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Review

Southern Ocean seaweeds: A resource for exploration in food and drugs

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ABSTRACT

Benthic macroalga or seaweed, a wonder plant in the sea, has been attracting the human mind since centuries. Countries of south and south East Asia have put in extensive use of this plant for various purposes such as food, feed, fodder, etc. Development of seaweed in these countries was favored by their ready availability and proximities to centers of human population that were particularly concentrated in coastal areas. In the beginning, those seaweed species that could be used for food were the first to be utilized and later the other species were found to yield industrial, medicinal, pharmaceutical and cosmetic products.

A number of constraints will be required to be adapted if world's seaweed industry is to be developed and stabilized. This is mainly because of uncertainty in supply of raw material and sudden burst in demand that occur in cycles. The seaweed resources have undergone successive periods of over exploitation and neglect. Alternatively, new areas shall have to be explored which could supply rich and high quality seaweeds. The Southern Ocean has immense potential for attracting urgent attention for development and exploitation of seaweed resources.

A number of investigations are underway to assess the uses of Antarctic seaweeds. Recently, an active ingredient from Antarctic seaweed has been identified, which blocks the effects of metalloproteinase, an enzyme that accelerates the skin aging process. A skin care products derived from polar seaweeds has been a latest craze in France and are dedicated to men between 25 and 50 years of age. Antarctic red algae have recently been identified for their chemodiversity, containing compounds possessing antibacterial and other inhibitive properties to marine animals. The important fact remains that before we go for actual harvesting it is necessary that we have full details of their ecophysiology and annual cycle of occurrence at particular region and devise a legal framework after extensive debate with experts, for sustainable use of this valuable resource.

Contents

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1. Introduction

The Southern Ocean being highly productive ecosystem, it supports various components of potentially high commercial value. Recently, there has been a renewed interest in the “Living Resources of the Southern Ocean”, following the decline in the world fisheries. The resultant efforts are towards the critical appraisal of the stocks, harvestable fish quantities, and environmental health of the region, for sustainable management of this invaluable resource. However in addition to fisheries, yet another crucial renewable living resource that sustains the Southern Ocean is the marine benthic macroalgae or seaweed.

The geographical distribution of seaweeds are related to temperature regime of the region for growth, reproduction, and survival (Van den Hoek, 1982a,b; Breeman, 1988). The taxonomy and distribution of the seaweed flora of the Southern Ocean has been studied since very beginning of the Antarctic explorations (Heywood and Whitaker, 1984; Moe and Silva, 1989; Dayton, 1990; Chung et al., 1990, 1994; Kloser et al., 1994). Lawson (1988) recorded the first numerical analysis using “Detrended Correspondence Analysis (DECORANA)”, on 1200 seaweed species from 36 sites in the Southern Ocean. John et al. (1994) further revised this particular data, with addition of new-recorded seaweed species form Macquarie, South Georgia Islands and Terra Nova Bay.

Attempts on Antarctic seaweed physiology studies are made with particular emphasis on photosynthesis, respiration, plant growth, and tissue composition (Drew, 1977; Drew and Hasting, 1992). The macrophyto-benthos component in Antarctica often serves as a hard substratum for numerous sessile organisms supporting the development of complex benthic communities (Kloser et al., 1996). In such an environment, macroalgae serves as an important source of energy for associated grazers (Dhargalkar et al., 1988) and contribute remarkably to the benthic detrital food chains (Reichardt, 1987). However, quantitative observations on the density and biomass of algal population are yet to receive due attention.

Information on the benthic food web of the Southern Ocean is a fundamental necessity for comprehension of the food web structures as well as other functions such as seaweed productivity, quantitative assessment of biomass, grazing pressure and anti-grazing strategies, under extreme environmental conditions. Recently, Wiencke et al. (2007) summerised life strategy, ecophysiology and ecology of seaweeds in polar waters. Their study reveals that understanding of the specific characteristics and adaptations of Polar seaweeds necessarily explains the ecological success of this resource under environmentally extreme conditions. However, these authors opine that more in-depth studies on eco-physiology of supra and eulittoral species, protection from harsh environmental stresses and biochemical adaptation in extreme environment are essential to address the problem in detail.

The present communication therefore aims towards the assessment of seaweed population in the Southern Ocean for biomass and productivity. Attempts have also been made to quantify the potential seaweed species for commercial exploration for its unique use as bioactive compounds, cosmetic ingredients, high quality phycocolloids and many other properties. Methodologies are proposed to develop and manage this resource for sustainable utilization.

2. World seaweed resources

The total world seaweed production estimated to be 8.5 million metric tones (excluding Antarctic seaweeds). Of this, 88.65% i.e. 7.5 million metric tonnes are produced by cultivation in an area of 200×10^3 ha, while remaining 0.96 million metric tonnes are exploited from the natural seaweed beds world over (FAO, 2003). The seaweed industry uses 7.5–8 million metric tonnes of wet seaweeds annually, either from the wild or from cultivated crop. The estimated value of wide variety products that derived from the seaweeds is US$ 5–6 billion (FAO, 2004).

The three commercially important phycocolloids obtained from seaweeds are alginates, agar-agar and carrageenan. Seaweed genera used for extraction of alginates are *Ascophyllum*, *Durvillaea*, *Eclonia*, *Lessonia*, *Laminaria*, *Macrocystis*, *Sargassum*, *Turbinaria* etc. The major alginate producing countries are Scotland, Norway, China, Argentina, Australia, Canada, Chile, Mexico, Ireland, Japan and USA. Alginate production is valued US $ 213 million annually. None of the alginate yielding seaweeds is cultured so far, as they cannot grow by vegetative means. Cultivation of alginophytes warrants insight into the reproductive cycle involving alternation of generation that make their farming expensive and time consuming when compared to the cost of harvesting and transportation of wild seaweeds. Only *Laminaria japonica*, an alginate yielding seaweed is being cultivated in China mainly for food while some surplus used for the extraction of alginate.

Carrageenan production was originally dependent on wild seaweeds species, especially *Chondrus crispus* (Irish moss). Cultivation of species namely *Kappaphycus alvarezii* and *Eucheuma denticulatum* became widespread as the carrageenan industry expanded. Denmark, Ireland, New Zealand, Nova Scotia, China, Japan and Mozambique are the major carrageenan producers in the world and their annual produce is valued at US $ 240 million. Of the total production, only 20% is obtained from the natural seaweed stock while the balance of 80% from the cultivated species by countries such as Philippines, Indonesia and United Republic of Tanzania.

Another important colloid with wide industrial application is agar-agar, derived principally from two genera of red seaweed namely *Gelidium* and *Gracilaria*. *Gelidium* yields high quality product from natural resource. Yield from *Gracilaria* is of low quality. However, the recent technique of pre-treatment with alkali before extraction increases the quality of agar. Although supply of *Gracilaria*, still derived from the wild, cultivation in ponds and open coast started in Chile and other countries. Spain, Portugal, Korea, France, Morocco, USA, Mexico, Chile, New Zealand and Japan are the major agar producing countries with a produce value of around US $ 132 million annually.

Earlier, industrialization of seaweeds began with the production of soda and potash from the brown seaweeds for manufacture of soap, glass and iodine (Jensen, 1979). The multipurpose uses of seaweed phycocolloids, such as emulsifier in dairy products, leather, textile and pharmaceutical industries, treatment of arthritis, metal poisoning, bone grafting, immobilization of biological catalyst in the industrial processes, therapeutic health booster, beauty enhancer etc; have immense value (Dhargalkar and Periera, 2005). Seaweeds are also used as fertilizer in agriculture and horticulture, food supplement for animals, feed for aquaculture, etc. Presently, seaweed based food additives are commonly used in preparation of fast food. In that, virtually every one eats some processed seaweeds every day. Seaweeds are easy to digest and rich in vitamins, mineral salts and oligo-elements.

All these and many more uses investigated will require large quantity and high quality seaweed raw material that will exert great pressure on the existing natural seaweed resources. The demand for phycocolloid increases by 8 to 10% every year. The colloid producers need to secure their seaweed resource and draw their supply from the variety of geographic areas. In case seaweed supply from a particular location is affected by climatic conditions (such as the El Nino event that had destroyed *Ecklonia* sp. population in Northern and Southern Hemispheres), over exploitation, pollution or disease, etc; then the same could be restored from an alternate site. It is likely that harvesting of wild seaweed resource on continuous year round basis may result in overexploitation and loss of ecological balance.

Notwithstanding the shortage in the supply of seaweed resource and rapid rising cost of certain species on the coastal mainland of the world, it is important to search new untapped grounds. Perhaps the Southern Ocean region, which is pristine, virgin, and so far unexplored, could be a potential alternative for seaweed resource. This is particularly true with reference to the phycocolloid producing industries, which can draw uninterrupted supply of raw material.

3. Southern Ocean seaweeds

The exploratory voyages of the L'Uranie and the La Physicienne during 1817–1920 led to the discovery of rich and varied seaweed flora from Antarctic and sub Antarctic waters (Papenfuss, 1964; Godley, 1965). These studies mostly related to the taxonomy and bio-geographic distribution that resulted in the publication of a seaweed catalogue (Papenfuss, 1964). According to Papenfuss (1962, 1964), out of 550 species of seaweeds recorded from the Antarctic and sub-Antarctic regions, 250 species were endemic. This researcher however, opined that there exists an inadequacy in the taxonomy of Antarctic species. Subsequently, several attempts were made to explain and summarize the distribution of seaweeds of the Southern Ocean (Ekman, 1935, 1953; Delepine, 1963, 1966). South (1979) based on comprehensive evaluation and synthesis of biogeography of the marine algae, concluded that there are numerous gaps in our knowledge of algal taxonomy and distribution.

Further taxonomic revision on the benthic marine macroalgae of the Southern Ocean was carried out by Moe (1985), Ricker (1987), Moe and Silva (1979, 1983, 1989). In addition to this, Smith and Simpson (1985), Zielinski (1981, 1990), Cormaci et al. (1992a), John et al. (1995) undertook the shore exploration of benthic macroalgae.

Subsequently numerous diving investigations conducted in West Antarctica were by Neushul (1965), Delepine (1966), Lamb and Zimmermann (1977) Moe and DeLaca (1976), Richardson (1979), Kloser et al. (1996), and East Antarctica by Zaneveld (1968) and Cormaci et al. (1996). Together with this, the results obtained from dredging investigations (Zielinski, 1981, 1990) gave first insight to zonation patterns of Antarctic seaweeds. Clayton and Wiencke (1986) and Wiencke (1988) carried out isolation and culture of Antarctic seaweeds. Before this, the life history of Antarctic seaweeds was mostly unknown and eco-physiological data fragmentary. Clayton (1994) summarized the present state of our knowledge regarding the evolutionary aspects of Antarctic seaweeds, while Krist and Wiencke (1995) presented an account of eco-physiology of micro and macro algae from Antarctic and Arctic.

Information on distribution of seaweed species from the various sub-Antarctic and Antarctic islands and some of the coastal areas of the Antarctic continent reveal that Southern Oceans supports rich and varied seaweed flora. (Lamb and Zimmermann, 1977; Santelices et al., 1980; Smith and Simpson, 1985; Ricker, 1987; Lawrence, 1986; Dhargalkar, 1990; Beckley and Branch, 1991; Amsler et al., 1990; Fisher and Wiencke, 1992; Brouwer et al., 1995; Cormaci et al., 1996; Gallardo et al., 1999). The vast seaweed beds in vicinity of the sub Antarctic islands and coastal Antarctica hold potential seaweed resource for future exploitation. This part of the Ocean sustains an estimated in all 700 seaweed species belonging to 300 genera. However, not all the species are of interest for exploitation purpose except for some 60 genera, which include species of commercial interest.

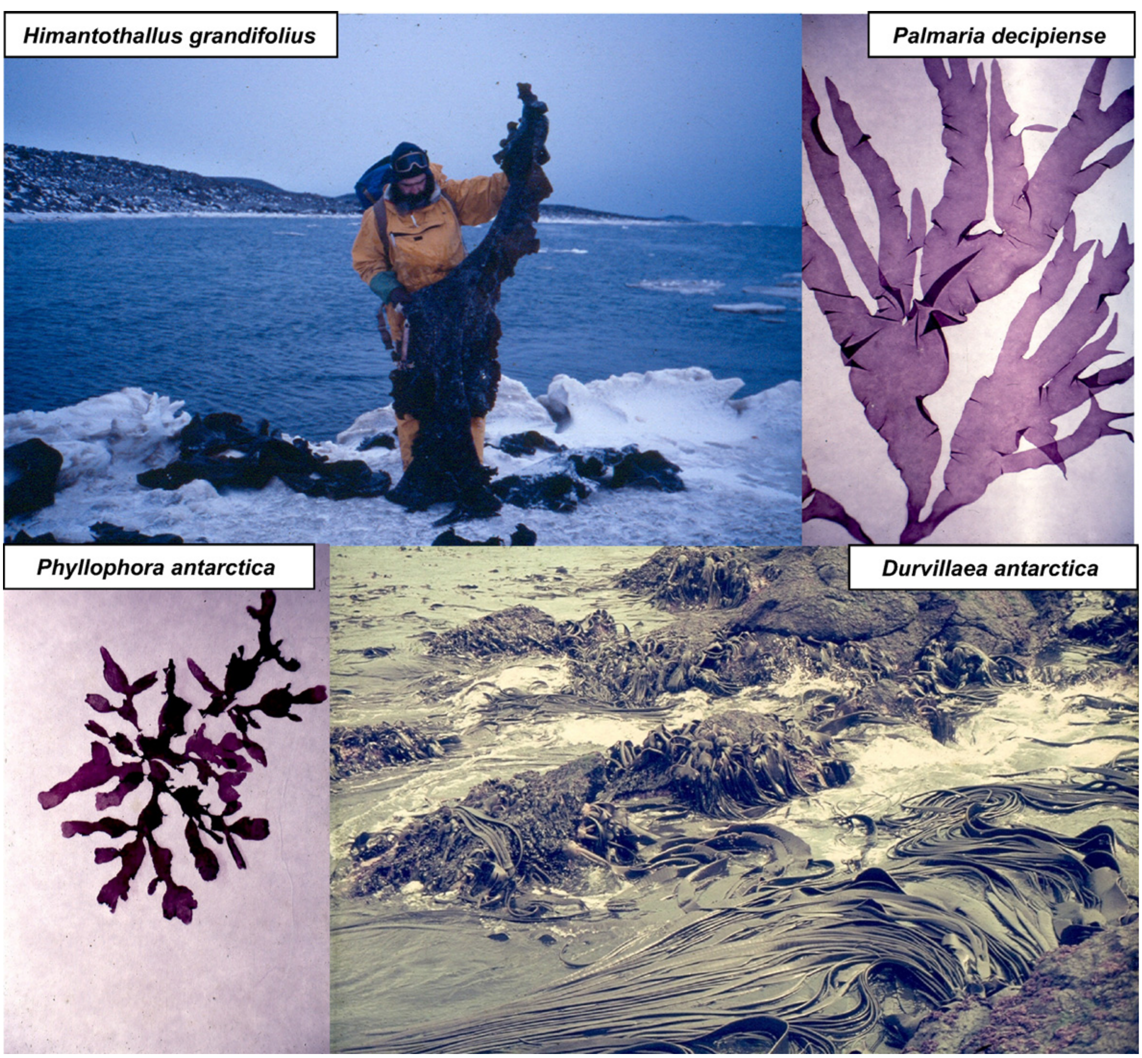

Plate 1. Commonly occurring Southern Ocean seaweeds: a) truly Antarctic species—*Himantothallus grandifolius*, *Palmaria decipiense* and *Phyllophora antarctica* b) sub-Antarctic species *Durvillaea Antarctica*.

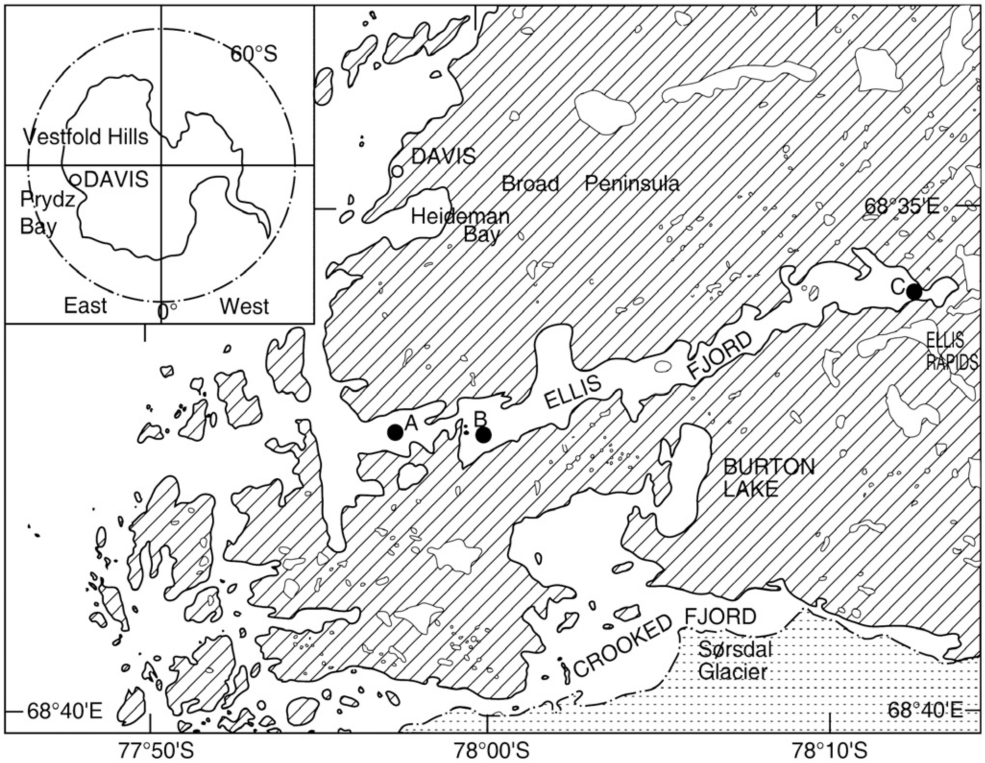

Fig. 1. Map of the Vestfold Hills, Antarctica showing stations sampled in the Ellis Fjord.

Although, quantification of the seaweed resources of the Southern Ocean has not been systematically documented, nevertheless, the reliable biomass estimates of some of the economically important seaweed species could certainly be made available. These seaweed species are widespread and largely unexplored and hence could be the future resource, awaiting critical attention for exploitation (Lamb and Zimmermann, 1977; Beckley and Branch, 1991; Gallardo et al., 1999).

3.1. Eco-biological studies

The eco-biological studies of any region help to understand the major ecological factors that shape the various communities in the ecosystem. Although, our understanding of the biology of Antarctic seaweeds has increased considerably, a lot more remains to be done as regards the structure and biodiversity of the algal communities, life histories of the individual species, adaptation to the seasonal variations and their physiological mechanism to grow and survive in harsh cold environment. Antarctic seaweed communities can be classified into i) ice-abraded zone of poorly developed seaweeds in shallow sub-littoral, b) a zone in central sub-littoral dominated by *Desmarestia anceps* and *D. menzeisii*, and c) a zone of *Himantothallus grandifolius* (Plate 1) at greater depths (Heywood and Whitaker, 1984; Dayton, 1990).

Table 1
Average underwater light intensity (μE m $^{-2}$ s $^{-1}$) at Vestfold Hills from May to December, 1983

Depth(m)	May	June	July	August	Sept.	Oct.	Nov.	Dec.
0	1.19	1.54	0.91	3.19	56.00	44.10	193.20	413.70
1	0.7	0.07	0.67	1.33	37.80	00.00	18.20	11.20
2	0.21	0.00	0.31	0.79	21.00		13.44	8.40
3	0.17		0.21	0.62	12.60		9.24	5.32
4	0.08		0.15	0.53	14.70		7.56	4.90
5	0.00		0.15	0.45	8.40		6.30	4.62
6			0.03	0.28	4.20		5.88	4.48
7			0.00	0.08	2.10		5.46	4.28
8				0.00	0.00		0.00	3.22
9								0.00

Sea-ice is the most important factor as far as the distribution of Antarctic seaweed is concerned. It precludes seaweed growth in the intertidal zone and down to 2 m below tide level for 10 to 12 months of the year. Interesting results were obtained on the year round studies on distribution, abundance, animal association and biodiversity of Antarctic seaweeds, undertaken by one of the authors, in the inshore waters of the Vestfold Hills (Fig. 1; Dhargalkar, 1990) in relation to sea-ice and environmental components. Exposed bare rocks in the intertidal area were colonized by *Porphyra endiviifolium*, *Geminocorpus austrogeorgia*, *Urospora penicilliformis*, *Enteromorpha bulbosa* and crustose coralline *Lithothamnium granuliferum* in the rock crevices and small rock pools.

The sub littoral zone was occupied by *Palmaria decipiens*, *Phyllophora antarctica* (Plate 1), *Cladophora subsimplex*, *P. endiviifolium* etc. *P. decipiens* shows luxuriant growth in summer. With the approach of winter, the growth became stunted and at many occasions basal portion of seaweeds almost withered. Non-availability of sufficient light, grazing by

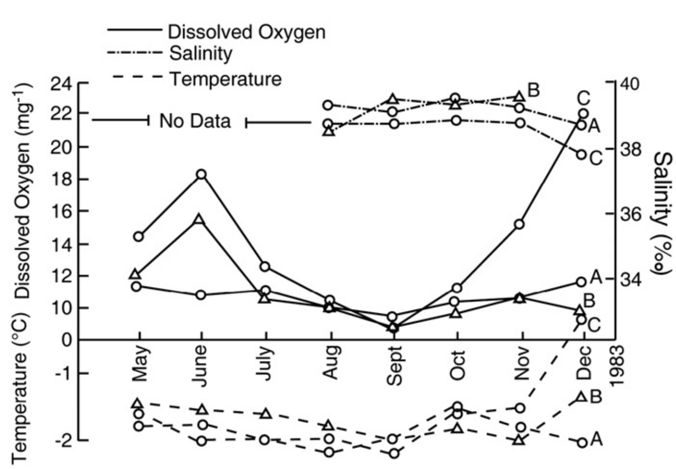

Fig. 2. Changes in water temperature, salinity and Dissolved oxygen at the sampling site in the Vestford Hills, Antarctica from May to December.

invertebrates and erosion of the meristimatic tissue due to the water movement and ice floes probably hindered the development of this seaweed in winter. The faster and luxuriant growth was seen during summer months by the brown algae, *H. grandifolius* (Plate 1) and *Desmarestia menzeiesii* in the deeper waters of Vestfold Hills. The large size of these species recorded during summer sustained their presence during winter/spring under the sea-ice. With the approach of the favourable conditions such as increased light (Table 1), accompanied by high temperature and abundant nutrient supply in summer these seaweeds tend to grow fast (Figs. 2 and 3). Physico-chemical observations at Vestfold Hills indicated that surface light intensity increased from September (256.2 µE m^{-2} s^{-1}) to December (413.7 µE m^{-2} s^{-1}) with proportionate attenuation at subsequent lower depths. Nitrate in the water ranged from 6.4 to 44.79 µmol l^{-1}, with highest concentration in November. The phosphate ranged from 0.93 to 2,2 µmol l^{-1}, with lowest values in May. Perhaps, the phosphate utilization in seaweeds is enhanced to overcome winter stress. These observations revealed that the coastal waters of the Vestfold Hills harbour rich and varied seaweed flora (Dhargalkar, 1990).

Observations on seaweed assemblages in Potter Cove as reported by Quantino et al. (2005) indicated that the difference in species composition between the groups was mainly related to depth and environmental parameters. The nitrogen (nitrates and nitrites) in the water of the Potter Cove ranged from 12.1 µM to 28.3 µmol l^{-1}. During the summer months, the surface water at the western coast was enriched with nutrients washed from the land drainage in Barton, Pinitos and Penon de Pesca. In Penon de Pesca the nitrate concentration was even higher at 20 and 30 m depth than near the surface. The phosphate concentrations ranged from 1.23 µM to 3.68 µmol l^{-1} with higher values only near the surface. At the intermediate depth in the cove species like *H. granadifolius*, *D. anceps*, *Georgia confluence*, *and Ballia callitricha* showed luxuriant growth (Quantino et al., 2005).

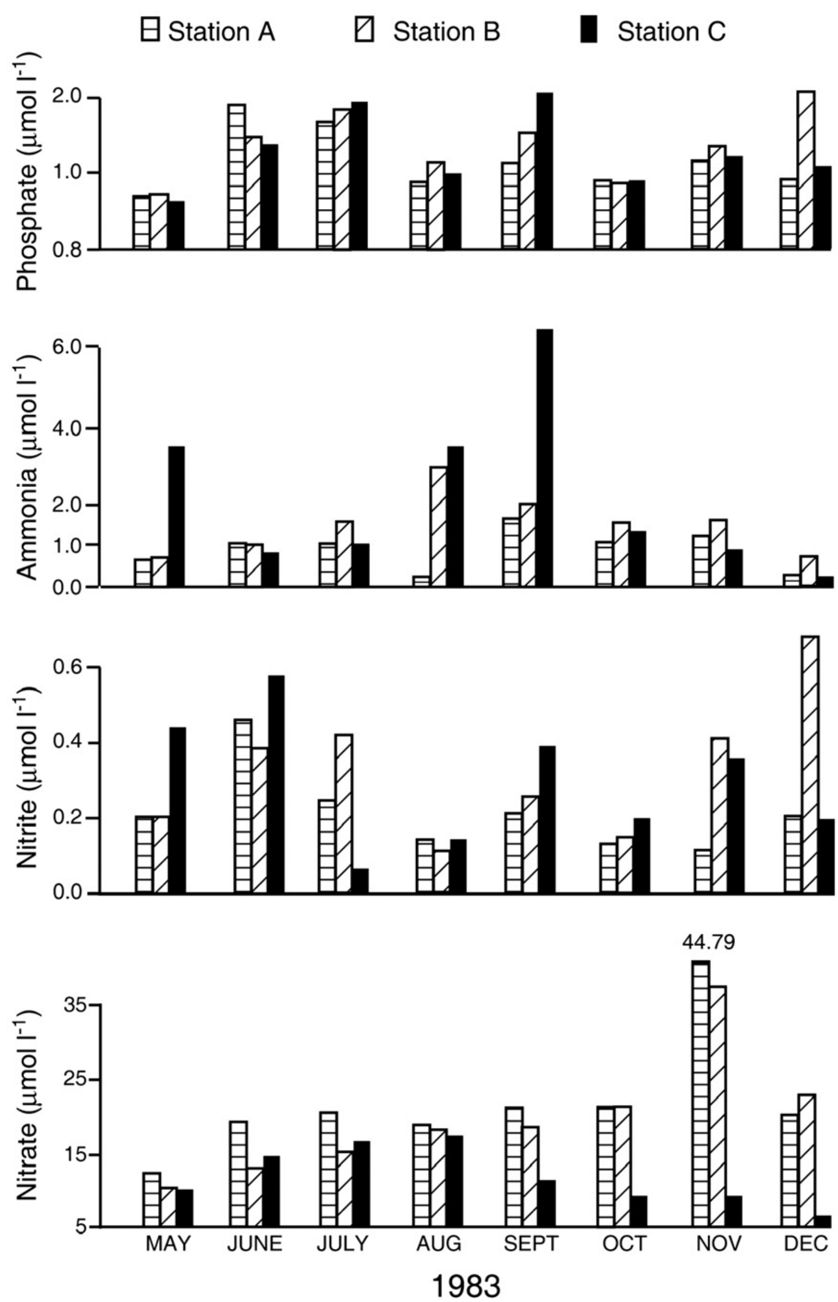

Fig. 3. Nutrient concentrations at three different sites in the Ellis Fjord, Antarctica (Station A—Oceanic site, Station B—inside the Fjord and Station C—end of the Fjord).

It has been observed that Antarctic seaweeds can tolerate dark periods up to one year without damage (Tom Dieck, 1993; Wiencke, 1988, 1990). They seem to have an extraordinary ability to live under the cover of sea ice, use low light, maximize photosynthesis when the light is stronger, and survive the long winter darkness (Dhargalkar, 2004). These properties determine the ability as to where the different types of seaweed can grow and contribute to rich Antarctic biomass production.

The tendency of seaweeds to grow on fine substrate (pebbles, gravel, and sand) with increasing depth has been observed in Potter Cove and on South Orkney Islands (Gomez et al., 1997). This is perhaps due to low turbulence in deep waters allowing the seaweeds to colonize substrate which could not provide sufficient encourage in shallow and more turbulent sites. Individual seaweed species may react to different factors in various ways such as *Desmarestia anceps* and *D. Antarctica*. These seaweeds indicate similar preference with regard to depth. However, the perennial *D. anceps*, out competes all other species at moderately exposed site, while the annual *D. antarctica* is a poor competitor, proliferating on terrain denuded by ice impact (Richardson, 1979; Kloser et al., 1994).

3.2. Biodiversity and distribution of seaweeds

The diversity and abundance of seaweeds depend on many environmental, chemical and biological factors. The low species diversity in Antarctic waters may be related to adverse physical conditions such as low water temperatures, reduced light caused by ice cover, seasonal solar declination and ice scour. Most abundant and diverse aggregation of seaweed species seems to be in open area exposed to waves and currents (Moe and DeLaca, 1976; Zielinski, 1990). As suggested by Moe and DeLaca (1976) the difference in algal assemblages is the result of variation in light penetration. These differences may be related to suspended sediments in the water column, shading by the phytoplankton bloom, temperature difference in water column, duration of ice cover, ice quality and ice thickness (Kloser et al., 1993).

Because of the extreme environmental conditions in the eulittoral, polar seaweeds are mainly sub tidal. Thus low light demand and tolerance to darkness are the pre-requisite for their occurrence down to greater depths (Zielinski, 1981; Richardson, 1979; Kloser et al., 1993; Amsler et al., 1995). Although, Antarctic seaweeds are sub tidal, there are some species that grow exclusively in the supra littoral zone. These species are *Prasiola crispa*, a green seaweed which grow more inland in the vicinity of sea bird rookeries, where low pH and high nutrients conditions prevail (Knebel, 1936) and red seaweed *Bangia atropurpurea* (Bird and Mclachlan, 1992; Clayton et al., 1997). Filamentous green seaweeds such as *E. bulbosa*, *C. subsimplex*, *U. penicilliformis*, *Ulothix* spp. and brown seaweed *G. austrogeorgia* grow in the rock crevices or furrows and rock pools in the lower supra littoral. They are subjected to high light intensity, freezing, high temperature, desiccation, osmotic shocks and large excess of essential nutrients especially the nitrogen and phosphorous.

An exposed bare rock in the intertidal area is colonized by *P. endiviifolium*, *Monostroma hariotii* and crustose coralline *Lithothamnium granuliferum*. The most common species in upper eulittoral is *P. endiviifolium* and in the lower eulittoral the green seaweed *E. bulbosa* and the brown *Adenocystis utricularis*. In the tide pools and rock crevices in the upper sub littoral are colonized by *P. decipiens* and *Iridaea cordata* (Dhargalkar, 1990). As this zone is exposed to ice floes, it is devoid of large perennial seaweeds, however, crustose coralline seaweeds and developmental stages of other seaweeds occur here. *P. antarcica*, an endemic Antarctic species is frequent and abundant throughout infra-littoral and in upper few metres of the sub-littoral zones. This species along with *I. cordata* grow abundantly forming a dense canopy between 4 and 8 m depth and forms homogeneous population at 12 m depth. Bischoff-Basmann and Wiencke (1996) demonstrated that *P. antarctica* showed a growth optimum between 0 and 5 °C with a specific growth rate of 6% d $^{-1}$ at 0 °C and upper survival temperature (UST) between 7 and 14 °C. This species has been included in the group of endemic stenothermal species.

Below this zone large brown seaweeds like *Ascoseria mirabilis*, *D. menzeisii* occur in the upper sub littoral, *D. anceps* in mid sub littoral and *H. grandifolius* in lower littoral (DeLaca and Lipps, 1976; Amsler et al., 1995; Kloser et al., 1996; Quantino et al., 2001, 2005). *H. gandifolius* occurs at greater depths on fine grained substrate (Wiencke and Clayton, 2002; Neushul, 1965; Delepine, 1966; DeLaca and Lipps, 1976; Kloser et al., 1994, 1996; Fisher and Wiencke, 1992). This species becomes dominant in places where *Desmarestia* spp. cannot grow due to the absence of suitable substrate (solid rocks or boulders). *D. menzeisii* prefers wave exposed sites on solid rocks and boulders in the upper and mid sub-littoral zones.

Low light conditions are major limiting factor for seaweeds to grow at great depth. Gomez et al. (1997) owes that the metabolic carbon balance determines the lower depth distribution limit of an individual species. For the red seaweeds *P. decipiens*, and *Gigartina skottsbergii*, a metabolic carbon balance between 0.6 and 0.8 mg C g $^{-1}$ FW d $^{-1}$ sets the limit for growth at >30 m. *H. grandifolius* that grows luxuriantly at 15 m depth shows that its daily carbon balance is low but relatively similar between 10 and 30 m. This, indicates that the species can grow much deeper, while in *D. anceps* growth is limited to 30 m depth due to its negative carbon balance (−1.9 mg C g $^{-1}$ FW d $^{-1}$; Gomez et al., 1997).

Weykam et al. (1996) and Gomez et al. (1997), while reporting the relation between photosynthetic characteristic and seaweed zonation, in 36 seaweed species from King George Island indicated, high degree of shade adaptation in these seaweeds. They observed that: a) the photosynthetic efficiency (α) was high in all the studied species, reflecting a clear shade adaptation over broad range of depths, b) seaweed growing at depth >10 m exhibited low saturation point for photosynthesis (E_k:<40 μ mole m $^{-2}$ s $^{-1}$), irrespective of their taxonomic position, c) the highest E_k values (>50 μ mole m $^{-2}$ s $^{-1}$) were observed in species common in the upper sub littoral or eulitoral and d) shallow water species had higher photosynthetic capacity (P_{max}) than form deeper waters (Wiencke et al., 1993; Eggert and Wiencke, 2000).

Antarctica has been isolated from other continents since opening of the Drake Passage in the Oligocene and its water characterized by low temperatures since the Miocene period (Hempel, 1987). This isolation has resulted in a high degree of endemism in Antarctica. About 33% of seaweed species are endemic to the Antarctic region. Because of strong effect of Antarctic Circumpolar Current on the dispersal of seaweed propagules (Luning, 1990) many non-endemic species of the Antarctic seaweed flora have a circumpolar distribution. At least twenty seaweed species from Antarctic waters are cosmopolitan. Red seaweed *I. cordata*, *Plocamium cartilagineum*, *Petalonia fascia* and *Ulothrix flacca*, brown seaweed *Geminocarpus geminatus* and green *Monostroma hariotii* are among the species occurring in sub-Antarctic Island and Terra del Fuego (Papenfuss, 1964; Wiencke and Clayton, 2002). Some species such as *B. callitricha* and *A. utricularis* occur in New Zealand and Australia.

In Antarctic waters photosynthesis show considerable adaptation to low temperatures. Maximum photosynthetic 4 rates in endemic Antarctic seaweed species are at a temperature of 0 °C (Drew, 1977; Thomas and Wiencke, 1991; Eggert and Wiencke, 2000). The lowest temperature optima for brown seaweeds *A. mirabilis* have been determined at 1–10 °C and *H. grandifolius* at 15–19 °C (Drew, 1977; Wiencke et al., 1993). The red seaweeds *B. callitricha* and *G. skottsbergii* also exhibit values between 10 and 15 °C, where as *Kallymenia antarctica*, *Gymnogongrus antarcticus* and *Phyllophora ahnfeltioides* exhibited broad temperature optima between 10 and 20 °C (Eggert and Wiencke, 2000).

About 119 species of seaweeds have been recorded from Antarctic waters (Wiencke and Clayton, 2002). Most of these occur in the Antarctic Peninsula region and very few from southern most distribution limit in

Ross Sea. Amsler et al. (1995) quantified seaweed communities of the Antarctic Peninsula while two other studies dealt with Ross Sea species were by Miller and Pearse (1991) and Cormaci et al. (1996). Lower number of seaweeds species seen in the Ross Sea is attributed to lasting ice cover of 10 months (Zaneveld, 1966; Cormaci et al., 1992a). In Terra Nova Bay the most abundant species haven been reported to be *U. penicilliformis*, *I. cordata*, *P. antactica* and *Clathromorphum lemoineanum* (Cormaci et al., 1992b).

Most of the information at Potter Cove is the result of the studies carried out in the sub tidal flora through SCUBA diving (Kloser et al., 1994) or using video cameras (Kloser et al., 1996). These methods assessed the variability in the abundance of species with larger thalli than the differences in the qualitative composition of the flora. The most abundant species at 5 m depth were *A. mirabilis* and *Curdiea racovitzae* that grew exclusively on boulders. The number of seaweed species recorded from the sub-Antarctic and Antarctic region are given in Table 2 and Fig. 4.

3.3. Seaweed biomass

Interestingly Antarctic Peninsula holds a luxuriant submerged forest of seaweeds along its rocky shores. This is hopefully a critical seaweed resource which extends right from the shallow sub tidal to depths of 30 m and survives the cold temperatures and low light conditions in the Southern Oceans (Lamb and Zimmermann, 1977; DeLaca and Lipps, 1976; Moe and DeLaca, 1976; Wiencke and Clayton, 2002; Neushul, 1965; Amsler et al., 1998).

Cape Evans, on Ross Island, has the world's southernmost populations of seaweeds. Miller and Pearse (1991) studied *P. antactica* population at 12 m depth at Cape Evans. At the south of Terra Nova Bay from November to December 1983 an average biomass value recorded for *P. antarctica* was 960 g m $^{-2}$ WW. Ten years later in December 1993, almost similar biomass value of 899 g m $^{-2}$ WW was observed for the same species at the same location. The three red seaweeds, namely *I. cordata*, *Leptophyllum coulmanicum*, and *P. antarctica* (Amsler et al., 1995), showed luxuriant growth in the vicinity of this island. *P. antarctica* was the dominant seaweed south of 77°S latitude which formed dense beds from 10–25 m depth by the end of January, reaching 10,000 plants per square meter and biomass of 1.5 Kg m $^{-2}$ WW (Cattaneo-Vietti et al., 1999). Coastal locations further north in the Ross Dependency, at Cape Hallett are colonized by the largest Antarctic seaweed *H. grandifolius*, which can grow up to more than 10 m long (Plate 1).

Table 2
Number of seaweed species recorded at 22 sites in the Southern Ocean

Site	Species nos.	Source
1. Mac Robertson coast	31	John et al., 1995
2. Vestfold Hills	27	Dhargalkar, 1990, 2004
3. Queen Astrid coast	3	John et al., 1994
4. Queen Mary coast	4	John et al., 1994
5. Wilkes Land	12	John et al., 1994
6. Adelie caost	10	John et al., 1994
7. George V caost	8	John et al., 1994
8. Victoria Land	16	John et al., 1994
9. Terra Nova Bay	17	Cormaci et al., 1992a,b
10. Antarctic Peninsula	96	Lamb and Zimmermann, 1977; Fisher and Wiencke, 1992.
11. South Shetland	67	Gallardo et al., 1999; Clayton et al., 1997
12. Tierra del Fuego	334	John et al., 1994
13. Pantagonia	119	John et al., 1994
14. Falkland Island	176	John et al., 1994
15. South Georgia Island	97	John et al., 1994
16. South Orkney Island	36	Brouwer et al., 1995
17. Prince Edward Island	6	John et al., 1994
18. Marion Island	16	Beckley and Branch, 1991
19. Crozet Island	38	John et al., 1994
20. Kerguelen Island	120	John et al., 1994
21. Heard Island	17	Smith and Simpson, 1985
22. Macquarie Island	105	Ricker, 1987

Compiled from published reports.

The distribution and biomass of seaweeds at Signy Island were estimated by Price and Redfearn (1968) and Miller and Pearse (1991). On the Antarctic Peninsula, quantitative studies conducted on Signy Island (Gomez et al., 1997), King George Island (Richardson, 1979) and Anvers Island (Delepine, 1966; Moe and DeLaca, 1976), revealed that seaweed biomass, which consists mainly of large over story brown algae, covers over 80% of the bottom with standing biomass exceeding 8 kg m $^{-2}$. Near Anvers Island, four species of large brown algae (*D. antarctica*, *D. menziesii*, *D. anceps*, and *H. grandifolius*) can constitute up to 75% of the overall percent cover and biomass (Moe and DeLaca, 1976).

The result of the studies on seaweed distribution and biomass from the inner Potter Cove along a depth profile across different substrates during summer indicated that biomass of *D. menzeisii* was highest at 5 m depth and gradually decreased with increasing depths. *D. anceps* and *D. antarctica* were the most abundant species at 10 m depth. *G. skottsbergii* occurred on all substrate types and at all depths with highest values at 5 and 10 m. *H. grandifolius* was more or less evenly present at 10 to 20 m. *G. confluens* and *P. cartilagineum* had higher biomass at 20 m depth. Twenty two species recorded from Potter Cove, were approximately half of the recorded species of this area. Lower number of species was due to strong preponderence of the brown seaweeds, *D. anceps*, *D. Menzeisii* and *H. grandifolius* which compete with other species for light and space. These three large brown seaweeds exhibited the highest mean biomass value 307±592 −538±1363 g DW m $^{-2}$, while in the remaining species, biomass varied between 0.06±0.4 and 65.18±260.91 g DW m $^{-2}$ (Table 3; Quantino et al., 2001).

In Antarctic waters, members of Desmarestials provide the bulk of the biomass of benthic seaweeds. They are perennial, covering large areas of bottom to depth about 35 to 40 m. The largest and most abundant species of *D. anceps* and *D. menzeisii* form thickest but not protective canopy characteristic of much kelp. The Desmarestiales, a very important component of Antarctic marine flora, originate in the Southern Hemisphere and includes the very large *H. grandifolius* (10×1 m) and *Desmarestia* spp. (3–4 m; White and Robins, 1972). In the southern hemisphere *Laminarians* such as *Macrocystis pyrifera* have not yet adapted to Antarctic habitat (Peters et al., 1997). Molecular genetic evidence strongly favours a recent (Pleistocene) movement of genus *Macrocysits* to the Southern Hemisphere (Luning, 1990). Another species, *A. mirabilis*, is also known to occur in great abundance on the Antarctic Peninsula (Richardson, 1979).

The genus *Durvillaea* is conspicuous in the austral region because it is a major primary producer and repository of organic material and energy in the coastal waters of the Southern Ocean. The biomass of this species has been measured in Chile, Marion Island and Kerguelen Island (Coyer et al., 2001; Lamb and Zimmermann, 1977; Arnoud, 1974). Biomass of *Durvillaea* spp. was determined for the shores of Marion Island with different degree of exposure. The total fresh biomass of *D. antarctica* was approximately 3,300 tonnes (WW). The calorific content varied with season and with different plant organs (Table 4). This species is the major contributor to biomass and plays a fundamental role in primary production and nutrient cycling in the near shore and littoral ecosystem of Marion Island (Haxen and Grindley, 1985).

In the south of the western Indian Ocean, enormous resources of *Macrocystis* and *Durvillaea* have been reported along with *Iridaea* spp., in commercially attractive abundance in fjords and Kerguelen Island (Lawrence, 1986). At a depth of 11 m at Signy Island, maximum biomass of 1.25 Kg m $^{-2}$ WW was recorded for *H. grandifoilus*, 5.66 Kg m $^{-2}$ WW for *D. anceps* and 1.85 Kg m $^{-2}$ WW for *D. menzeisii* giving total maximum biomass of these brown algae at 8.8 Kg m $^{-2}$ WW. The average biomass of the other seaweeds at various localities in the Southern Ocean is shown in the Table 5.

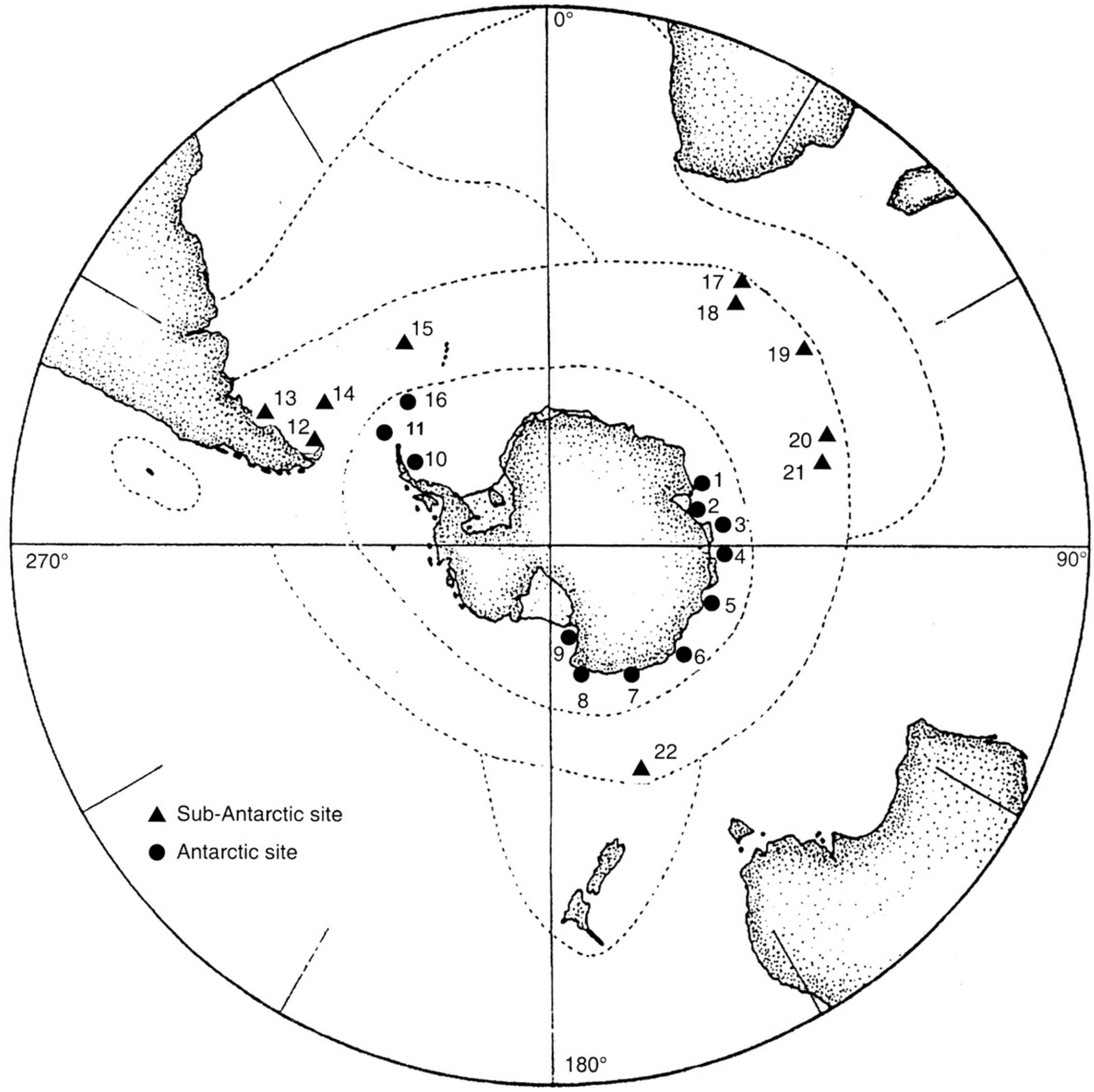

Fig. 4. Map showing Antarctic and sub-Antarctic seaweed sites (Modified after John et al., 1994).

3.4. Nutritive value of seaweeds

World wide, around 221 seaweed species belonging to 32 Chlorophyta, 64 Phaeophyta and 125 Rhodophyta are being used for variety of purposes. Of these, about 145 species (66%) are used for food (Zemke-White and Ohno, 1999). From a nutritional point of view, edible seaweeds are low calorie food, with a high concentration of minerals, vitamins and proteins and a low content in lipid. Seaweeds are excellent source of vitamins A, B_1, B_{12}, C, D and E, riboflavin, niacin, pantothanic acid and folic acid (Nisizawa, 1988) as well as minerals such as Ca, P, Na, K. Quality of protein and lipid in seaweeds are most acceptable for consumption compared to other vegetables mainly due to their high content in essential amino acids and relatively high level of unsaturated fatty acids. They have more than 54 trace elements, required for human body's physiological functions in quantities greatly exceeding vegetables and other land plants (Chapman and Chapman, 1980). These essential elements are in chelated, colloidal, optimally balanced form hence easily bio-available.

To date, C:N data has been reported from 54 (8 green, 10 brown and 36 red seaweeds) seaweed species from Antarctica (Dhargalkar et al., 1987; Weykam et al., 1996; Dunton 2001; Peters et al., 2005). Work on the nutritional status of Antarctic seaweeds mainly pertains with reference to the variety of Antarctic animals (Iken et al., 1998; Horn and Neighbors, 1984; Duffy and Paul, 1992, Bolser and Hay, 1996).

The important edible seaweed genera are *Porphyra*, *Chondrus*, *Rhodymenia*, *Hypnea*, *Gigartina*, *Gracilaria*, *Laurencia*, *Iridaea*, *Phyllophora* (red) *Undaria*, *Durvillaea*, *Ecklonia, Sargassum*, *Turbinaria* (brown) and *Ulva*, *Enteromorpha*, *Monostroma*, *Caulerp*a (green) etc. Japan and China are the major producers, cultivators and consumers of seaweeds in the world. Other countries such as Scotland, Chile, Philippines, Malaysia, Bali, Korea, Singapore, Sri Lanka etc. also consume seaweeds in a variety of forms.

Some of these genera representing number of species are available in the Antarctic waters in abundant quantities and could be a potential source for future utilisation. Presently, some of the Southern Ocean seaweed species used for human consumption especially in Chile are, *Durvillaea antarctica*, *I. cordeta*, *P. endiviifolium*, *M. hariotti*, *Lessonia flavicans*, etc. However, to assertain their nutritive value more work needs to be done.

3.5. Phycocolloid yielding seaweeds

Alginic acid, a linear copolymer of D-manuronic (M) and L-guluronic (G) residues, is the major structural polysaccharide of brown algae. It is extracted from several brown seaweed species in commercial quantities and has a wide range of application in food and pharmaceutical industry (King, 1983; McHugh, 1991). Large alginate yielding brown

Table 3
List of studied species, their mean biomass ± standard deviation (expressed as dry weight), dominance and frequency in 48 samples taken during summers 1992, 1993 and 1994 from Potter Cove, Antarctica

Sr. nos.	Species	Biomass (g DW m $^{-2}$)	Dominance	frequency
	Phyophyta			
1.	*Adenocystis mirabilis* (Bory) Skottsberg, 1907	0.06 ± 0.40	<0.1	2.1
2.	*Ascoseira mirabilis* Skottsberg, 1907	65.18 ± 260.91	4.7	25.0
3.	*Desmerastia anceps* Montagne, 1942	323.06 ± 978.36	23.1	50.0
4.	*D. Antarctica* Moe and Silva, 1989	27.31 ± 88.58	1.9	27.1
5.	*D. menzeisii* J. Agardh, 1848	537.77 ± 1362.85	38.5	56.3
6.	*Himantothallus grandifolius* (Gepp et Gepp) Zinova, 1959	306.77 ± 591.85	22.0	54.2
7.	*Phaeurus antarcticus* Skottsberg, 1907	0.74 + 3.04	0.1	10.4
	Phodophyta			
8.	*Ballia callitricha* (C. Agardh) kutzing, 1843	0.59 ± 1.78	<0.1	18.8
9.	*Callophyllis* sp.	1.04 ± 4.39	0.1	6.3
10.	*Curdiaea racovitzae* Hariot in De Wildeman, 1900	25.83 ± 80.81	1.8	31.3
11.	*Geoggiella confluens* (Reinsch) Kylin, 1956	7.88 ± 12.54	0.6	39.6
12.	*Gigartina skottsbergii* Setchell et Gardner, 1936	30.75 ± 55.10	2.2	45.8
13.	*Gymnognrus antarcticus* Skottsberg, 1953	0.19 ± 0.94	<0.1	6.3
14.	*Gymnognrus turquetii* Hariot, 1907	4.65 ± 15.79	0.3	14.6
15.	*Hymenocladiopsis crustigena* Moe, 1986	3.84 ± 10.98	0.3	10.4
16.	*Iridaea cordata* (turner) Bory de Saint-Vincent, 1826	3.47 ± 7.37	0.2	41.7
17.	*Kallymenia antarctica* Hariot, 1907	11.55 ± 26.77	0.8	35.4
18.	*Myriogramme* spp. [*M. mangini* (Gain) Skottsberg, 1953 and *M. smithii* (Hooker et Harvey) Kylin, 1924]	4.66 ± 12.79	0.3	47.9
19.	*Palmata decipiens* *Reinsch) Ricker, 1987	5.57 ± 20.81	0.4	14.6
20.	*Plocamium cartilagineum* (Linne)	29.63 ± 77.89	2.2	81.3
21.	*Sacrodia montagneana* (Hooker et Hooker) J. Agardh, 1872	3.44 ± 0.73	0.2	16.7
22.	Sp. A (O. Cryptonemiales)	2.95 ± 10.45	0.2	8.3

Source: Quantino et al., 2001.

seaweed species such as *D. menzeisii*, *D. anceps*, *D. antarcitca*, *H. grandifolius*, *L. flavicans*, *M. pyrifera* exhibit highest mean biomass (Lamb and Zimmermann, 1977; Moe and DeLaca, 1976).

Most of the Southern Ocean seaweeds have not been analyzed for alginate content, however, similar species present elsewhere in the world, indicated the presence of high quality alginate contents. *D. antarctica* (Plate 1) and *D. willana* collected from the southern New Zealand recorded about 35 to 55% (dry wt.) alginate content (McHugh, 1991). On an average the alginate content and frequency of manuronic acid (Fm) was higher in *D. antarctica* than in *D. willana*. Blades contained more alginate than laminae and stipes were rich in manuronic acid, whereas holdfasts were rich in guluronic acids. The variation in composition is considered to be associated with the functional differences of the tissue. Greatly flexible and elastic blade and stipes of the brown seaweeds that can withstand extremely high hydrodynamic environment of the Southern Ocean could provide high quality alginate contents. These values are similar to those previously reported for *Durvillaea* spp. from Australia and Chile (Kelly and Brown, 2000). They are also considered higher than those species belonging to the orders Laminarials (Cheshire and Hallam, 1985; Marini-Bettolo, 1948; Black, 1948) and Fucales (Black, 1950). The direct comparison of the alginate contents of these seaweed species is difficult due to the various extraction and quantification methods employed. It is also pertinent to note that seaweeds growing in the more turbulent conditions usually have higher phycocolloid contents (Cheshire and Hallam, 1985; Daly and Prince, 1981).

Table 4
Total biomass and energy values of different organs of *Durvillaea antarctica* for three types of shore on Marion Island

Shore category and plant organ	Shore length (km)	Fresh mass (g × 10 ^{8})	Dry mass (g × 10 ^{8})	Kj (× 10 ^{8})
Exposed	38.23			
Fronds		5.880	1.078	11.800
Stipes		2.058	0.307	3.651
Hold fast		1.145	0.238	1.776
Sheltered	25.93			
Fronds		11.240	2.061	22.550
Stipes		1.821	0.272	3.231
Hold fast		1.115	0.232	1.730
Boulder	11.92			
Fronds		3.856	0.707	7.738
Stipes		1.329	0.195	2.324
Hold fast		0.567	0.117	0.879

Source: Haxen and Grindley, 1985.

Another seaweed *Lessonia trabeculata* is main source of alginate along the Northern Chelian coast. It usually grows in area heavily or moderately exposed to wave action and occasionally in sheltered habitat (Santelices, 1989). The alginate from *L. trabeculata* was studied from biochemical perspective, M:G ratio in stipe (Percival et al., 1983), M:G ratio from different tissues (Matsuhiro and Zambrano, 1989) and block composition of alginic acid from blade, stipe and holdfast (Zambrano, 1989). The average alginate content in blade, stipe and holdfast ranged from 15.3 to 21.3% (Venegas et al., 1993). Craigie et al. (1984) suggested that the differences in alginate composition between localities might reflect unequal growth rates due to the incomplete enzymatic conversion of mauronic to guluronic.

The carrageenan yielding species such as *G. scottsbergi*, *I. cordata*, *Leptosomia simplex*, *P. antactica* etc. indicate substantial biomass in the vicinity of islands and along the coastal waters of the Antarctic continent (Amsler et al., 1995; Cormaci et al., 1998). *G. skottsbergii*, *Sarcothalia crispate* and *Mazzella laminaroides* are currently most valuable species collected form natural resources in Chile. Small quantity of *G. skottsbergiis* is also harvested from Mexico and *Hypnea musciformis* from Brazil. Vast beds of *P. antarctica*, and *I. cordata* are present along the coast of South Orkney, Terra Nova Bay (Cormaci et al., 1992a,b), McMurdo sound (Miller and Pearse, 1991), Depot Island, Franklin Island, Coulman Island as well as from Victoria Land (Zaneveld, 1966).

The major sources of agar yielding seaweeds are *Gelidium*, *Pterocldia* and *Gracilaria.* The best quality agar is extracted form *Gelidium* and *Pterocldia* while *Gracilaria* yield low quality agar. Vast beds of these species are available along the coastline of Peru, Chile, Argentina, the south at Terra del Fuego and Falkland Islands. Presently no commercial cultivation of agar producing seaweeds is carried out in the world, largely because technique of producing good quality agar is not available and whatever quantity is produced is from the wild. Therefore, the Southern Ocean seaweeds could be a best resource for agar yielding seaweed.

Table 5
Distribution and biomass of economically important seaweeds of the Southern Ocean

Seaweed species	Substrate	Length	Average biomass (kg m^{-2} wet wt.)	Geographical distribution
Durvillaea antarctica, D. willana	Rocky, intertidal, sub littoral	8 to 1 m	19.8	TDF,FLK,GEO,PEDW,KER,CZT,HRD,AUCK,CAMP, MAR,MAC.
Lessonia flavicans	Rocky sub littoral	4 to 5 m	7.0	TDF,FLK,KER,HRD,MAC,AUCK,MAR.
Macrocystis pyrifera,	Rocky sub littoral	30 to 40 m	22.6	TDF,FLK,GEO,PEDW,CRZ,MAR,KER, MAC.
Desmarestia anceps, D. menzeisii, D. antarctica	Rocky sub littoral	3 to 4 m	16.0	KER,HRD,FLK,GEO,ORK,SHT,QML,LHB, AP,MAC.
Himantothallus grandifolius	Rocky sub littoral	8 to 10 m	14.8	AP,QML,ADC,WIL,ORK,SHET,VH,LHB,
Gracilaria spp.	Rocky intertidal	10 to 15 cm	2.3	KER,FLK,GEO.
Ahnfeltia sp.	Rocky intertidal	7 to 8 cm	1.7	MAC,KER,CZT,FLK,GEO.
Palmaria decipiens	Rocky intertidal	15 to 30 cm	1.8	MAC,MROB,QML,END,ADC, LHB,AP,
Phyllophora antarctica	Rocky, intertidal, sub littoral	30 to 40 cm	1.2	MAC,MROB,QML,END,ADC,AP, RKVIC,LHB,SHT.
Iridaea cordata	Rocky, intertidal, sub littoral	20 to 40 cm	1.4	VIC,LHB,AP,GEO,CZT,KER,SHT,HRD,MAC,FLK.
Gigartina skottsbergii	Rocky, intertidal, sub littoral	50 cm to 1 m	1.8	MAC,TDF,FLK,KER

Terra del Fuego TDF, Falkland—FLK, S. Georgia—GEO, Prince Edward—PEDW, Kerguelen—KER, Crozet—CZT, Heard—HRD, Macquarie—MAC, S. Marion—MAR, Orkney—ORK, S. Shetland—SHT, Auckland, AUCK, Campbell—CAMP, Ant. Peninsula—AP, Queen Mary Land—QML, Adelie coast—ADC, Wilkes Land—WIL, Victoria Land—VIC, Mac Robertson coast—MROB, Enderbay Land END, Lutzow–Holm Bay—LHB, Vestfold Hills—VH, S. Sandwich Island—SAND. (Compiled from published reports).

3.6. Seaweeds for drugs

The various ecological interaction within the Antarctic pelagic food web have successfully used fatty acids as tropic markers to answer the question "Who is feeding whom?" (Graeve et al., 1994a,b, 1997; Phleger et al., 1998; Nelson et al., 2000, 2001; Graeve et al., 2002). Fatty acid composition in fourteen macroalgal species belonging to Rhodophyta, Phaeophyta and Chlorophyta from King George Island, were analyzed to reveal the potential for identification of phylogenetic relationship (Khotimchenko and Vaskovsky, 1990). The major polyunsaturated fatty acids of the Rhodophyta were 20:5(n−3) and partly 20:4(n−6) and those of Phaeophyta 20:5(n−3) and 18:3(n−3), while 18:3(n−3) was dominant in the Chlorophyta. Extraordinarily high levels of 20:5(n−3) were determined in the Antarctic Rhodophyta, *Audouinella purpurea* (60.3%). These levels of fatty acids are much higher than those reported for seaweeds from lower latitudes (Aknin et al., 1992; Banaimoon, 1992; Fleurence et al., 1994; Khotimchenko, 1998). Fatty acids seem to be a promising tool for studying trophic relationships in polar waters since the lipid composition of seaweed is made up largely of characteristic polyunsaturated fatty acids.

3.7. Natural products from cold water seaweeds

Algae in polar habitats reflect substantially in their to cold-water chemodiversity. In this at least one important group of compounds (antifouling fembrolides has been reported (De Nys et al., 1995; Ankisetty et al., 2004). The red Antarctic alga *Delisea pulchra* has been found to elaborate three new dimeric halogenated furanones, pulchralides as well as several known fembrolides (Ankisetty et al., 2004). Another Antarctic red alga, *P. cartilagineum*, is reported to produce a new Halogenated monoterpene, anverene (Ankisetty et al., 2004). Anverene has shown moderate bioactivity against vancomycin-resistant *Enterococci faecium* (VREF) with a zone of inhibition of 8 mm, but does not show bioactivity against methicillin-resistant *Staphylococcus aureus* (MRSA), methicillin-sensitive *S. aureus* (MSSA), *Escherichia coli*, or *Candida albicans*. The red alga *Myriogramme smithii*, also from Antarctica, has been reported to produce *p*-methoxyphenol and *p*-hydroxybenzaldehyde (Ankisetty et al., 2004). These simple aromatic compounds have been determined to be responsible for the feeding deterrence of the sympatric sea star *Perknaster fuscus*. The Antarctic brown alga *D. menziesii* elaborates a new quinone derivative, menzoquinone, as well as two minor metabolites, the chromenol derivatives (Davyt et al., 1997). Menzoquinone displayed growth inhibition of MRSA (8 mm), MSSA (6 mm), and VREF (7 mm), along with significant feeding deterrence against the sea star *Odontaster validus* (Ankisetty et al., 2004). The Antarctic brown alga *Cystosphaera jaquinotii* produces the steroid Cystosphaerol the bioassay data of which has not been reported so far (Ankisetty et al., 2004).

Table 6
Endemic seaweed species of the Southern Ocean and their temperature requirement for growth

Seaweed species	Growth range temp. (°C)	Optimum temp. (°C) for growth	Upper survival temp.(°C)
Palmaria decipiens	0 to 10	5	16 to 17
Phyllophora antarctica	0 to 8	3	10 to 12
Himantothallus grandifolius	0 to 5	0	11 to 13
Desmarestia anceps	0 to 5	0	11 to 12
D. antarctica	0 to 5	0	11 to 13
Ascoseria mirabilis	0 to 10	5	9 to 11
Phaeurus antarcticus	0 to 5	0	9 to 11

Source; Wiencke and Dieck, 1989.

3.8. Seaweeds for cosmetic formulation

A cosmetic ingredient from the Antarctic seaweeds seems to be the latest craze of cosmetic formulation in France. Cosmetic makers are looking for pure and uncontaminated natural ingredients. The resistance of Antarctic seaweeds to the cold environment is boosted by their specific composition in polyunsaturated fatty acids and sugars, which allow them to resist to difference in osmotic pressure as well as to low temperatures. According to Greentech (French supplier of cosmetics), the extracts obtained from such seaweeds are highly concentrated in active substances giving them protective, moisturizing and soothing properties.

Paris based laboratories Kurbiel launched their Polar Skin-ethics range that features marine micro algae and Antarctic seaweed which grow in the freezing waters of Antarctica. These seaweeds develop active ingredients that block the effects of metalloproteinase, an enzyme that accelerates the skin aging process. These products are dedicated to men between the ages of 25 and 50 (Gallon, 2006).

The cold water conditions and suitable habitat have been persisting for at least 14 million years in the Southern Hemisphere that has resulted in the strong adaptation to low temperature especially in endemic Antarctic seaweeds (Wiencke et al., 1994). Adaption to survive cycle of freezing and thawing at low temperatures could be an essential quality of these seaweeds as potential source (Table 6) for cosmetic and pharmaceutical industries (Wiencke and Dieck, 1989).

3.9. Resource assessment and harvesting strategy

Many of the known major untapped seaweed resources in the world are located in regions that are exceedingly remote from the industry and market. Some of the rich seaweed resources are available in the north west of North America, southern extremities of South

America and vast resources of the Sargasso Sea. Harvesting of these resources, although, is regarded as practically difficult due to the distance, transport cost effectiveness etc; seaweed industries rely on these resources. Similarly, vast seaweed resources of the Southern Ocean are exceedingly far off, but they are quality and quantity resource that need to be developed and utilized. Some seaweeds species /genera that are analyzed for food, feed, phycocolloid, cosmetic ingredients and pharmaceutical applications elsewhere in the world and abundantly present in the Southern Ocean region hold great promise as future potential resource for exploitation (Table 7).

To assess economic feasibility, more detailed statistically valid system of surveys, eco-biological studies, proper biomass estimation, standing stock, seasonality of harvesting are needed, based on the information that indicate where the greatest potentials of quality resource lie and the order of magnitude of possible harvest. Perhaps, the best way to go about is to explore peripheral areas such as northern sub-Antarctic islands of the Southern Ocean, which are accessible from September–October onwards. Further, as and when sea-ice breaks and clear water free of ice appears, southern islands and coastal areas of the Antarctic continent could be approached during Austral summer (December–January). For harvesting wild seaweed resources of the Southern Ocean on the continuous year round basis, the conventional fisheries model described by Gulland (1969) and Ricker (1987) could be adopted with appropriate modifications. These could be worked out by taking into account knowledge of growth, reproduction, the harvesting efficiency and also measurement of the size of the standing stock, new recruitment and rate of indirect loss of the resource due to herbivore grazing and harvest wastage.

Once, quantification, standing stock estimation and seasonality of harvesting is achieved, further economics with regards to the level of investment, manpower deployment, harvesting machinery, other equipments, processing, preservation and storage of seaweed material and transportation could be worked out with sustainable management plan. The commercial exploitation of the Southern Ocean seaweeds, initially, could be taken as joint venture along with the fishing industry in the Southern Ocean with bulk storage capacity on board the ship. The fishing activities could be planned in such a way that period between September to November could be utilized for seaweed collection, processing of the seaweed material and storage, while November to March for other fishing activities. Once economic feasibility to harvest seaweeds of the Southern Ocean is achieved, commercial venture could be taken independently.

As has already been discussed most of the Antarctic endemic seaweed species are season anticipators that grow and reproduce in strategic annual rhythm suitable for the species. This strategy is regarded as adaptation to strong seasonal variation of light condition at high latitudes. Besides light penetration efficiency and temperature, other abiotic factors such as winter ice cover, ice flows in the beginning of summer and predators also determine their cycle of growth and occurrence. The other seaweed species which are season responders, have opportunistic life strategies as they grow in spring and summer with prevalence of favourable conditions. Most of these species occur in the eulittoral and widely distributed in Antarctic, sub-Antarctic and cold temperate waters (Wiencke et al., 2007). While the Antarctic weather is highly unpredictable and as the seaweeds in the region are extremely sensitive to external factors, a similar growth condition cannot be expected year after year. For this purpose, a moratorium period for growth stabilization is a major requirement as far as exploitation of resources is concerned. With this intention, a time space of 5 years in between the two harvesting seasons is proposed. This 5 year period will give sufficient time for the Southern Ocean seaweeds to mature to a suitable marketable size and be ready for the next harvest. In the meantime the requirement for this 5 year lean period could be fulfilled by utilization of main land seaweed resources especially those obtained from tropical and subtropical regions, in a phased manner. Furthermore, there is a vital need to ensure that: a) the health of seaweed species of the Southern Ocean is maintained with confirmed uses, b) harvested population assessed and monitored, c) ecological interaction between the harvestable and other species defined and quantified and finally, d) harvested population prevented from falling below a critical level.

Table 7
The potential seaweed species from the Southern Ocean for commercial exploitation

Name of species	Length of thallus	Potential uses	Geographical distribution
Chlorophyta			
1. *Acrosiphonia pacifica*	10 cm	Pharmaceutical	TDF, FLK,SHT,GEO, CZT,KER, HRD, MAC, AUCK, CAMP
2. *Monostroma hariotii*	30 to 40 cm	Edible	AP,ADC.WIL,FLK, SHT,ORK,VH.
3. *Ulva lactuca*	70 cm to 1 m	Edible, animal feed	TDF, FLK,GEO, MAC,KER, CZT,AUCK,CAMP,VH.
Phaeophyta			
4. *Ascoseira mirabilis*	4 m	Alginate, Pharmaceutical	AP,SHT,ORK,GEO,SAND.
5. *Desmarestia anceps*	3 to 4 m	Alginate, Pharmaceutical	AP,SHT,ORK,GEO,VH,KER,HRD,FLK,QML,LHB,MAC
6. *D. menzeisii*	3 to 4 m	Alginate, Pharmaceutical	KER,HRD,FLK,GEO,ORK,SHT,QML,LHB,AP,MAC, VH.
7. *D. antarctica*	3 to 4 m	Alginate, Pharmaceutical	KER,HRD,FLK,GEO,ORK,SHT,QML,LHB, AP,MAC.
8. *Himantothallus grandifolius*	10 m	Alginate	AP,QML,ADC,WIL,ORK,SHET,VH,LHB,
9. *Durvillaea antarctica*and *D. willana*	10 m	Alginate, edible	TDF,FLK,GEO,PEDW,KER,CZT,HRD,AUCK,CAMP, MAR,MAC.
10. *Cystosphaera jacquinotii*	3 m	Alginate	AP,SHT.
11. *Lessonia flavicans*	4 to 5 m	Alginate, edible	TDF,FLK,KER,HRD,MAC,AUCK,MAR.
12. *Macrocystis pyrifera*	30 to 40 m	Alginate	TDF,FLK,GEO,PEDW,CRZ,MAR,KER, MAC.
Rhodophyta			
13. *Porphyra endiviifolium*	15 to 20 cm	Edible	AP,ORK,GEO,VH,MAC,KER,QML,END,LHB.
14. *Ptilonia megellanica*	30 cm	Pharmaceutical	TDF.AP,FLK,KER
15. *Cladonta ilyalii*	50 cm	Pharmaceutical	TDF.AP,FLK,KER,PEDW,MAC
16. *Gigartina skottsbergii*	50 cm to 1 m	Carrageenan	MAC,TDF,FLK,KER
17. *Iridaea cordata*	40 cm	Carrageenan	VIC,LHB,AP,GEO,CZT,KER,SHT, HRD,MAC,FLK.
18. *Palmaria decipiens*	30 cm	Carrageenan	MAC,MROB,QML,END,ADC, LHB,AP,
19. *Phyllophora antarcitca*	40 cm	Carrageenan	MAC,MROB,QML,END,ADC,AP, RKVIC,LHB,SHT.
20. *Plocamium cartilagineum*	30 cm	Pharmaceutical	TDF,AP,MROB,ADL,WIL,VIC,FLK,GEO,ORK,KER,AUCK,CAMP,VH.
21. *Callophyllis variegate*	40 cm	Pharmaceutical	TDF,AP,FLK,ORK,CZT,KER,MAC,AUCK,CAMP.
22. *Gracilaria* spp.	10 to 15 cm	Agar	KER,FLK,GEO.

Terra del Fuego TDF, Falkland—FLK, S. Georgia—GEO, Prince Edward—PEDW, Kerguelen—KER, Crozet—CZT, Heard—HRD, Macquarie—MAC, S. Marion—MAR, Orkney—ORK, S. Shetland—SHT, Auckland, AUCK, Campbell—CAMP, Ant. Peninsula—AP, Queen Mary Land—QML, Adelie coast—ADC, Wilkes Land—WIL, Victoria Land—VIC, Mac Robertson coast—MROB, Enderbay Land END, Lutzow–Holm Bay—LHB. Vestfold Hills—VH, S. Sandwich Island—SAND. (Compiled from published reports). (Compiled from published reports).

Fisheries Department of FAO is concerned with the development and rational management of the Living Resources of the world oceans. However, no legal fame work is available so far with respect to the exploitation of seaweed resources from Southern Ocean. The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), a leading organization in many aspects of international marine resource conservation and management, does not spell out the legalities for seaweed exploitation, while framed guide lines for the said purpose are not made available so far for Antarctic waters. There is an urgent need to consider some of the aspects detailed below before we go ahead for any commercial seaweed exploitation programme. These are: a) detailed resurvey in the fishing areas to assess biodiversity, species abundance, seasonality and standing stock of the respective species, b) precautionary harvesting quantity of seaweeds from respective fishing areas, c) development of performance measures and risk assessment studies., d) eco-biology, life cycle, eco-physiology studies, e) long term scientific monitoring programme on ecosystem (this is a must as it would provide the data that will allow scientific committee to investigate the effect of harvesting) and f) a license to harvest seaweed resources form respective fishing areas demarcated by CCAMLR. As and when sufficient data on the above aspects is available, Commission could bring about extensive discussion on “Exploitable Seaweed Resources in Southern Oceans” in the form of series of workshops, inviting participation of various experts such as algologists, scientists, stakeholder, environmentalist, policy makers, members of various government organizations dealing with fisheries, seaweed industries etc. Finally, after debating pros and cons on available seaweed resources, a suitable legal frame work and guidelines could be framed and adopted for seaweed exploitation on similar lines as that available for other Southern Ocean resources.

4. Conclusion

Our understanding on the biology of Antarctic seaweeds has increased considerably in the recent times, however the knowledge of seaweed flora of the Southern Oceans is still fragmentary due to extreme remoteness of the Antarctic region and infrequency of scientific studies. Although, the quantification of Southern Ocean seaweeds has not been fully documented, the reliable biomass estimates show that the greatest potential resources are awaiting critical attention. It is proposed that the Southern Ocean seaweeds could yield higher phycocolloid contents compared to the similar species present elsewhere. This is because Antarctic seaweeds grow in the stressful and turbulent conditions, which result in increased phycocolloid contents, high bio-active potential, pure and uncontaminated natural ingredients, etc. For proper exploration of the resources more studies are needed, precisely to document the biodiversity of these seaweeds. The taxonomic studies coupled with molecular aspects would necessarily demonstrate, the presence of gene flow between population of same species in the Antarctic and the adjacent regions. Along with this extensive culture studies are also needed to provide pertinent insight into the life strategies of polar seaweeds with respect to the temperature tolerance, geographic distribution, light requirement and depth zonation. The broad perspective in trying to identify appropriate direction for further quantitative and qualitative assessment of seaweed resources have been summarized in this communication. It is envisaged that large efforts on part of algologist, scientists, seaweed industries and fisheries workers would be required to support the scientific management of the seaweed resources of the Southern Ocean, for effective exploration and utilization for commercial prospects.

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