Marine Bioprospecting for Income and Employment

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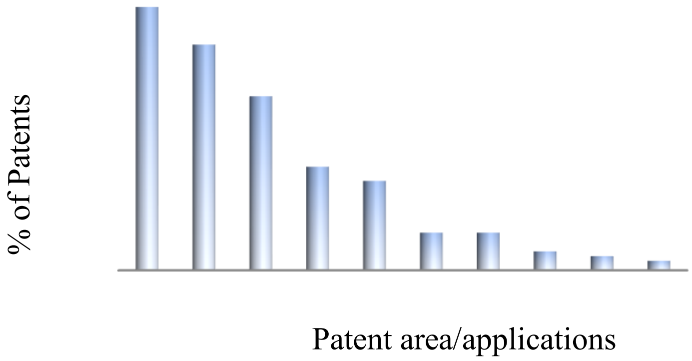
Introduction

There are four major phases of bioprospecting activity. The phases range from sample collection, isolation, characterization to product (drug) development and commercialization. Bioprospecting does not only comprise of a provider and an acceptor but the entire process of bioprospecting involves various components including the owner(s) of marine genetic resources, the bioprospectors, research and development group (if separate from the bioprospector) and end product users. A wide range of products include marine biological resources, from those domesticated for food through to high-value cosmetic markets and high-end pharmaceuticals and nutraceuticals for human health. Not all of these can be characterized as being produced as a result of bioprospecting, and uses range from the direct incorporation of seaweed in food supplements, for example, through to the use of bioactive ingredients in creams, lotions and ointments as cosmeceuticals, and the isolation of active compounds for the pharmaceutical industry. Investments in marine bioprospecting are typically extremely costly and risky due in part to the high costs of sampling in cases where this occurs in the deep sea, and the significant regulatory hurdles for product approval. For example, it took more than three decades for Prialt®, the first pharmaceutical based on a marine source – the poison released by a tropical marine cone snail to paralyse its prey – to be approved in the United States as a treatment for chronic pain (Marris 2006, Molinsky *et al*., 2009). Paradoxically, commercial supplies of Prialt® were obtained through standard pharmaceutical manufacturing processes and exploitation of the natural source of this compound was never considered for supplying sufficient material for development. Regulatory hurdles are still significant but the time taken between the discovery of a molecule and product commercialisation has over the past decade significantly shortened due to technological advances in synthesising and scaling up production using biotechnology and aquaculture (Leal *et al*., 2014, Martins *et al*., 2014).

Obtaining a sustainable supply of marine sources, often sparsely distributed, and located in inaccessible sites, presents a considerable challenge to product research and development. While bioprospecting typically requires the collection of only a limited amount of biomass in the discovery phase, recollection of interesting species, or scaling up for commercialisation may pose significant ecological threats. Technological advances over the past decade have, however, begun to address this "supply" concern (Davies-Coleman and Sunassee 2012, Leal *et al*., 2014). For example, aquaculture is increasingly being used to produce assemblages of marine invertebrate-microorganisms that can be manipulated to produce higher yields of target metabolites (Leal *et al*., 2014). The accelerated development of classical analytical technologies, such as nuclear magnetic spectroscopy and mass spectrometry, also means that new compounds can now be identified from mere micrograms of source material. Advances in chemical sciences and pharmacophore mining are presenting ample scope for the scaling-up of marine bioprospecting in future, in particular for marine organisms (Molinsky *et al*., 2009, Leal *et al*., 2012).



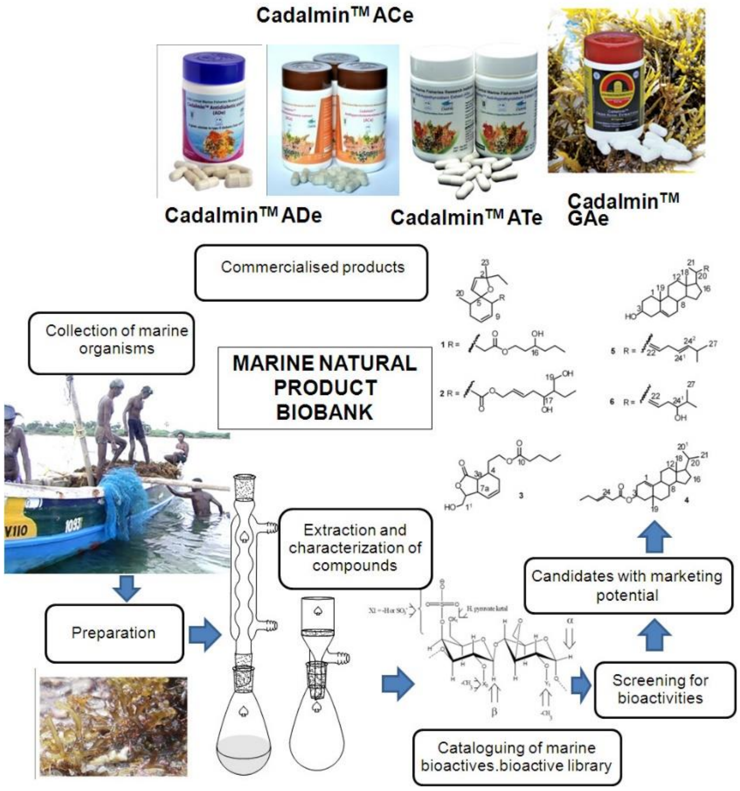
Synthesis of the uses proposed in the claims or description of 460 patents deposited at the International Patent Office and associated with genes isolated in marine organisms.
Source: Arrieta *et al*., 2010.

Blue biotechnology and marine bioprospecting

Although the term "blue biotechnology" has been used in different ways, it is understood here as comprising the range of economic sectors and related policies that together determine whether the use of oceanic resources is sustainable. An important challenge of the blue Biotechnology is thus to understand and better manage the many aspects of oceanic sustainability, ranging from sustainable fisheries to ecosystem health to pollution. A second significant issue is the realization that the sustainable management of ocean resources requires collaboration across nation-states and across the public-private sectors, and on a scale that has not been previously achieved. Marine bioprospecting can be described as targeted and systematic search for components, bioactive compounds or genes within marine organisms. This include microorganisms and larger organisms such as sea plants, shellfish and fish. The result of the bioprospecting could be a purified molecule that is produced biologically or synthetically, or the entire organism.

The biological diversity of the oceans range from 700,000 to 1 million eukaryotic species and millions more prokaryotic and viral taxa, is an important source of novel genes and natural products, with applications in medicine, food, materials, and energy and across a wide array of bio-based industries. Marine biological prospecting includes the discovery from the ocean environment of novel genes and biological compounds that can lead to commercial development of pharmaceuticals, enzymes, cosmetics, and other products. Because of the low quantities of raw material that must usually be sampled, bioprospecting can generally be considered as having more limited environmental impacts and thus be a potential alternative to more-intensive extractive activities. There is growing commercial interest in marine genetic resources, with the rate of patent applications related to marine genetic material rapidly increasing at rates exceeding 12 percent a year. A majority of these patents have been filed by a few highly developed countries, highlighting the increasing biotechnology capacity gap between nations.

Over the last few decades, increasing attention has been given to the commercial potential of exploiting marine genetic and associated natural product resources for a range of industries including pharmaceuticals, food and beverage, cosmetics, agriculture and industrial biotechnology (de la Calle 2009, Arrieta *et al.*, 2010, Arnaud-Haond *et al.*, 2011, Global Ocean Commission 2013, Martins *et al.*, 2014). Since initial reports in the 1950s, some 23 570 natural products have been reported from marine organisms, growing at a rate of 4 per cent per year (Arrieta *et al.*, 2010, Leal and Calado 2015). Only a small number of these products have reached the commercialised phase, yet marine bioprospecting provides significant economic opportunities with the global market for marine biotechnology products alone projected to reach US$ 4 900 million by 2018 (Global Industry Analysts Inc. 2013).



A schematic diagram of marine natural product biobank and product commercialization.

The purpose of marine bioprospecting, from a business perspective, is to find components, compounds or genes that may be included as components in products or processes. Marine bioprospecting, therefore, is not an industry in the traditional sense, but it may procure different compounds that may be used in many different industries. Marine bioprospecting makes exploitation of bioactive compounds from marine organisms possible. Collection and extensive analysis/preparation of the collected material is necessary before the substance is suitable for further development to an end product or product component.

ICAR-Central Marine Fisheries Research Institute (CMFRI):

A leading tropical marine fisheries research institute in the world working in the frontier area of marine bioprospecting/bioactive molecule discovery from marine organisms. The research works at ICAR-CMFRI is the pioneering one in India in marine bioprospecting/ from marine organisms and development of high value nutraceuticals as dietary supplements and health management. It has culminated in an unraveled database of marine organisms with small molecular weight bioactive molecules responsible to combat various life-threatening diseases (Chakraborty, 2010). CMFRI has developed and commercialized the nutraceutical products Cadalmin^{TM} Green Algal extract (Cadalmin^{TM} GAe) and Antidiabetic extract (Cadalmin^{TM} ADe) as green alternatives to synthetic drugs to combat rheumatic arthritic pains and type-2 diabetes, respectively to Celestial Biolabs Limited, Hyderabad. The anti-inflammatory nutraceutical Cadalmin™ Green Mussel extract (Cadalmin™ GMe) from Asian green mussel *Perna viridis* has been commercialized with Amalgam Group of Companies. The active principles in Cadalmin™ GMe isolated from *P. viridis* exhibited potential capacities to inhibit experimentally induced inflammation, and can act as dual inhibitors of membrane arachidonate oxygenation by cyclooxygenase-2 (COX-2) and lipoxygenase (5-LOX) pathways, thus decreasing pro-inflammatory prostaglandin (PGE_2 and $PGF_{2\alpha}$)/leukotriene synthesis and down-regulating the inflammatory sequence. Cadalmin^{TM} Antihypercholesterolemic extract (Cadalmin^{TM} ACe) has been developed from seaweeds to combat dyslipidemia and obesity, and the product was out-licensed to VLCC Personal Care Limited, a leading Indian MNC in wellness and obesity management in particular, with manufacturing facilities in India and Singapore). Bioactive lead pharmacophores purified from seaweed showed potential to inhibit the modulators leading to hypothyroid dysfunctionalities, and were utilized to develop the nutraceutical product Cadalmin^{TM} Anti-thypothyroidism extract (Cadalmin^{TM} ATe) to combat hypothyroid disorder. Cadalmin^{TM}ATe is a natural remedy of hypothyroidism from the marine source. The bioactive leads concentrated in Cadalmin^{TM} ATe were found to stimulate thyroid releasing hormone and increase the activity of selenodeiodinase to produce metabolically active thyroid hormones tetraiodothyronine (T_4) and 3, 5, 3′-triiodothyronine (T_3).

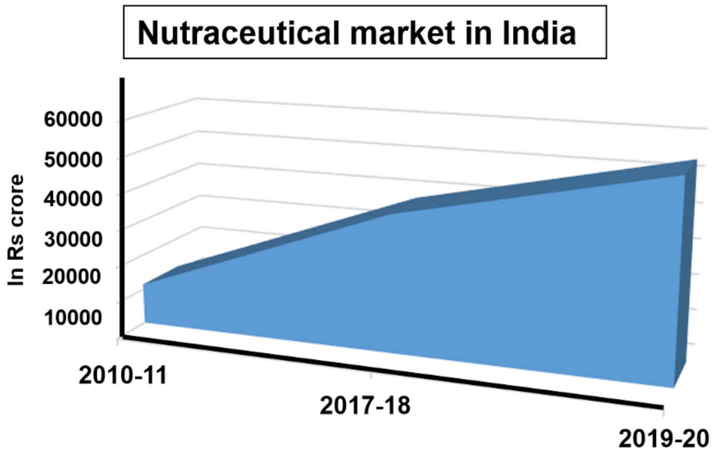
Marine macroalgae as a source of bioactive compounds and nutraceuticals

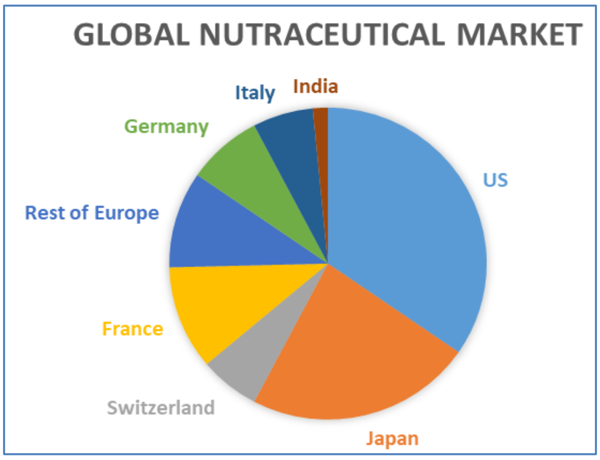
An increasing interest in algae-based bioactive compounds and functional food ingredients as evidenced by the scientific publications and patents in the last decade have appropriately demonstrated the possibilities of bioactive compounds from seaweeds to maintain and improve human health and well-being. Various nutraceutical or functional food supplements and biomedical products from marine algae provide a myriad of benefits for human health and multiple life threatening diseases, and therefore, are the attractive options for the pharmaceutical and healthcare industry. Specific constituents of marine algae were found to function as chemical intermediaries, which control the stimulations associated with mammalian defense mechanism, and produces inflammatory deregulators. Among various abundantly available marine algal species, brown and red algae (classes Phaeophyceae and

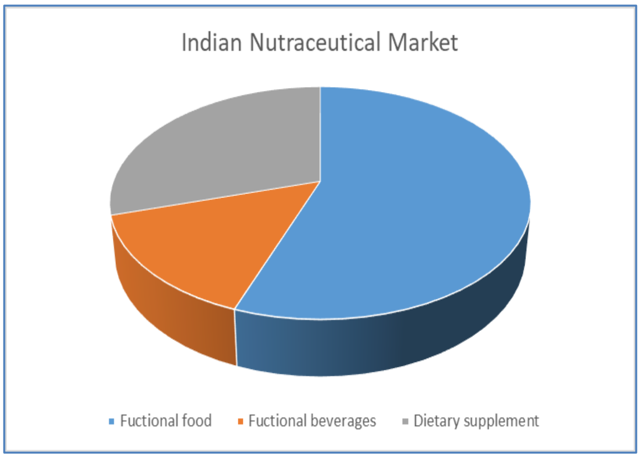
Rhodophyceae, respectively) were found to be the potential sources of bioactive substances. Although global utilization of marine algae is a multibillion dollar industry, their bioactive potential is still underexplored. For centuries, the medicinal properties of marine algae were limited to traditional and folk medicines. However, in recent years, industries from different branches (cosmetics, pharmaceutical and food) have been focusing their attention on the discovery and development of compounds from the marine algae. The research works at the Central Marine Fisheries Research Institute in India developed a hitherto unraveled database of marine algae with small molecular weight bioactive molecules responsible to combat various life-threatening diseases. Marine algae are fast growing and potentially renewable resources that are currently being explored as novel and sustainable sources of compounds for both pharmaceutical and nutraceutical applications.

Nutraceuticals

Nearly 400 million people in India belong to the middle class and have disposable income which have made them capable of buying nutraceuticals and dietary supplements. It is an inevitable fact that affluence is one of the causes of lifestyle diseases, which nutraceuticals and dietary supplements often address.







Major marine nutraceuticals industries in India and their products

Sl. No.	Name of Industry	Products
1	Pioneer Pharmaceuticals, Kochi-682 025, Kerala	Seaweed based nutraceuticals
2	Accelerated Freeze drying Company Ltd., Kochi	Mollusk based nutraceiticals
3	Chazah Pharmaceuticals Ltd, Kochi	Seaweed based nutraceuticals, astaxanthin
4	SNAP Natural and Alginate Products Pvt. Ltd., Ranipet, Tamil Nadu	Alginates, carrageenan, plant growth stimulant, aquaculture inputs etc.
5	AquaAgri Processing Private Ltd., New Delhi	Carrageenan, plant growth stimulant, animal feed ingredient etc.
6	Marine Hydrocolloids, Cochin, Kerala	Agar, agarose, carrageenan, sodium alginate, pulverized seaweed
7	Biostadt India Limited, Mumbai	Growth stimulant, fish growth stimulant
8	HiMedia Laboratories, Mumbai	Agar, alginic acid
9	AquaRev, Una, Gujarat	Carrageenan, stabilizer for ice cream, khoya & paneer
10	Jumat Agar-Agar Industries, Tirupur, Tamil Nadu	Agar-agar
11	Hifield - Ag Chem. India Private Limited, Aurangabad, Maharashtra	Seaweed powder, flakes
12	Sarda Biopolymers Pvt. Ltd., Mumbai	Carrageenan
13	Altrafine Gums, Ahmedabad, Gujarat	Food grade kappa carrageenan

Nutraceuticals and their manufacturing companies/developing organizations

Products	Description	Company/ Organization	Country
AstaFirst	Astaxanthin	Wefirst Biotech Co.Ltd	China
AstaPure	Astaxanthin	Alga Technologies	Israel
Red alage capsules	Extract of red algae *Gracilaria gracilis* to be used for blood circulation	Ahana Nutrition	USA
Red marine algae	Immune support, digestive health	Bio Nutrition Inc.	USA
Red Algae Calcium Powder	multi-mineral complex from marine red algae	Now Foods	USA
Red seaweed	Nutrition source	Omega One	USA
Cadalmin®ATe	Thyroid	Cadalmin® (ICAR-CMFRI)	India
Cadalmin®ACe	For lowering cholesterol levels	Cadalmin® (ICAR-CMFRI)	India

Cadalmin®ATe	Thyroid support	Cadalmin® (ICAR-CMFRI)	India
Cadalmin®AOe	For curing osteoporosis	Cadalmin® (ICAR-CMFRI)	India
Cadalmin®AHe	Regulation of hypertension	Cadalmin® (ICAR-CMFRI)	India
Cadalmin®AOe	Osteoporosis	Cadalmin® (ICAR-CMFRI)	India
Cadalmin®GAe	Arthritis	Cadalmin® (ICAR-CMFRI)	India
Cadalmin®IBe	Immunoboost	Cadalmin® (ICAR-CMFRI)	India
Cadalmin®ADe	Regulation of blood glucose level	Cadalmin® (ICAR-CMFRI)	India
Brown Seaweed Extract	Supports Healthy Weight & Healthy Immune System	NusaPure	USA
Brown Seaweed Plus	Immune stimulating properties	Only Natural	USA
Kelp Iodine Supplement	Thyroid Support, Strengthen Immune System, Regulates Metabolism, Boost Cognitive Ability	Natural Nutra	Russia
Marine-D3	Anti-Aging	Marine Essentials	USA
Brown Seaweed Extract	boost the immune system	Modifilan	USA
Brown Seaweed Extract	Weight loss, lowing cholesterol and hypertension, relief of constipation, and boosting the immune system.	SeaHerb	Korea
Xanthadrene	Promotes & supports healthy metabolic rate & breakdown of fat.	Newton-Everett Nutraceuticals	USA
Organic Irish Carragheen Moss	Traditionally used to set jellies and puddings, can be used as thickening agent also for soups and sauces.	AlgAran Seaweed Products	Ireland
Organic Irish Kombu / Kelp	High in calcium and magnesium	AlgAran Seaweed Products	Ireland
Savory Seaweed Thai rice chips	Made with nutrient-packed seaweed flakes for an umami-rich flavor in this crunchy, savory snack.	Dang Foods Company	USA
Seaweed Snacks Full Sized Seaweed Sheets	Gluten free, vegetarian	gimMe Health Foods Inc.	USA
Irish Moss & Irish Spirulina Capsules	The blend of red and green seaweeds provide a complete protein with all of the essential amino acids, many vitamins, minerals and other trace elements	Irish Seaweeds	Ireland

Triple Blend Seaweed Capsules	source of over 70 vitamins and minerals (nothing added) also contains proteins, selenium, antioxidants, essential fatty acids,(including omega 3) phenol's, enzymes, trace elements, amino acids, and all the rare nutrients like B12	Irish Seaweeds	Ireland
Kelp Seaweed Capsules	natural source of Iodine which supports healthy thyroid function and is good for general health and skin condition	Irish Seaweeds	Ireland

Marketing of seaweed-based products/nutraceuticals

The rise in demand for seaweed is owed to increased use of seaweed in dietary supplements, due to its health benefits. Presence of bioactive compounds, antioxidants, and antimicrobial properties has led to the use of seaweeds in the pharmaceutical industry also. Asia-Pacific was the leading regional market for commercial seaweeds (61.7%) in 2018. Increased demand for organic foods as well as already well-established market will be fueling the growth for seaweeds in this region. North America had a market share of 18.5% in the year 2018. North America is expected to register the highest CAGR of 8.9% in the commercial seaweeds market between 2019 and 2026. Europe had a market share of 12.7% in the year 2018 with a CAGR of 8.3% between 2019 and 2026 (Reports and Data, 2019).

The global commercial seaweed market is estimated to value USD14.8 billion in 2020 and is anticipated to reach USD 24 billion by 2027, with a CAGR of 7.1% during 2020-2027. The US commercial seaweeds market is estimated at USD 4 billion in 2020. The market size of China is projected to reach USD 5.3 billion by 2027. Other notable markets Japan and Canada are expected to grow at a CAGR of 3.9% and 6.4% respectively during 2020-2027. Germany is expected to grow at a CAGR of about 4.6%. The Asia-Pacific market, led by Australia, India, and South Korea, is anticipated to reach USD 3.3 billion by 2027, while Latin America is expected to grow at a CAGR of 7.2% during 2020-2027 (Research and Markets, 2020). Seaweed utilization is being considered as a priority area by the Government of India promoted under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), a scheme approved in May 2020 and launched by the Prime Minister of India on September 10, 2020. An investment of Rs.640 crores (a direct investment of Rs. 354 crores for over next 5 years (till FY 2024-25) for seaweed cultivation and Rs. 286 crores for additional activities) have been earmarked under PMSSY for seaweed cultivation, processing and marketing.

Global best practices standards and guidelines that are essential to develop a sustainable Blue Biotechnology and promote doing business in the country

Marine bioprospecting depends upon access to marine organisms, which in turn is governed by multiple legal regimes and national and international laws. Marine genetic resources found within the Exclusive Economic Zone (EEZ) are subject to national laws, and to the CBD and the Nagoya Protocol. This means that coastal states have the sovereign right to allow, prohibit and regulate marine bioprospecting in the EEZ; that users of genetic resources who wish to access this material must obtain prior informed consent from national competent authorities; and there must be mutually agreed terms on access and the sharing of benefits. In practice, it has been extremely difficult to implement ABS principles for marine genetic resources, due in large part to their widespread occurrence and the challenges of determining ownership, but also to the evolving nature of ABS law and policy, and the absence of workable policy approaches in many countries. In all likelihood, therefore, most cases of marine bioprospecting in the EEZ have not been approved by national authorities, thus leaving the patent applicant and commercial entities as sole beneficiaries (UNCTAD 2014). In India, an increased awareness is, however, leading to recognition of the importance of ABS in bioprospecting initiatives by NBA (national Biodiversity Authority, Chennai) as an apex body. The commercial success and long-term nature of natural product research suggest that monetary benefits associated with scientific engagement and technology transfer are likely to be some of the more significant benefits to emerge from marine bioprospecting in the short-term. In the high seas, or Areas Beyond National Jurisdiction (ABNJ), natural resources are considered to be the "common heritage of humankind" and are subject to the provisions of UNCLOS. Specialised ABS rules for these resources have not yet been developed and UN members are presently debating the desirability of a new international instrument arising from the conservation and sustainable use of marine biodiversity in these areas (Global Ocean Commission 2013). A central question is whether the benefits arising from the commercial use of these resources should be shared by the entire international community, or whether the States and corporations with the intellectual and technological know-how to exploit these resources should benefit. Unsurprisingly, the G77, which comprises countries that largely do not have suitable scientific and technological capacity, are supportive of an ABS regime that distributes benefits from this common resource more equitably. To date, the debate has focused largely on the potential economic value of marine genetic resources, as most research has been on resources from inside National jurisdictions (Oldham and others, 2013).

Marine bioprospecting and commercialisation of products: An ICAR perspective

ICAR has created Technology Transfer Units (ITMUs) alone or with other stakeholders to contribute to the commercialisation of their research results. Thus today there are established commercialisation stakeholders who are closely linked to the most prominent publicly-funded research institutions in ICAR. ICAR-CMFRI is one of the prominent research Institutions in the World, and its ITMU has a central role to play in relation to marine bioprospecting and the associated commercialisation.

The ITMU system was established fairly recently, and it still needs more time to further develop the system in a positive direction. Commercialisation of marine bioprospecting results will not differ greatly from commercialisation of research results from life sciences. However, there is a broad range of applications, and the volume of marine bioprospecting results that may be commercialised will not be such that it is practical to develop separate commercialisation centres for this activity. The Government believes, however, that there is a need to strengthen and utilise the various commercialisation stakeholders' expertise through increased collaboration and specialisation among the ITMU. It is important to note that the most important contribution that the universities and research institutes will make to the bioprospecting-based business development will not solely be through commercialisation in the form of patents, licensing and new start-ups. The importance of the role as a developer of knowledge and collaboration partner for established companies is just as important.

Actionable policy measures involving multiple ministries:

Investment in marine bioprospecting is an important part of the Government's plans for building knowledge and the development of industry and commerce. The importance of marine bioprospecting as an investment area with significant business development potential is stressed. The Government of India along with the Minsitry of Agriculture and Ministry of Earth Sciences (MoA & MoES) is convinced that India's long coastline and our maritime zones provide major opportunities with regards to access to resources and biodiversity. The MoA & MoES encourage culture of marine organisms utilized for drugs to prevent their unsustainable extraction from the wild.

Regulations pursuant to the National Biodiversity Act of the National Biodiversity Authority (NBA) as the apex organisation shall be drawn up to secure control of the search and extraction activity that is started in Indian waters. This ensures control of where such activity takes place, and it lays the foundation for the community to reap the benefits that may eventually be generated through utilising our common resources. Furthermore, this will be important to ensure that wild marine resources or vulnerable marine areas are not damaged by the extraction. The NBA outlined that the search and extraction activity should not be permitted before the administrators have obtained information about where the extraction will take place, its purpose and scope. The NBA as an apex body will handle applications for permits to search for and extract marine genetic material, and it will enter into agreements connected with utilising material with the applicants. A registration system that provides an overview of collected material is in place. The administration of this system may be added to the appropriate centre, e.g. in connection with a national marine biobank. Regarding permits for search and extraction activity, terms may be put in place pursuant to the NBA act that agreements have to be entered into with the public authorities, which ensure that the community receives a share of the benefits that may be generated by the utilisation of marine genetic material from Indian waters. This may include, among other things, access to knowledge, relevant information and sample parts from Indian marine genetic material. Such agreements may also contain provisions regarding the sharing of financial gains. This enables the community to benefit to a greater extent from the utilisation of marine genetic material. These provisions should be clear so that predictability in relation to commercial utilisation is secured. The NBA Act also has the legal authority to impose conditions regarding the utilisation of marine genetic material.

The Indian Ocean Region is abundant with resources, particularly in the sectors of food and pharmaceuticals, and provides tremendous economic opportunities. A strong impetus on Research and Development, and Innovation in the areas of marine bioprospecting must be provided for the Nation to achieve significant market shares in these sectors. It is necessary for India to tap the enormous potential of the Ocean based Blue Biotechnology, which will propel the nation into a higher growth trajectory. The development of Blue Biotechnology can serve as a growth catalyst in realizing the vision to become a leading Nation in harnessing the marine bioactive compounds from the sea by 2030. Notably, the countries in the Indian Ocean Rim Association (IORA) exhibited significant dynamism in the past few years as the trade in the region from marine bioactive compounds/healthcare products increased by over four times from US$ 302 billion in 2003 to US$ 1.2 trillion in 2012 .

Special focus on integrating flagship schemes of Government of India

Oceans cover three-quarters of the Earth's surface, contain 97% of the Earth's water, and represent 99% of the living area on the planet. Oceans are claimed to be 'last frontiers' of growth and development, but the immense potential that the Oceans present remains to be tapped fully. However, this potential needs to be harnessed in a balanced manner, where the preservation and health of Oceans are given their due importance, along with adherence to the United Nation's Sustainable Development Goal #14 that states "Conserve and sustainably use the oceans, seas and marine resources for sustainable development".

The Cabinet Committee on Economic Affairs, chaired by the Hon'ble Prime Minister Shri Narendra Modi has given its approval for the umbrella scheme "Ocean Services, Technology, Observations, Resources Modelling and Science (O-SMART)" of Ministry of Earth Sciences, for implementation during the period from 2017-18 to 2019-20 at an overall cost of Rs.1623 crore. The scheme encompasses a total of 16 sub-projects addressing ocean development activities such as Services, Technology, Resources, Observations and Science. Implementation of O-SMART will help in addressing issues relating to United Nation's Sustainable Development Goal #14, which aims to conserve use of oceans, marine resources for sustainable development. This scheme (O-SMART) also provides necessary scientific and technological background in marine bioprospecting that is required for implementation of various aspects of Blue Biotechnology. This scheme also emphasized fish and marine bioresources as valuable tools in food security, nutrition and health, whereas marine fish is particularly critical source of nutrition among the coastal populace. Even in small quantities, provision of fish can be effective in addressing food and nutritional security among the poor and vulnerable populations around India.

Notably, the Declaration of the Indian Ocean Rim Association on Enhancing Blue Biotechnology Cooperation for Sustainability emerged, focusing on sustainable development in the region, and placing fisheries and aquaculture as one of the priority sectors of the Blue Biotechnology. The Hon'ble Prime Minister Shri Narendra Modi has also stated that Blue Biotechnology would be a tool for developing India, and made it a feature of his vision for the sea in Security and Growth for All in the Region.

Nanoparticles, enzymes, biopolymers, biomaterials for industry and the development of other life science products

Enzymes have for many years been the driving force of biotechnology. There is an ever increasing demand for novel enzymes for a variety of applications ranging from the degradation of natural polymers such as cellulose, starch and proteins, or for use in the pharmaceutical and chemical industries, involving numerous chemically and structurally diverse molecules. Up to the present time, over 3000 microbial enzymes have been isolated. Because they live in a unique environment, marine organisms can provide some potentially useful characteristics such as an increased salt tolerance and stereochemical properties. A limited number of biocatalysts such as amidases, lipases, proteases and carbohydrases, have been isolated, biochemically characterised, and in some cases, optimised through protein engineering. For example, enzymes from marine hyperthermophilic archaea are used in molecular biology research, diagnostics, food safety and environmental monitoring. They include DNA-dependent DNA polymerases, DNA ligases from marine *Thermococcales* (*Thermococcus* and *Pyrococcus*) that are the enzymes of choice for high-fidelity *in vitro* gene amplification. In addition, Shrimp Alkaline Phosphatase (SAP) from Marine Biochemicals has become a popular DNA-modifying enzyme due to its heat inactivation properties. The luminescent properties of the jellyfish *Aequorea victoria* led to the characterisation of the green fluorescent protein (GFP). The aequorin protein from the *Aequoria* jellyfish has also found use as a biosensor for Ca^{2+} signalling in the research laboratory. Enzymes such as silicateins involved in biosilicia production in marine sponges and enzymes involved in dissolving or etching silica such as silicases, have enormous potential in nanobiotechnology and biomedicine. For example, biosilica can be used as a coating for metal implants used in surgery, for drug delivery via encapsulation of bioactive compounds, and in microelectronic fabrication. In addition, silicateins and silicases may also find uses in organosilicon chemistry, specifically in drug design through the synthesis of novel drug analogues by the replacement of specific carbon atoms with silicon, or the regeneration of tooth and bone defects. Future applications may be in structuring nanoengineered fibre-optics and etching nanoscale silica structures.

Biopolymers of marine origin are currently being examined for a wide variety of applications. There is a particularly strong interest in the biomedical sphere, with developments such as pharmaceutical and medical polymers, bio-adhesives, wound dressings, dental biomaterials, tissue regeneration and 3D tissue culture scaffolds. Polysaccharides (also called glycans) are an emerging class of marine-derived biopolymer with numerous applications. In addition to their potential direct use as biomaterials, marine derived polysaccharides are readily amenable to chemical modification, permitting a greater flexibility in the design of, for example, novel alginate co-polymers which have significant promise as drug delivery systems. Marine macroalgae synthesise a great diversity of polysaccharides, which constitute their cell wall and energy storage. They are characterised by their high levels of sulphated polysaccharides which have no equivalent in land plants and which are currently being investigated as potential immune boosters in cattle. The ban on using antibiotics in cattle feed adds extra impetus to the development of these novel approaches using compounds derived from marine organisms. Red algae produce agars and carrageenans and brown algae produce alginates, fucans and laminarins. These hydrocollids are well-known for their gelling properties and are used in a variety of laboratory and industrial applications. Laminarin for example is used for the stimulation of natural defences in terrestrial crop cultures thus allowing the partial replacement of pesticides used in conventional agriculture. In this application, the priority is given to the crop protection rather than to the pathogen destruction. Chitin (and its derivative chitosan), derived principally from shellfish waste (prawn, crab, crayfish), can be used in combination with natural or synthetic polymers and is widely used in biomedical applications due to its lack of toxicity, biodegradability, anti-bacterial and gel-forming properties. In addition to the characteristics detailed above, chitin and chitosan are capable of forming films and chelating metal ions. Collagen-based marine sponges have been utilised as a potential collagen biomaterial for bone repair. Once again, native sponge materials and chemically modified derivatives have been investigated. Hydrothermal conversion of calcium carbonate to hydroxyapatite, a calcium phosphate compound found at high levels in mineralised tissue/bone of vertebrates, has received much attention in the past 10-15 years. Hydroxyapatite formed in this manner permits synthesis of a compound with a similar microstructure to that of bone. In recent years, bioceramics based on calcium phosphates, have been examined extensively as bone substitutes, since these materials may be bioactive (hydroxyapatite, bioactive glasses), resorbable (tricalcium phosphate), porous for tissue in-growth (hydroxyapaptite coated metals) or composites. Recently, the hydrothermal conversion of coralline algae to hydroxyapatite has also been investigated.

Conclusion

Marine derived bioactive components with potential health benefits are an emerging area of research. Considering their underutilization, exploring bioactive compounds and development of any biologically useful products has duel benefits-as health products and their commercial farming of seaweeds in coastal habitats, resulting in C- sequestration and C-budgeting in a scenario where climate change may pose a serious threat in future. Development of value-added products from these underutilized species will also promote their farming in coastal habitats, which has not been seriously explored earlier due to the lack of knowledge about their commercial importance. ICAR-Central Marine Fisheries Research Institute has devoted research program to develop various health products from marine organisms towards their utilization based on the National Policy to harness the potential of this natural wealth of Indian coastal waters. ICAR-Central Marine Fisheries Research Institute is also in the process of developing more health products from the underutilized seaweeds for treatment against thyroid disorder, hypertension and other lifestyle diseases. Several cosmeceutical products, such as seaweed-based antimicrobial ointment, hybrid drug delivery system are also in the pipeline, and are being commercialized. This prestigious marine fisheries research institute of Indian Council of Agricultural Research (ICAR) is working in the broad national interest of producing high value nutraceutical products/pharmaceutical leads from the marine organisms, which will provide promising therapeutic agents against various diseases. The marine genetic resources of India are likely to continue to be attractive for natural product research, especially with the accelerated development of marine bioprospecting for pharmaceutical applications. While marine bioprospecting presents a number of important opportunities, these are currently not being fully optimised. Appropriate laws are not yet in place; the costs of research and technologies remains prohibitively high; scientific capacity is low; and there are significant gaps in taxonomic and ecological knowledge.

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