seaweeds Indonesia. Part II: country status reports. Report of the Regional Workshop on the Culture & Utilization of Seaweeds, FAO, Cebu City, Philippines, 27–31.

Mukhopadhyay A, Pal R. 2002. A report on biodiversity of algae from coastal West Bengal (South & North 24–Parganas) and their cultural behaviour in relation to mass cultivation programme. *Indian Hydrobiol*. 5 (2): 97–107.

Munir M, Qureshi R, Bibi M, Khan AM. 2019. Pharmaceutical aptitude of *Cladophora*: A comprehensive review. Algal Research, 39, 101476. doi: 10.1016/j.algal.

Muthuvelan B., Chennubhotla VSK, Nair KVK, Sampath V Ravindran M. 2001. Seaweed standing crop biomass and comparative distribution in eastern shoreline of Middle and North Islands. *Indian Hydrobiol*. 4: 139–148.

Nedumaran T, Arulbalachandran D. 2014. Seaweeds: A Promising Source for Sustainable Development. Environmental Sustainability; 65–88. Doi:10.1007/978-81-322-2056-5_4.

Oza RM, Zaidi SH. 2001. A Revised Checklist of Indian Marine Algae. CSMCRI, Bhavnagar, India. 1–296.

Palanisamy M, Yadav SK. 2019.Seaweed flora of Goa coast. Technical report. Botanical Survey of India, Kolkata.

Palanisamy M, Yadav SK. 2015.Seaweeds of Kerala coast, India. Technical report Botanical Survey of India, Kolkata.

Pati MP, Sharma SD, Nayak L, Panda CR.2016. Uses of seaweed and its application to human welfare: a review. *International J. Pharm. Pharm. Sci*. 8 (10): 12-20.

Pereira N, Almeida M R. 2014. A preliminary checklist of marine algae from the Coast of Goa. *Indian J. Geo–Mar. Sci.* 42 (4): 655–665.

Piwalatkar, SS. 2010.*Marine Algal Flora of the Maharashtra Coast, India*. Botanical Survey of India, Western Regional Centre, Pune. Ph.D. thesis. University of Pune, India.

Priya P, Murugesan S Kotteswari M, Shanthi N and Sivamurugan V. 2018. Antibacterial activity of marine red alga *Grateloupia lithophila* Boergesen. *International J. Pharmacy Biol. Sciences* 8(3):1125-1129

Ramachandra TV, Deepthi H. 2016. Bioethanol prospects of Algae in Central West Coast of India. *Synergy with Energy* 51-59. Saket Publishers.

Rani MV, Usha SR, Josephine MM. 2011. Seaweeds as an alternative natural resource for mitigating Cu/Pb stress in Dolichus biflorus L. *Seaweed Res. Utiln.* 33 (1&2): 133 – 142.

Rani P, Bast F. 2019. First Report of *Ulva sapora* (Ulvales, Chlorophyta) from Indian Subcontinent. *International J. Plant Environ*. 5(1):50-56.

Rao PSN, Gupta RK. 2015. *Algae of India*, Vol 3: A checklist of Indian Marine Algae (Excluding Diatoms & Dinoflagellates). BSI, Kolkata. 1–93.

Rao PVS, Mantri VA.2006. Indian Seaweed resources and sustainable utilization: Scenario at the dawn of a new century. *Curr. Sci.* 91 (2): 164-174.

Roy S, Anantharaman P. 2018. Biosynthesis of Silver Nanoparticle by *Amphiroa anceps* (Lamarck) Decaisne and Its Biomedical and Ecological Implications. *J. Nanomed Nanotechnol*. 9: 492. doi: 10.4172/2157-7439.1000492.

Sahoo D, Sahu N, Sahoo D. 2003. A critical survey of seaweed biodiversity of Chilika lake, India. *Algae* 1–12.

Sangeetha, P, Babu S, Rengasamy R. 2011. Potential of green alga *Chaetomorpha litorea* (Harvey) for biogas production. *International J. Curr. Sci*. 24-29.

Shahnaz L, Shehnaz H, Haider A. 2019.Fourier transform infrared (ft-ir) spectroscopic investigations of four agarophytes from northern Arabian sea. *Bangladesh J. Bot.* 48(4): 925-932.

Shanmugam M, Mody KH, Ramavat BK, MurthyA, Sai K, Siddhanta, AK. 2002. Screening of Codiacean algae (Chlorophyta) of the Indian coasts for blood anticoagulant activity. *Indian J. Mar. Science* 31(1): 33-38

Sharmila S, Rebecca L. 2012. GC-MS analysis of esters of fatty acid present in biodiesel produced from Cladophora vagabunda. *J. Chem. Pharm. Res*. 4: 4883–4887.

Shynu SP, Shibu S, Jayaprakas V. 2014. The economically valuable seaweeds of Thirumullavaram, southwest coast of Kerala. *J. Aquat. BioI. Fish.* 2(1): 133–237.

Siddhanta AK, Shanmugam M, Mody KH, Goswami AM, Ramavat BK. 1999. Sulphated polysaccharides of *Codium dwarkense* Boergs. from the west coast of India: chemical composition and blood anticoagulant activity. *Inter. J. Biol. Macromolecules*. 1999 Nov;26 (2-3):151-154. DOI: 10.1016/s0141-8130(99)00079-3.

Simpi CC, Nagathan CV, Karajgi SR, Kalyane NV. 2013. Evaluation of marine brown algae *Sargassum ilicifolium* extract for analgesic and anti-inflammatory activity. *Phcog. Res*. 5 (3):146-149.

Singh, HS. 2003. Marine protected areas in India. *Indian J. Mar. Sci*. 32 (3): 226–233.

Smit AJ. 2004. Medicinal and pharmaceutical uses of seaweed natural products: A review. *J. Appl. Phycol*. 16: 245 – 262.

Sobha V, Santhosh S, Ghita G, Valsalakoijumar E. 2008. Food products from seaweeds of south Kerala coast. *Seaweed Res. Utiln.* 30(1&2): 199–2003.

Stabili L, Acquaviva MI, Angile F, Cavallo RA, Cecere E. Del C.L, Fanizzi FP, Gerardi C, Narracci M, Petrocelli A. 2019. Screening of *Chaetomorpha linum* Lipidic Extract as a New Potential Source of Bioactive Compounds. *Mar. Drugs17*, 313.

Sujatha K, Vethanayagi G, Ramamoorthy K. 2011. Studies on the effects of seaweed extracts on storage potential in bhendi seeds. *Seaweed Res. Utiln.* 31 (1&2): 125 - 131.

Surayot U, Lee JH, Kanongnuch C, Peerapornpisal Y, Park W, You S. 2016. Structural characterization of sulfated arabinans extracted from *Cladophora glomerata* Kützing and their macrophage activation. *Biosci. Biotechnol. Biochem*. 80: 972–982.

Taskin E, Ozturk M, Taskin E, KurtO. 2007. Antibacterial activities of some marine algae from the Aegean Sea (Turkey). *African J. Biotech*. 6 (24): 2746-2751.

Thivy F. 1960. Seaweed utilization in India. *In* Proc. Symp. Algology. Indian Council of Agricultural Research, New Delhi.

Tseng CK. 2004. The past, present and future of phycology in China. *Hydrobiologia* 512: 11–20.

Usha SR. Rani MV, Josephine MM, Flora G. 2013. Effect of *Padina pavonica* extract o n soil fertility and biochemical profile of *Vigna unguiculata* under unduced lead stress. *Seaweed Res. Utiln.* 35 (1&2): 129 – 137.

Yadav SK, Palanisamy M. 2020: Eleven new additions to marine macro algal flora of Karnataka coast, India. *Nelumbo* 62 (1): 90-102.

Zhao C, Yang C, Liu B. 2016. Biological activities of green macroalgae *Enteromorpha prolifera* for potential applications. *MOJ Food Process. Technol*. 2(5):153–155.

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