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A Review of the Biology, Culture, Exploitation and Utilization Potentials Seaweed Resources: Case Study in Nigeria

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Abstract: The importance of seaweeds cuts across various environmental, ecologic, socio-economic benefits and services as food for man, in the phycocolloids and expanding phycosupplement industries, as sink for excess carbon dioxide and excess nutrients; for sustainable energy generation and as fossil fuel substitutes. In view of this, seaweeds could become an important economic niche for Asian(Japan and China), Nigeria and other coastal African countries provided adequate research is undertaken in studying their diversity, biochemical compositions and potentials for culture in order to harness the numerous opportunities which can be derived. This article reviews the biological characteristics, potential products and uses, culture and transplantation, distribution and biodiversity, status of exploitation and conservation. Benefits of developing seaweed sector and challenges to the exploitation, culture and utilization of potential seaweed resources, aimed at unveiling the potentials in the utilization of seaweed in Nigeria and other interested countries.

Key words: Biological characteristics, culture and transplantation, distribution and biodiversity, Nigeria, potential products and uses, seaweed resources

INTRODUCTION

Seaweeds constitute a source of non-phytoplankton production; provide energy for associated grazers and contribute remarkably to the benthic detritus food chains. From an ecological perspective, seaweeds are providers of the structural integrity of many biotopes especially low energy shores where they are predominant in terms of size and occupiers of space. Seaweed beds also form important habitat for fishes and invertebrates. In addition, they are useful as indicators of climate change; can be used to study diversity patterns and are particularly useful for planning the conservation and sustainable use of inshore marine resources (John and Lawson, 1991; Jennings *et al*., 2001; Bolton *et al*., 2003).

An earliest record of seaweeds utilization dates to 13,000 years ago at a late Pleistocene settlement in Chile. Other archaeological evidences also indicate that seaweeds have been included in folk medicine for many thousands of years in Japan (13,000-300 BC), China (2700 BC), Egypt (1550 BC) and India (300 BC) (NAAS, 2003; Teas, 2005). Being excellent sources of vitamins, amino acids, carbohydrates, proteins, lipids, growth hormones, micro- and macro-elements including iodine, many seaweed species are used as food throughout Asia and the Pacific region. Furthermore, occurrence of goiter is very rare among the seaweed-eating populations in Japan and other South-East Asian countries (King, 2007).

Industrial utilization of seaweeds began with the production of soda and potash from the brown seaweeds for manufacture of soap, glass and iodine (Dhargalkar and Verlecar, 2009), while industrialization of seaweed polysaccharides or phycocolloids as thickening, binding, stabilizing, gelling, emulsifying, clarifying and protecting agents expanded in the second half of the 20th century (McHugh, 2001). Development of the phycosupplement industry with various utilizations in pharmaceuticals, botanicals, nutraceuticals, cosmeceuticals, fish and animal feed additives, agrichemicals, soil additives and as sources of natural pigments, bioactive substances, antiviral agents etc., is in full expansion (Chopin, 2007).

Seaweeds were the source of about 35% of newly discovered chemicals followed by sponges (27%) and cnidarians (22%) between 1977 and 1987 (Smit, 2004). Currently, Carraguard, a non- spermicidal microbicide containing carrageenan, a red seaweed derivative has been clinically tested to be a promising product capable of blocking the transmission of HIV/AIDS and lowering the risks of women in contracting the disease (Robertson-Andersson, 2007). Regular consumption of dietary seaweeds in Japan and Korea is attributed to low

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Table 1: World seaweeds production (Tons, wet weight)

	Brown algae Paeophyta	Red algae Rhodopyta	Green algae Chlorophyta	Other seaweeds	Total
World total	2,160.667	972,957	12,231	97,231	3,243,424
China	1,073,400	122,850	-	-	1196.250
Japan	294,516	330,549	1,284	37,772	664,123
Korea	339,289	93,140	11,248	12,979	456,715
The Philippines	-	222,003	-	-	-
Norway	174,109	-	-	-	174,109
Chile	33,532	83,643	-	117,115	

FAO (2003)

prevalence rates of HIV/AIDS and low risks of various cancers (Teas, 2005). However, as demand for phycocolloid is expected to increase by 8-10% every year. (Dhargalkar and Verlecar, 2009), a much higher demand for seaweed natural products should be expected from the rapid development of novel applications in the phycosupplement industry culture, and utilization as food.

In Japan, overexploitation of natural beds of the edible Nori (*Porphyra yezoensis*) spurred intensive seaweed cultivation in the 17th century. Global production of seaweeds soared from 11.66 million metric tones in 2002 to 16.83 million metric tones in 2008 (FAO, 2010). Approximately 90% of estimated total world seaweed production is derived from cultivation (McHugh, 2001; FAO, 2003). Seaweed cultivation represents close to half of the biomass of the world mariculture production (Chopin, 2007). Tseng and Borowitzka (2003) posit that future supplies are expected from even in countries without a tradition of seaweed culture; improvements of culture techniques and genetically improved culture stock as well as from development of culture techniques for new culture species. However, Dhargalkar and Verlecar, (2009) are of the opinion that new areas would have to be explored to provide rich and high quality seaweeds. They also reported that alginate yielding seaweeds with the exception of *Laminaria japonica* cannot be grown by vegetative propagation. Therefore, the dependence on wild stock of alginophytes could be expected to persist for several years.

Emphasis on seaweed exploitation and cultivation to meet growing global demand for the expanding phycosuplemment industry and phycocolloids implies that the technology for their artificial production is practically not yet feasible. Dhargalkar and Pereira (2005) mentioned the presence of formidable chemical barriers in the structures of these commercially important products as a serious constraint to their chemical synthesis. Hence, the dependence on seaweeds particularly as sole source of phycocolloids is bound to continue in the absence of alternative biological sources.

According to FAO statistic, over 30 countries around the world produce a total yearly harvest in recent years of between 3.1-3.8 million tons (Wet weight) of seaweeds, which are used profitably either for human consumption or industries. Among these countries, Japan, along with Korea and China, rank as the major producers as well as, a principal consumer of seaweeds (Table 1). Throughout their history; the Japanese people have made abundant use of seaweeds. For example, in recent times they burned seaweeds to produce salt from their ashes. With the development of agriculture, people learned to plow seaweeds into their fields as a form of fertilizer, and to use them as feed in animal husbandry. In modern times, with the appearance of chemical industries, seaweeds were used abundantly as sources of potassium and iodine. However, compared to these non-edible uses, the Japanese use of seaweeds, as foodstuffs for human consumption have always been more active and enduring.

In inland areas and Coastal areas, seaweeds have been eaten as substitute for vegetable "greens" and in times of need, as a nourishing emergency food. Since the 17^{th} century, with the development of nationwide trade infrastructures for foodstuff, and with development of processing industries producing regional specialists, seaweeds assumed a larger and lasting place in the Japanese diet. Traditionally, the Japanese diet has been made up of grains, tubers and beans, with seafood and vegetable to supplement them. To this basic diet the Japanese have added seaweeds as a unique supplementary food or an ingredient in a variety of dishes.

Through this long history of culinary adaptation, the Japanese have developed an appreciation for the special taste and texture of a variety of seaweeds. At two periods in its modern history, the opening of Japan to foreign trade in the Meiji period (1868-1912) and the rapid economic growth period following World War II, Japan has undergone intense stages of "Westernization" in which the country's eating habits have also changed dramatically. But the Japaneses' love for seaweeds has not changed, and even today, seaweeds enjoy a stable place in the national diet. There are roughly 50 species of seaweed that the Japanese eat, but the largest volume of consumption falls among the three groups of laver (Porhyra) (Plate 1), kelp (Laminaria)(Plate 2, 3 and 4) and Undaria (Plate 1 and 5). With regard to these three groups, the Japanese have engaged in not only the gathering of naturally occurring seaweeds, but also a variety of method of artificial propagation and marine culture. In the 1960s, the techniques for the artificially

Plate 1: *Ascophyllum nodosum*, http//en.wikipedia.org/wiki/File:Asco-nado.jpg

Plate 2: *Codium fragile*, http//en.wikipedia.org/wiki/File:Codiumfragile.jpg

Plate 3: Kelp forest, http//en.wikipedia.org/wiki/File:Kelp-forest-Otago-1s..jpg

induced germination of laver were perfected, and this turned out to be a revolutionary advancement. As a direct result, culture activities for laver quickly spread thorough the country.

Subsequently, artificial germination technique for Undaria and Kelp were also undertaken and perfected, resulting in a dramatic increase in their production,

Plate 4: Laminaria, http://en.wikipedia/wiki/File:koeh-214

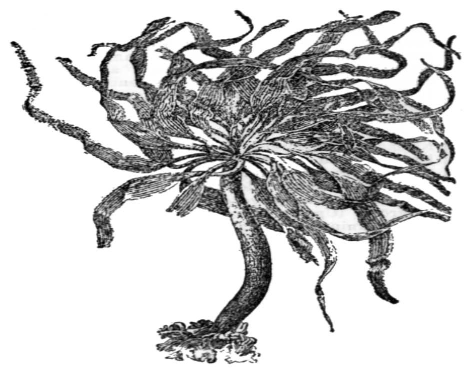

Plate 5: Undaria http//upload.wikimedia.org/Wikimedia/common/8/8e/Alger

as well. Entering the `70s, germination techniques for a number of other species of seaweeds were developed and their culture came to constitute significant local industries in the various regions. Some example includes "Matsumo" (*Analipus japonicus*) "histoegusa" (*Monestroma latissimum*) and "Okinawamozuku" (Clapdosiphon okamuranus).

Nigeria has a coastline of about 860 km exclusive of indentations in the Niger Delta. The coastal zone has the largest area of mangroves on the continent. However, there is limited information on her seaweed resources. Hence, information on biomass, productivity and utilization of seaweeds resources has not been documented. This study highlights some basic objectives pertinent to research and utilization of her seaweed resources in the near future.

BIOLOGICAL CHARACTERISTICS OF SEAWEEDS

The term "seaweed" we shall use it here means leaf-forming species of algae that grow in seawater. Algae contain a wide variety of species from single - cell organism to multi cell plants with an equally wide variety

Table 2: Utilization and products of potential seaweed resources in Nigeria

Potential u/tilization/product	Species
Human consumption	*Entromorpha* sp., *Gelidium* sp., *Gracillaria* sp., *Grateloupia* sp., *Dictyopteris* sp., *Sargassum* sp., *Ulva* sp., *Asparagopsis* sp., *Chaetomorpha* sp., *Centroceras* sp., *Cla dophora* sp.
Medical/ pharmaceutical-related	*Dictyota* sp., *Sargassum* sp., *Ulva* sp., *Bryopsis* sp., *Jania* sp.
Industrial	*Gracillaria* sp., *Gelidium* sp., *Centroceras* sp., *Sargassum* sp.
Agricultural	*Sargassum* sp., *Gelideum* sp., *Cladophora* sp., *Chaetomorpha* sp.
Environmental	*Gelidium* sp., *Gracillaria* sp., *Ulva* sp.

Chapman and Chapman (1970); Tseng and Borowitzka (2003); Dhargalkar and Perreira (2005); Dhargalkar and Verlecar (2009)

of body form and life cycle. Among these, the ones called "Seaweeds" are limited to macrophytes visible to the naked eye, and include three botanical groups: Green algae (Cholophyta), red algae (Rhodophyta) and "brown algae" (phaeophyta). Since seaweeds live in seawater with high salinity, their cell walls are thicker than land plants, having developed a special structure for controlling the passage of ions. Their cell wall consists of a cellulose framework embedded with gelatinous polysaccharides. In the case of brown and red algae, intercellular polysaccharides usually account for 30% of the dry weight of the algae cell. These cellular carbohydrates in the seaweeds make them suited for life in the seawater environment.

Seaweeds life cycle: When the British algologist, Kathleen M. Drew published a report about her experiments concerning the germination of laver (Porphyra) carpospores in 1949, it created a sensation among seaweed specialist around the world. What she proved was that the microscopic thread like seaweed found growing in the calcareous surface of shells, previously known as conchocllis, was in fact nothing less than the germinating form of the female laver. This discovery filled in the "missing link" in the life cycle of laver.

After that, many Japanese researchers began to investigate the remaining blank spots in the life cycle of laver until its entire life history became clear. By the middle of the 17th century, Japanese fishers had learned methods for obtaining laver conchospores to attach themselves to bamboo poles driven into shallow water areas and germinate there and this led to widespread culture of the natural seeding type. After Drew's report, however, Japanese seaweed researcher experimented with the seeding of shells with laver carpospores and raising conchocelis over the course of a summer. The success of these experiments then led to the perfection of artificial seed production technique for laver.

As this episode demonstrated the birth of modern culture techniques for seaweeds, it has depended on clarifying the life cycle of the particular species involved and then finding solution to employ the mechanism of its reproduction process. In land plants, sex differentiation is simple, but with seaweeds, different reproductive patterns have been recognized.

POTENTIAL PRODUCTS AND USES OF SEAWEEDS

The uses of seaweeds have gone beyond the culinary and nutritional values as a food for human consumption. In the mid 17th century, the Japanese learned to cook "tengusa" (*Gelidium amansi*) into a gelatin consistency and cool it to make a jelly type food called "tokoroten", which was later found to be used when freeze dried and powered into an agar called "Seaweed gum", suitable as a base for raising bacteria etc, in medical research and other industrial uses. Chapman and Chapman (1970); Tseng and Borowitzka (2003) elucidated some uses and products of commercial seaweeds. Dhargalkar and Perreira (2005); Dhargalkar and Verlecar (2009) reported more comprehensive uses of seaweeds and their extracts. Based on these, some related seaweeds in Nigerian waters hitherto identified are shown in Table 2. However, utilization of these seaweeds upon harvesting would be based on the design of appropriate technology for colloid production and processing. This and further socio-economic analyses would clearly depend on the production ecology of the wild, cultured or transplanted seaweeds.

Furthermore, in recent years it is being proven that a variety of organic substance found in seaweeds have medicinal effects on the human body. The useful qualities of seaweed can be grouped into;

- A food with preservation characteristic
- A health food with medicinal quality
- A seaweed gum, a good source of colloid material for industrial use.

With regard to all three qualities, the high percentage of polysaccharide in the seaweeds seems to be an important factor.

Preserved food from seaweeds: Seaweeds can be eaten in a number of ways. Some are eaten raw as salads, some are flavored before eating and some are made into processed foods. However, the fact that so many species are eaten in so many ways can be seen as the result of an early recognition of the fact that, when processed in the right way, they became long lasting and easily stored preserved foods. Here are some of the observations that surely led to the use of seaweeds as processed foods:

- When dried seaweed is soaked in water again, it regains its original shape and can be eaten with very little loss in nutritional substance or texture.
- The common seaweed dish “tsukudani”, which is made by cooking seaweed in soy sauce, can be left out for several days without losing its density or without its liquid component separating out.
- “Dried laver” is made by chopping up the seaweed and setting it out to dry in thin sheets. In this process, the resinous substance that exudes from the seaweed serves to paste the leaf fragments together and give the sheet a shinny external gloss

These food qualities are all due to the functions of the intercellular polysaccharide. The processing method for seaweeds include, drying (Kelp, undaria, laver) drying with flavouring (laver), salt preserving (Undaria, mozuku)” tuskudam” (Kelp, Undaria, laver and hitoeagusa), and other flavoured processing (for all types of seaweeds).

Seaweeds as health foods: The cell wall material and internally stored substances, which seaweeds produce through photosynthesis, are extremely diverse in terms of their chemical composition. This fact gives seaweeds their exceptional value as health foods.

- Modern nutritional studies have shown that seaweeds contain a great amount of vitamins and trace minerals essential to the human body.
- Some unique organic substances found in seaweed help in the prevention of the degenerative diseases. For example, the fucosterol found in kelp and Undaria is believed to reduce blood cholesterol and prevent thrombosis in the blood vessels. Also, experiments with mice have shown that alginic acids are anti tumor agents.
- Recent studies have also focused attention on edible seaweeds as a valuable source of dietary fibre. The digestive juice of the stomach cannot dissolve the polysaccharide of seaweeds, but they are broken down by the bacterial action in the large intestine. In short, their difficult- to-digest complex carbohydrates, act to stimulate the digestive function of the intestine, thereby invigorating them.

Seaweed gum as a source of colloid: Polysaccharides are high molecular compounds composed of carbohydrates. Among such high molecular compounds, the water soluble one, which forms colloid, creates those material characteristics of viscosity or gelatin when coupled with water.

Utilizing the chemical behaviour of these colloids, people have long employed hydrophilic polymerized compounds as a wide range of stabilizing agents that induce thickening suspending gelling, emulsifying, film farming and so on. Polysaccharides are so numerous and diverse that they can be used for a wide range of products from ingredient for foods, cosmetics, pharmaceutical, textiles, paper making, paints, printing inks adhesives and detergents to building materials and many other industrial products.

In the commercial market, the seaweed gums derived from the intercellular tissues of seaweeds compete with seed gum such as guar gum and locust bean gum, with plant extracts (Arabic gum and pectin for example), and with bio-sun ethic gums like xanthan gum and others. However, because seaweed colloids offer distinct chemical and economic advantages, the gums can be trusted as a healthy food source and as practical material for various industries (Table 3).

Today, the main industrial seaweed products employing polysaccharides include:

- Alginic acid derived from brown algae
- Agar - agar found in the red-algae, *Gelidium* and *Gracilareia*
- Carrageenan derived from the red algae, *Chondrus* and *Eucheuma*

Seaweed gum production in recent years can be summarized in Table 3. In Japan, with the exception of the raw material for “tokoroten”, seaweed materials for industrial use come entirely from imported produce.

Culture and transplantation of seaweeds: Approximately 741.509 and 48.695 ha of the brackish water and marine environments are amenable to aquaculture activities (Anethekai *et al*., 2004), which invariably includes seaweed farming. However, they also opined that certain environmental factors, both natural and man-induced limit development of aquaculture in these vast and underutilized areas of the coastal zone.

Consequently, culture of potential useful indigenous species and/or transplantation of exotic species could complement fishing and allied occupations in the brackish water and coastal communities providing the much needed economic niche. These areas which are often isolated or entirely remote from the inland are substantially rural with a high prevalence of poverty and poor socio-economic development owing to declining fish catch, inadequate infrastructural development and lack of basic social amenities, as well as environmental degradation.

The adoption of an appropriate and suitable raft-based method in the absence of rocks and stones which are natural suitable settlings, on-growing substrates and sites for seaweeds could significantly enhance production potentials or capability in their habitat. This method

Table 3: Uses of seaweed gum

Uses	Products	Main functions
Food additives	Dairy products	Gelatin, foaming and suspension
	Baked goods	Improving quality and controlling moisture content
	Sweets	Gelatin, increasing viscosity and suspension
	Sauces and brewing	Increasing viscosity and emulsification
	Alcohol brewing	Precipitation and suspended matter
	Processed meats	Adhesion and prevention of juice separation
	Frozen fish products	Adhesion and moisture retention
Cosmetics and pharmaceuticals	Shampoo	Interface vitalization
	Tooth paste	Form retention and increasing viscosity
	Milky lotion	Emulsification
	Tablets	Coking
	Laxative	Indigestibility and lubrication
	Bacteria agar	Gelatin
	Dental molding material	Form retention
Other industrial uses	Paints	Increased viscosity and suspension
	Thread making	Prevention of thread breaking
	Textile	Increase printing viscosity
	Paper making	Sizing
	Starch and adhesives	Increasing viscosity
	Pottering making	Suspension
	Casting	Molding sand coking
	Welding rods	Coking

FAO (2010)

Table 4: Seaweed-derived polysaccarides production

	World production	Japanese production	Japanese import
Algini acid	15,000	1,500	5000
Agar	8,500	1,700	700
Carrageen	15,000	700	800

Yamah fishery Journal (1990)

should permit changing of culture depth in response to reception of appropriate amount of light due to effects of high wave action and varying sea levels. This method should also permit easy movement during harvest operations than the placement of large stones or rocks. Artificial substrates are then provided with cuttings or their zoospores for subsequent on-growing. The successful application of the floating raft method particularly in China, has enabled the country achieve higher production levels than Japan in the culture of the Japanese Kelp (*Laminaria japonica*) (Table 4) (Tseng and Borowitzka, 2003). Transplantation of exotic species may be another option. Thus, it may be feasible to introduce commercial species such as *Eklonia* sp. and *Eucheuma* sp. from Togo, Ghana and Cameroon. These countries share similar ecological and biological conditions in their coastal and marine environments with Nigeria in the Gulf of Guinea.

Among these, many species produce both sexually differentiated and non-differentiated reproductive cells in the course of their overall life cycle in a pattern of "alternation of generations". By a "generation" it means a period in which the individual seaweed begins to produce reproductive cells at one point while supporting its life through the metabolism of stored nutrients. In this way, when there is a phenomenon in which the individual seaweed produces alternating "generations" with differing reproductive processes during its life cycle, it is called "alternation of generation".

In the alternation of generation in seaweeds, an investigation of changes in the nuclear phase in cell chromosomes revealed extremely complex patterns. It is best to think in terms of the two principal patterns known an isomorphic alternation and heteromorphic alternations of generation.

Isomorphic alternation of generation: This is the type in which the gametophytes (sexual) and sporophyte (asexual) are exactly the same in terms of configuration and body shape. Only the nuclear phase and the reproductive organs differ. Examples of this type are Ulva and Enteromorpha.

Heteromorphic alternation of generation: This is the type in which the configuration and body shape differ between the sexual and asexual generation. Either the gametophytes or the saprophyte will develop into a thallus of macroscopic proportions while the other remains a threadlike or spherical body microscopic proportion. An example of seaweed in which the sporophyte develops to especially large size is kelp. Seaweeds in which the gamefophyte develop are divided between monoecisous like laver and dioecious like histoegusa.

Culture technology for seaweeds consist of two techniques: The cultivation of reproductive cells at the microscopic stage and the raising of thallus in the macroscopic stage. The process of cultivating reproductive cells is referred to as "seed production." It involves:

- Gathering of gameophytes or soprophytes released by the mother seaweed, and
- Keeping them in indoor tanks under the proper water temperature, water quality and lighting conditions.

Raising of the thallus consist of:

- Obtaining the reproduced reproductive cells to attach to a net or other artificial attaching material like ropes
- Hanging out these nets or ropes in sea areas with favourable water conditions once they have germinated
- Raising the thallus to a harvestable size under a controlled schedule that involves such steps as prevention of foreign plant growth, weeding out and sun-drying

At present, most of the seaweeds being produced by "full process" culture involving the artificial production of seeds are heteromorphic alternation of generation types. An example of isomorphic alternation seaweed that is cultured with artificial seed production is 'Sujiaonori" (*Enteromorpha prolifera*). However, since the demand for sujiaonori is not large and it requires clear water raising grounds at the mouths of rivers, the number of regions involved in its culture is limited. Regarding other isomorphic types like "tosakanori" (*Meristotheca papulosa*) and "tengusa" (*Gelidium amansii*), research had begun on artificial seed production technology as yet there is no prospect of practical application in the near future.

Kelp culture: The name "Kombu" (kelp) refers to Laminaria and other related large edible Pacphyta like Kjellmaniella, Cymathaere and Arthrothamnus, but here the discussion will be limited to Laminaria only. The Japanese have long valued kelp as delicacy, eaten alone or as a flavouring called "dashi-Kombu". Until recently, the production of kelp has been limited to its areas of natural distribution. Now however, since the development of culture techniques, its production has spread beyond its areas of natural distribution.

Laminaria is cold-water seaweed living in waters that range from 0ºC in winter to 20ºC. It grows below the low tide line in rocky bottom areas of outer seashores, with highest concentration being found at depths of 8-12 m.

When the water temperature begins to drop in autumn the kelp thallus produce a mature zoosporagiums and in late autumn it releases large numbers of zoospores into the water. After a period of free - floating migration, the zoospores attached themselves to some substratum in the sea and begin the germination process. After passing through the gametophyte stage they become sporophyte once again and by mid-winter, have grown into infant thallus large enough to be seen by the naked eye.

From winter into spring the activity of the meristerm increase and the thallus grows in length. In summer the kelp becomes ripe enough for harvest. From summer into autumn the growth becomes slower and because, the amount of plants being washed away surpasses the rate of growth, the thallus begins to fade. In late autumn, the growth section of the thallus ceases activity, ending the first year of growth.

In the kelp genus, there are one year, two years and even some three years species. At present the kelp that is the object of culture fisheries are all two years kelp. The most common method is one of two years culture, and because, in the winter, the meristem of the kelp becomes particularly active and new holdfasts are easily formed. Some areas take advantage of this fact in the transplantation method of culture.

Furthermore, a "forced cultivation" method that produce the equivalent of second year kelp in one year was developed in 1970; and this method has spread in the comparatively warmer water region.

Seed production consists of the two steps have seedling and "provisional planting". Seed fixation is achieved under controlled conditions of water quality and temperature, and amount of light. Mature mother seaweed are washed and soaked in sterilized water at a temperature of 10º - 15ºC to bring about zoospore release.

Seaweeds containing high concentrations of zoospores are filtered with gauze. This sporophyte water is then added to a tank of sterilized water at a ratio of 3-5%. Then a triangular spore collector wound with about 300 m of synthetic thread is placed in the tanks and left undisturbed for about half a day for spores to fix themselves to it. After verifying that enough spores have attached themselves to the collector, it is transferred to a cultivation tank. Within 30-50 days young seaweeds of 3-5 mm would have appeared, after which they can be moved to seawater cultivation grounds.

The type and configuration of the regular cultivation apparatus varies with sea condition of the different regions. Control of the cultivation process can be done by:

By handling the main line near the surface, one gains the added nutritional value of the upper water layer, but on the other hand the increased wave activity increases the danger of part of the seaweed population being washed away. Therefore, in winter, the main line is lowered to a depth of about 5 m. In winters, the concentration of nutritional salts in the seawater increases so there is little problem of nutritional deficiencies.

In spring, as the seaweeds grow in size and the seas become calmer, the number of floats is increased to raise the apparatus closer to the surface. This increases the amount of solar energy and improves the supply of nutrients through the increased water flow near the surface.

As the kelp grows in size, the density of the culture population increases, thus obstructing the supply of solar energy and nutrients. In order to raise good quality kelp, it is necessary to thin out the crop two or three times during the regular cultivation period. At the same time this "thinning" is performed; those seaweeds which are not firmly attached to the ropes are given additional support with vinyl tying.

Thinning of excessive fronds is first carried out late in December to early January and second in early March. The final number should be 4 or 5 fronds on each position, and 60 -75 fronds per rope in total. Tying down of unstable holdfasts is carried out every time thinning is carried out, but must be done also when occasion demands. This can be done fast moderately with thin soft polypropylene tape.

The uses of domestically produced kelp in Japan are reported to be 30% sold in leaf form (for "dashi-kombu") 30% for "tuksudani" 10% for "tororo-kombu" (thin sliced kelp), 20% for various processed foods and 10% for export. The producers do a primary processing of their entire crop into dried kelp before shipping it to middlemen or for processing companies.

The leaf ends and roots are cut from the dried kelp and it is sorted into four grades depending on the degree of dryness, leaf width, thickness, colour and gloss. Then, 20kg stacks of the different grades are tied into bundle and boxed.

As soon as the kelp has been harvested, it is taken to a specially prepared drying area paved with cracked stones, where each leaf is spread out to its full length and dried for 3-4 h in the sun. After that, it is hung in a drying room where it is dried for another 3-4 h with hot air from oil heater until its water content is reduced to about 15%.

Laver (porphyra): The "hoshi-nori" (dried laver) made from laver has been one of the representative seaweed foods eaten by the Japanese since olden times. Of the red seaweeds that make up the laver group there are about 30 varieties of fronds in the coastal waters of Japan. Of these, eleven varieties were produced through culture fisheries in 1955, with "asakusa-nori" (porphyra) being the main species. With the development of artificial seed production methods in the 60s, however, the culture of varieties with better reproductively and larger harvest potential became more predominant. At present "Susabi-nori" (*Porphyra yezenosis*) is the representative variety in laver culture.

Laver grows primarily between the tide lines in the shallow waters of inner bay areas. As they display strong resistibility to exposure to the air, temperature changes and changes in salinity, all of which makes them suitable for inhabiting a wide range of environment. Thus, they are found growing in waters throughout the span of the Japanese islands. Lavers are thought to grow best in a water temperature range from 15 to 16ºC. But when considering harvests quality, it is believed that a temperature range from 8 to 10ºC gives the best balance of biotic metabolism and supply of nutrient salts. In the past, it was thought that low salinity water was the best growing environment for laver, but it has been established that low salinity is not essential.

Laver has the highest protein content of any seaweed group, and accordingly it needs large quantities of nutrient salts such as nitrogen and phosphorus for proper growth. Laver is suitable for a culture ground that receives a constant supply of nutrient salts from land, like a river mouth area. But at the same time, this type of ground is also susceptible to contamination by eutrophication. Therefore, it can be said that laver culture is a type of fishery that requires special attention. It depends on the reproductive capacity of the environment.

The life cycles of members of porphyra seaweeds can be divided into several types, but the ones that are the object of culture fisheries fall into the type that show thallus growth in winter and conchocelis propagation in the summer. In the case of "Susabi nori" and askasua - nori", when the infant thallus appears from the conchospore in October, by late November or early December, the thallus will have grown to table size of 10 cm. Growth is most active in the months from December to May. By June the thallus will begin to weaken, and by July it would have almost disappeared.

The culture process begins in the spring when conchospores are made to attach themselves to holdens, such as oyster shells and then produce conchocelis. The shells on which conchocelis have grown are kept in water tanks throughout the summer for cultivation. Then, in October when the water temperature begins to drop below 20ºC, nets in which the culture shells have been embedded at appropriate intervals are hung out in the seawater. The regular cultivation stage begins when conchospores are formed on the nets. About two months after this happens the first harvesting can begin. After that, subsequent harvests are repeated in accordance with the growth rate until the end of the culture season in March or April.

Laver culture underwent several technological developments after World War II that led to a dramatic growth in production. Beginning 300 years ago, fishers in Tokyo Bay began a form of laver culture in which naturally occurring spores that attached to bamboo sticks driven into shallow water area were cultivated. Using this method, the Japanese production of laver remained at about 50,000 tons up till World War II. By 1955, however, production began to grow, taking a dramatic leap in the 1960s.

The factors that caused this rapid take-off of synthetic fibers like Cremona, beginning from 1955, are the practical application of artificial seed production methods in the early 1960s. Since then, there has been a succession of further advancements in the culture technology. A complete spectrum of modern technologies regarding biological production, on-sea operations and on-land working methods appeared in the latter half of the 60s.

This sequence of technical development constituted a sort of overall "innovation" in seaweed culture that resulted in a second phase of expansion for the industry in the 70s. During the 10 years (1960 to 1970), the total was more than double.

The cultivation process should be controlled:

- Because unwanted seaweeds or floating sludge will sometimes cling to the culture nets, the culture ground must be patrolled regularly and the nets cleaned with a water pump when necessary.
- For three of four hours after down, the plants are artificially exposed to the air to prevent sudden growth of thallus.
- Sudden environmental changes like high air temperature or water temperature, and low salinity can cause undesirable effects like abnormal shape development, decay, abnormal cell development and wrinkling due to shrinkage. At these times, damaged leaves should be quickly cut away to allow new shoots to grow. Or, the entire net should be unstrung and replaced with a refrigerated seed net that had been kept in a refrigeration facility.
- With repeated harvesting, the plants start to produce tougher leaves and the quality of the product begins to drop. So the nets are replaced several times with refrigerated ones during the course.

The most notable characteristics of laver culture is the high added-value its operators achieve by completing the full process from growing the raw material to producing the finished product, dried laver, all by themselves. The harvested laver is immediately washed clean of foreign materials and put in a chopping device to produce slurry. The slurry is then spread out on draining nets to remove excess water before placing a drier to complete the processing of the dried laver products. Today, all steps of the process have been mechanized and automated. Even though, total production of dried laver in Japan has doubled many times in the past 20 years, a family can perform the entire manufacturing process. On the other hand, the capital investment necessary for the on-sea and on-land facilities has also grown very large.

Histoegusa (monostrroma): The Japanese distinguished between the porphyra and ulva by the terms "Kuro - nor" (black laver) and "ao - nori" (green laver) respectively. Concerning their product value as food, black laver makes superior sheet form dried laver, with green laver several classes below. When making tsukudani, green laver is considered more superior. Among the green lavers, Monostroma, Ulva and Enteromorpha of which the species considered most important for the production of tsukudani is known as "hitoegusa" (Monostroma lalissimum). The word "histoe" means, "single layer" and "gusa" means, "grass". As this name suggests, the thallus of "histoegusa" is thin and soft, consisting of a single layer of cells. The fact that it does not lose its flavour when boiled gives an added fragrance, another desirable quality of this species. The production of hitoegusa is 1200-1500 tons (dry weight) annually, and 70-80% of this is produced is mie perfections. "Hitoegusa" grows between the tide lines from the inner reaches of bays to outer seacoasts, but they thrive best in the relatively quiet shoaling beach areas of inner bays. Because it often grows on culture nets intended for laver, these culture operations dislike it as a kind of "foreign weed".

Compared to laver, it prefers waters of higher salinity. It also has strong resistance to environmental changes in air temperature, salinity and tidal exposure. But its poor resistance to chilling makes it unsuitable for the seed - net refrigeration technique used in laver culture.

The life cycle and culture schedule is as follows: From winter to early summer, the thallus releases its gametophyte, which produces zygote. The zygotes mature in the summer to produce zoosporangium, which releases zoospores in the autumn. Seed production involves.

- Collecting zygote in April and May
- Cultivating the sporophyte over the summer; and
- Collecting zoospores in September and making the seed nets.

The raising of the thallus and harvesting are roughly the same as in laver culture, occurring from the end of December to the end of April. Seed production involves.

Zygote gathering: The male and female gametophytes demonstrate positive photo taxis which means they conjugate most actively in light places. However, after conjugation begins, they exhibit negative photo taxis that cause them to gather in dark places. Therefore, the cultivation tank is placed in a light area for 20-30 min undisturbed. Then after conjugation has begun, it is moved to a dark place or covered with a black sheet.

Gathering zoospore: Mature zygote (zoosporangium) is stimulated by the change in early morning light to release their zoospore. Therefore, the introduction of light is a necessary part of the process. It has been shown that the use of 5,000 lux white fluorescent lights give more reliable results than relying on natural sunlight. The same kind of pole supported net (hibi) as in laver culture is prepared as regular cultivation apparatus. Although "histoegusa" does not require such intensive quality control as laver, the main job of cultivation control is the same as with laver. That is, to raise and lower the nets to the most suitable depth for growth depending on such factors as the tidal condition and amount of light. Care must be taken to prevent disease and quality determination from overly dense cultivation.

The traditional processing methods for "hitoegusa" include drying in sheets and in its original leaf form. Since in recent years, most of the "histoegusa" crop is used for making tsukudani, the farmers dry their harvest in leaf form under the sun and ship them in that form to the "tusakudani" processing factories. At the factory the dried leaves are soaked in water tanks. Such impurities as small stones and pieces of metal are speared by means of successive precipitation- tanks. Further more, brushes are used to separate out shellfish and small shrimps on the sorting table. The cleaned and sorted seaweed is then stored in a refrigerator until it is time for it to bused in the next step of the processing.

Distribution and biodiversity of seaweeds: Generally, seaweeds are known to flourish in temperate waters. Various macroalgal genera are postulated to have originated from the Indo-Pacific region (Chapman and Chapman, 1970). Variability in the distribution and diversity of seaweeds is almost identical with phytoplankton productivity in areas close to nutrient-rich upwellings (King, 2007). Bolton *et al*. (2003) broadly identified 4 major seaweeds floras in Sub-Saharan Africa. In an order of decreasing species richness, these are:

- A distinctive but depauperate Tropical West Africa flora
- A species-rich Tropical East Africa flora which is continuous with the much larger Indo-West Pacific flora
- A cool temperate, relatively poorer Benguela Marine Province along the West coast of South Africa and the entire Namibian coastline
- A species-rich warm temperate Agulhas Marine Province along the Eastern and Southern coastlines of South Africa

John and Lawson (1991) also opined that with the exception of Ghana, which experience;es upwelling along its coast, the tropical province generally has a low diversity of seaweeds. The warm temperate provinces of the Canaries (West African Flora to the North) and Namibia are also considered hotspots of seaweeds diversity. Also, relatively less diverse seaweeds beds are found in the subtropical provinces or transitional zones, North (Senegal-Mauritania) and South (Congo-Angola) of the equator.

So far, about 79 species of seaweeds comprising 38 red, 24 green and 17 brown species as shown in Table 1 have been identified in Nigeria (www.algaebase.org). Ecological factors prevalent in Nigeria's coastal waters and indeed in tropical West Africa such as low tidal amplitude, existence of a shallow, permanent thermo cline and negligible upwelling phenomenon imply low nutrient enrichment and consequently low phytoplankton productivity estimated at 100-150 mg/C/m^2/day are plausible reasons for poor seaweed diversity in Nigeria (Amadi,1991; Bolton *et al*., 2003). From this analogy, there seems to be a positive correlation between low phytoplankton productivity and low seaweed diversity and vice-versa. Besides these, other factors such as low habitat diversity and heterogeneity associated with predominance of long sandy beaches; a concurrent lack of suitable late rite rocks for attachment; presence of mangrove swamps lining edges of lagoon systems; dilution of coastal water with freshwater from heavy rainfall and large rivers or seasonal lowered inshore salinity and turbidity in coastal waters have also been postulated. Furthermore from a historical perspective, destruction of the tropical West African region during the Pleistocene glaciations and subsequent re-colonization by species from the tropical Eastern Atlantic that remained unaffected probably explains its impoverishment, low endemism and floristic similarity.

Status of exploitation and conservation of seaweeds: Most species of red and brown seaweeds are found in the eulittoral zone of brackish water and coastal environments (John *et al*., 2001). Common seaweed habitats in West Africa include a range of brackish water environments; the intertidal and subtidal of the coastal and marine environments (Lawson *et al*., 1995). Naturally, rich beds of seaweeds (Table 5) are found in the intertidal zone despite factors such as fluctuations in salinity, light intensity, temperature and exposure to dryness at low tides which characterize this zone as the most stressful habitat (Jennings *et al*., 2001). Ghana has moderately high seaweed diversity in its intertidal areas of the shore including natural rocky areas, oil rig and harbor systems (Lawson *et al*., 1995). Limited research on macroalgae in the marine, intertidal and brackish water environments rather than ecological factors may be the actual cause for the perceived poor status of seaweed diversity.

Table 5: Seaweed resources in Nigeria

Family	Species
Chlorophyta	*Bryopsis pennata*; *B. plumose*; *Chaetomorpha antanna*; *Cladophora montagneana*; *Cladophorosis menbraneacea*; *Enteromopha clathrata*; *E. flxus; Gayralia axysperma*; *Microcoleus Lynbyaceus*; *Phycopeltis expansa*; *Rhizoclonium africanum*; *R. riparium*; *Schizoteris caliola*; *S. Mexicana*; *Ulva clathrata*; *U. flexuosa.*
Phaeophyta	*Asteronema breviarticulatum*; *Bachelotia antillasum*; *Chenoospora minima*; *Dicthotabartayresiama*; *D. ciliate*; *Ectocarpus breviarticulatus*; *feldmania indica*; *Giffordia mitchlliae*; *Halopteri scoporia*; *Hincksia mitchelliae*; *Sargassium vulgar*; *Sphaeclaria ridula*; *Stypoculon scopaium*
Rhodophyta	*Acrochatum microsopium*; *Aglaothamnion roseum*; *Ahnfeltiopsis intermedia*; *Asparagosis taxiformis*; *Audouinella microscopic*; *Bangia atropurpurea*; *Bostrychia binderi*; *B. calliptera*; *B.tenella*; *B. tenuis*; *bryocladia thyrsigera*; *Callithamnion roseum*; *Caloglossa leprieurii*; *Catenella caespitosa*; *Centroceras clavulatum*; *Erythrocldia irregularis*; *Flakengergia hellebrandii*; *Gelidium coneum*; *Gonoiotrichumalsidii*; *Gracilaria rangifera*.

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Therefore, intensive sampling in the harbor systems off the coast of Lagos; the numerous oil rigs in the Niger Delta and the intertidal zones along the entire Nigerian coast and sub tidal collection by SCUBA-diving or Oceanographic Research Vessel may similarly reveal a corresponding abundance of seaweeds. However, in case of limited distribution of economically potential seaweeds, *in situ* and *ex situ* measures may become necessary to protect the resources from future over harvesting and degradation of the habitats from socio-economic activities. *In situ* measures for the resource in the habitat may be assimilated into an integrated zone management plan for the environment while *ex situ* or biotechnological methods may also similarly be adopted.

Benefits of developing seaweed sector in Nigeria: There is a general perception that seaweed farming is an environmentally non-destructive alternative livelihood that is considered relatively benign on the environment when compared to other mariculture activities (Crawford, 2002; NAAS, 2003). Seaweed cultivation holds great potentials for increasing primary productivity in coastal waters and to ameliorate global warming by sequestering carbon dioxide (Bunting and Pretty, 2007). Macroalgal farms have positive impact on the environment by improving fishing in and around the farm. Additional profits can also be realized by locating fish traps near seaweeds (Deboer, 1981). In their study, Eklof *et al*. (2006) concluded that in areas naturally lacking vegetations such as sand banks, presence of seaweed farms impacted positively on fisheries production by increasing fish catches of certain species. They also surmised that smaller or less intense seaweed farms and the use of farming methods such as long lines or rafts in suitable areas may have less effect on benthic community and sea grass ecosystem as a whole.

All these seem to contradict a growing body of evidence of negative impacts of seaweed farming on sea grass beds, which are important fishing grounds for artisans principally in the West Indian Ocean. Phyco-mitigation, through the development of Integrated Multi-Trophic Aquaculture (IMTA) systems rediscovered in Western countries over the last 30 years has existed for centuries in Asian countries (Chopin, 2007). In areas adjacent to open-water culture facilities such as cages, pens etc., seaweeds have proven capable of eliminating heavy metals; act as efficient biofilters or nutrient scrubbers removing dissolved inorganic nitrogen and dissolved inorganic phosphorous from aquaculture effluents; improving water conservation and economic yields when incorporated in ecologically integrated mari-culture systems (Costa-Pierce, 2002; Mcvey *et al*., 2002). Utilization of macro-algae as bioremediation in aquaculture systems does not only provide a second crop or product but also provides another source of food for other culture organisms (Tseng and Borowitzka, 2003).

Dietary seaweeds are sources of iodine and protein to combat goitre and protein deficiency; to protect or prevent from HIV/AIDS and as an alternative therapy to antiretroviral drugs that are not only cheaper, readily available but also non-toxic or with no side-effects to slow progression of HIV-infection to AIDS. Furthermore, extensive testing and costs associated with patenting would not be required for whole seaweeds because they are naturally occurring, widely available food (Teas, 2005).

Above all, seaweed biomass can be a veritable source of renewable energy through the conversion of eco-friendly technologies to biogas for electricity generation and biodiesel as low-cost alternative to petroleum-based fuels. Among biomass, algae have a higher photosynthetic efficiency (Dhargalkar and Perreira, 2005; Hossain *et al*., 2008). From a comparison of alternative processes for oil extraction, macro-algae have less growing costs than microalgae and may yield up to 20% extracted oil per kg of dry matter (Aresta *et al*., 2004). This could be part of the solution to boost power supply from dismally low levels in the country and may also be the only way to produce enough automotive fuel to replace current petrol/ gasoline consumption in order to combat the emissions of carbon, greenhouse gases and other air contaminants which contribute to global warming.

African coasts have a biodiversity of seaweeds where production from a relatively pollution-free environment may be a key marketing advantage. In addition, these coasts also offer good accessibility and hence are conducive to mari-culture. With the exception of countries such as South Africa, Senegal, Namibia, Tanzania, Ghana, Egypt, Togo and Cameroon, there is limited exploitation, cultivation and utilization of seaweeds on the African continent. Hence, this seriously undermines opportunities of direct job and wealth creation and indirectly through backward and forward linkages given the high unemployment situation in most coastal and brackish water communities and the concomitant high labor intensity involved in seaweed culture. As seaweed culture is not compulsorily dependent on imported inputs such as fertilizers, feeds and chemicals, it requires relatively lower investment capital thus providing a rapid and high return on investment. In addition, seaweed culture can be a potential export earner substantially increasing a country's Gross Domestic Product and a catalyst to improvement of trade balance (Hishamunda, 2007).

Development of a seaweed sector in the country will not only improve the standard of living and alleviate poverty but also help to control rural-urban drift in many brackish water and coastal communities where fish, a major aquatic resource is considerably over- exploited and hence fishing major occupation as well as auxiliary services vis-a-vis fish processing, fish marketing, fishing gear production/ repairs etc., are adversely affected. Alternative employment or additional income outside fisheries has often been mentioned as a panacea to help highly fishing-dependent communities tide over periods of loss of income resulting from declining fish catch. Considerable empirical evidence suggests that seaweed farming is a profitable venture for coastal households. Seaweed cultivation can be easily integrated with the traditional activities of fishing.

Smith and Renard (2002) reported on the requirements for developing artisanal seaweed cultivation as a source of income for coastal communities in the Caribbean. Seaweed cultivation has been proposed to reduce the use of unsustainable and destructive methods of fishing and as an income alternative to mangrove destruction. However, the attainment of primary goals of reducing fishing pressure from alternative or supplemental livelihood and prevention of economic over fishing is often temporary or not met at all. Job satisfaction among fishers, occupational multiplicity among rural coastal households and most importantly, market prices of seaweeds are determinants of the impact of seaweed farming on fishing effort (Crawford, 2002). Hence, diversification into seaweed farming among other activities is suggested to be a more pragmatic option to overcome large-scale ecological and global market changes.

The development of a seaweed sector is bound to have profound multipliers effect. For instance, in the farming of the Giant Tiger Prawn (*Penaeus monodon*) in Madagascar, every on-farm job generated additional employment in the downstream and upstream farm activities (Hishamunda, 2007). Similarly, the production of colloids from seaweeds will lead to the evolution of seaweed processors, marketing and distribution chain. A seaweed industry also holds the key to economic empowerment of the female gender in coastal/brackish water communities. In India, women outnumber men in the ratio of 70:30 in the collection of seaweeds and have equal employment opportunities in the seaweeds processing sector (Kaladharan and Kaliaperunal, 1999). Commercial interests assisted the establishment and development of an industry based on the culture of Carrageenan containing seaweed in poor rural villages in Zanzibar, Tanzania. Similarly, women also dominate seaweed farming and have utilized their cash incomes on modern housing materials and primary school tuition (Hishamunda, 2007). Thus, it may also be part of the solution to the lingering problem of youth restiveness, militancy and high rate of under-and unemployment in the Niger Delta.

Challenges to the exploitation, culture and utilization of potential seaweed resources in Nigeria: While the poor status of naturally occurring seaweeds may present a daunting task to their exploitation and utilization, the paucity of information on these resources poses a more daring challenge. Therefore, taxonomic and population biology besides quantitative assessments would be required to estimate the field stock value of seaweeds before commercial harvest, logistics, labor, marketing, processing, shipping costs and utilization of the wild stock could be considered. Further socio-economic and technological analyses would be based on the production ecology of the seaweeds. The objectives would be achieved by conducting a thorough study on the distribution, diversity, production ecology and physiology of natural seaweeds resources in a range of habitats occurring in the brackish water, coastal and marine environments in Nigeria and identify the potential useful species based on their biochemistry.

However, harnessing the full potentials of seaweed resources also implies basic research on economically viable species aimed at creating genetically improved and novel strains with increased yield and the capacity for producing new substances. Furthermore, if commercial quantities of potential seaweed species have been established in our environment, then these portends important consequences for conservation and coastal management. Alternatively, the option of transplantation and cultivation of commercially viable exotic species should be given serious considerations on the basis of a higher probability of success arising from similarities in ecological conditions in Nigeria and the exporting country. Such landmark achievement was demonstrated by Malaysia, which has become the world's largest producer of Palm Oil following successful transplantation of the Oil Palm seed from Nigeria in the 1970s.

Furthermore, the Federal Government has a pivotal role to play as facilitator and regulator to make feasible the evolution of a seaweed sector-as a fisheries subsector. This should be seen as a first step towards marine agronomy. Presently, Federal Government's support and opportunities in the development of Small and Medium Scale Enterprises (SMEs) are also favorable to the development of seaweed cottage industries in the country. Clearly, this shall involve funding for research and public enlightenment campaigns to sensitise the coastal communities and the country at large on the socio-economic benefits to be derived. As a matter of urgency, tertiary institutions, the Nigerian Institute for Oceanography and Marine Research (NIOMR) and other affiliated research institutes in the proximity of brackish water and coastal environments should undertake seaweed research.

Approach to conduct of research should be multidisciplinary to optimize funds and other resources required which may be limiting factors. Despite the fact that Nigeria is not mentioned as a country with prospects for seaweed production, it is not impossible that the country can still play an active role as a raw material supplier given the anticipated high demand for colloids and as phycosupplements, which guarantee relatively high market value. Previously, forecast in demand despite increased production kept market value relatively very high after a period of stagnation between 1984 and 1989 (Katavic, 1999). Even as prospects for processing is considered rather slim as a result of complexities involved in technology and engineering for production of seaweed extracts as well as the high capital cost of the equipments in developing countries (McHugh, 2001). Developing and strengthening human capacity building in acquisition of processing technology is fundamental to overcome this problem.

CONCLUSION

- West African coastal states must be well-positioned not only to satisfy local demands but also to become net exporters in view of the anticipated increase from the phycocolloids and phycosupplememt industries.
- Though, the poor state of research on seaweeds in Nigeria implies limitations in terms of abundance and species richness for commercial exploitation.
- However, the growing significance of seaweed cultivation in the world is a promising start towards realizing the goals of becoming a producer and harnessing the socio-economic benefits to be gained from establishing a seaweed sector.

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