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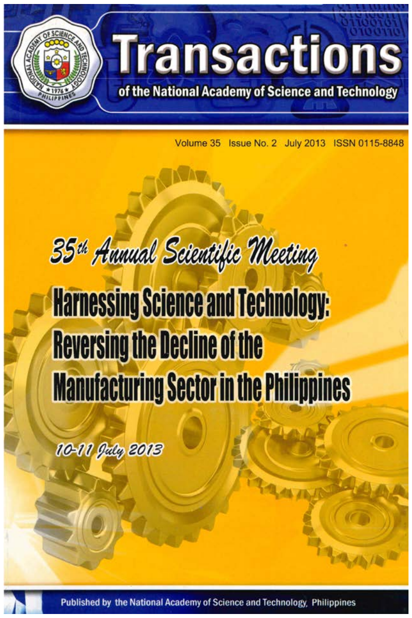

Prospects for Biofactories of High Value Aquatic Products in the Philippines

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PROSPECTS FOR BIOFACTORIES OF HIGH VALUE AQUATIC PRODUCTS IN THE PHILIPPINES

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Abstract

Marine biodiversity is a valuable and strategic national asset that provides various goods and services to our people. The fishery production and processing industries are critical for domestic food security and contribute a huge percentage to the national economy in terms of livelihood and trade. Apart from the fishery industry, there is tremendous potential for developing and adding value to other industries. In particular, discards from capture fisheries and aquaculture, and diverse seaweeds and invertebrate species provide immediately available raw materials for the development of high-value products such as pharmaceuticals, nutraceuticals, and biofuels. Biodiversity-based industries will contribute to sustainable development and inclusive growth by generating multiple benefit streams for various stakeholders, including poor coastal households through the increased value of harvests per unit volume and livelihood diversification. The prospects for ecological and socio-economic benefits should serve as incentives for greater public and private investments in research and technology development for high-value marine products. A holistic framework to harness optimal economic benefits and sustain our natural resources capital is presented, and the importance of multi-sectoral partnerships in realizing these potentials are discussed.

Keywords: marine biodiversity-based industries, development framework

Introduction

As an archipelago of about 7,107 islands, the Philippines has more water than land area (DENR, UNDP, and MERF, 2004), and the sea is a source of various goods and services, primarily fisheries, recreation, and marine transport. Of the provisioning services from the sea, the fishing industry (both capture and culture) is the most important for Filipinos. The contributions of the fishery sector include being a source of livelihood, income, employment, foreign exchange earnings, nutrition, and food security (Green et al. 2003). Fish serves as a major protein source, and about 6 million Filipinos are directly dependent on the fisheries sector (Barut et al. 2003). In 2010, the Philippines was the 5th highest fish-producing country in the world with a total production of 5.16 million metric tons of fish, crustaceans, mollusks, and aquatic plants. This constituted 3.06% of the total world fishery production, which amounted to 168.4 million metric tons worth 10.3 billion dollars (BFAR 2011).

The fishery production and processing sectors provide employment and significantly contribute to the national income. In 2011, the fishing industry's contribution translated to about P183.1 billion for current prices and P130.77 billion for constant prices of the country's Gross Domestic Products (GDP) of P9,734.78 billion (current prices) and P5,914 billion (constant prices) (BFAR 2011). Ironically, the fishery sector is the poorest sector in the Philippines (NSCB 2012). The country's fishing households are poorer, less literate, and have less access to necessities, such as good shelter, safe drinking water, toilet facilities and electricity, as compared to non-fishing households, Fishing households earn an average annual income equivalent to only half of the national average. In 1996, it was estimated that 80% of coastal households were living below the poverty threshold. Given that the poorest sector is found in the coastal areas and are highly dependent on aquatic resources for food and livelihood, the management and sustainable development aquatic resources is critical in meeting the Philippine Millennium Development Goals of eradicating hunger and poverty (Juinio-Meñez and Toribio 2013).

The Philippines is one of the richest countries in the world in terms of marine biodiversity (e.g., Sanciangco et al. 2013; Carpenter and Springer 2005). However, marine biodiversity as a valuable and strategic national asset is not well recognized. Apart from the current socio-economic values of marine capture and culture fishery industry, there is tremendous potential for developing and adding value to other marine biodiversity-based industries that can contribute to boosting the manufacturing sector of the country. Marine plants and animals, as well as the wide range of compounds they produce, can be used as raw materials to produce high-value industrial products apart from traditional fishery-based food products. Biofactories involve the production of commercially profitable quantities of high-value products such as novel biologically active compounds from aquatic species that can expand manufacturing options in terms of renewable energy (i.e., biofuels), marine natural products (e.g., pharmaceutical and nutraceutical products), and other high-value industrial products. This paper provides an overview of the status and potentials of high-value products from cultured and wild finfish discards, seaweeds, and marine invertebrates, and discusses prospects of developing biofactories based on locally available raw materials. An integrated framework to harness optimal benefits and sustain the country's natural resources capital is presented, and the importance of science and technology development and multi-sectoral partnerships in realizing these potentials are discussed.

Finfish Discards

Fish processing only utilizes about 50% (Sharp and Mariojouls 2012) of the fish, resulting in a considerable amount of wastes and by-products. Fish by-products include the viscera, scales, and bones, among others. Globally, fisheries and aquaculture industries produce 130 million tons of fish waste per year consisting of by-catch, onboard waste, home waste, and industrial waste (Sharp and Mariojuouls 2012). The waste is often disposed in landfills or dumped at sea. For example, in 1992, New Zealand turned out 1,667 tons of by-products, which ballooned to 47,782 tons in 2010 (Simmons et al. 2012). Much has been done to maximize the yield of directly edible products, but the production of waste or by-products still remains; much of which is generally discarded or used as low-value products. In Alaska, the total annual production of by-products reaches 2.2 billion pounds. Large processors have utilized this massive waste to produce fishmeal and fish oil, which are generally sold for additional profit. Protein from these by-products was proven comparable to products already used in food, dietary supplements, medical treatment, and animal feed (McGinnis and Wood 2007).

Fish wastes are nutritionally rich in valuable oils (e.g., omega-3), minerals, and bioactive compounds that have many alternative uses in food, pharmaceutical, nutraceutical, agricultural, aquaculture, and industrial applications (Figure 1). Value can be added to by-products by mass transformation (e.g., fish waste) and sorting (e.g., head, liver, bones) (Sharp and Mariojouls 2012).

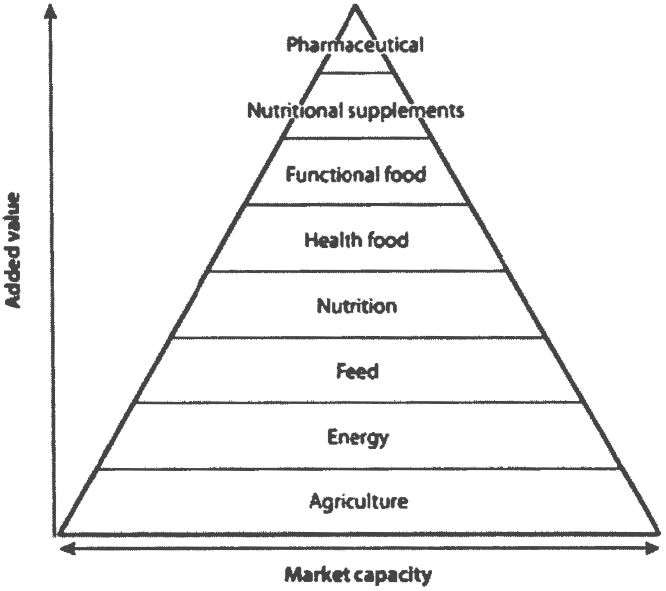


Figure 1. Market pyramid for different value adding applications for fish waste.
Source: J.P. Berge, 2012 (cited in Sharp and Mariojouls 2012)

In the Philippines, although the extent of losses in the post-harvest phase is difficult to quantify, Espejo-Hermes (2004) reported that at least 25% to 30% of the total production is lost due to improper handling. On top of these losses, the shortage of raw materials is one of the primary problems in the processing industry in the country (Espejo-Hermes 2004). Thus, optimization of fish utilization is necessary in order to prevent post-harvest fishery losses. Currently, fish by-products are converted to value-added food products, such as fish balls, fish sausages, and fish nuggets. To minimize waste, by-products of deboned milkfish are used to make fish rolls and dumplings (Espejo-Hermes 2004).

Potential Raw Materials for Higher–Value Products from Fish Discards

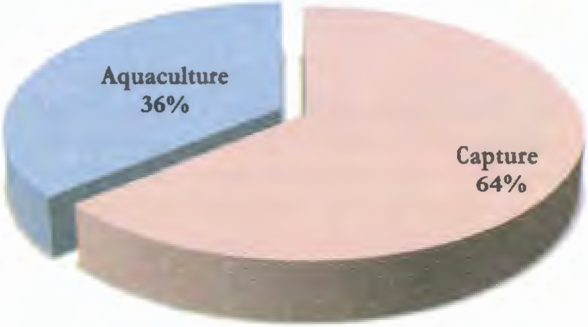
Cultured Milkfish and Tilapia

Over the last 10 years, major commodities from the 2 fishery sectors in the Philippines have increased (Bureau of Agricultural Statistics, Data 2000-2010) to a total production of 13,988,935.2 MT. Aquaculture and capture sectors constitute 36% and 64% of fishery production, respectively (Figure 2). During this period, the aquaculture sector produced 5,070,920.4 MT; of which, 59% milkfish and 37% tilapia comprised the majority (Figure 3). Both commodities are consumed locally fresh, dried, or processed (e.g., bottled Spanish style bangus).

Seventy percent of milkfish or *bangus* is primarily produced in regions I, III, and VI, and there was an estimated 40% increase in production from 2002 to 2012 (Santos et al. NAST RTD, 2013 from BAS 2012). Six companies from Mindanao have been reported to export *bangus* in the US, Canada, Australia, and China. Two of these companies have already penetrated the European market, which offers a better price than the US.

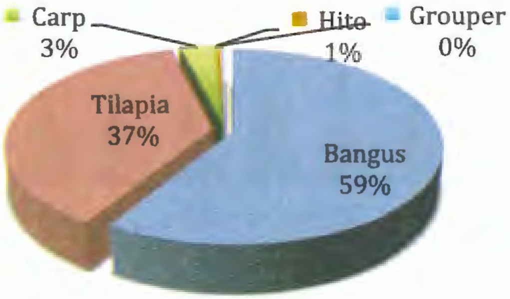
Pearl essence, which are crystals used in paint pigments and cosmetics that require luster, can be removed, collected, and purified from fish scales (Johnson et al. 2002). A diagnostic character of milkfish is its small, smooth, and silvery colored scales on its belly and sides (Bagarino 1999). Given the shimmery nature of milkfish scales, production of pearl essence, particularly from commercial scale milkfish export processing companies, could be explored.

Tilapia is one of the most important fishes that Filipinos consume. Eighty percent of tilapia is produced in regions III and IV, and there was an estimated 50% growth in production from 2002 to 2012 (Santos et al. NAST RTD, 2013 from BAS 2012). One value-added product from tilapia skin, which is normally considered a waste product, is tilapia leather. In Brazil, there is a popular market for tilapia leather, which is made into clothing and apparel (e.g., briefcases, purses, wallets, and belts) (Fitzsimmons 2000 cited in Watanabe et al. 2002). Tilapia leather can be developed as a novel raw material for the local shoe manufacturing or handicraft industries.



Total Production = 13988935.19 MT

Figure 2. Percentage contribution per fisheries sector from 2000 to 2010.
Note: Data included here are only major commodities produced in aquaculture and capture fisheries sectors.



Total Production = 5070920.41 MT

Figure 3. Relative percentage contribution of aquaculture production (2000 to 2010).

Tuna and Sardines

For capture fisheries, 31 species are commonly fished and the majority of which is locally consumed fresh, dried, or smoked. Of these, pelagic species (i.e., tunas, sardines) comprise the greatest volume (Figure 4), and are processed into canned products. These processed species generate industrial scale discards that can be utilized as raw materials for other high-value products since these pelagic species are rich in oils and other valuable natural compounds.

Since 1970, the country has stood as the 7th largest tuna producer in the world, and had contributed to about 10% of the world's tuna production in 2005. In addition, the value of production at constant prices of the commercial fisheries sector in 2013 reached 39,160,133.67 ('000 P), an increase of 4.30% from 2012 to 2013, which was owed to the increased fishing operations in the high seas (BAS 2013). The bulk of the tuna produced in the country is mainly exported frozen to the United States and Japan, whereas small quantities (i.e., those that were rejected or did not pass international standards) undergo processing for local commerce and consumption. Tuna, being one of the most economically important fish species, contributes a massive amount of by-products after processing.

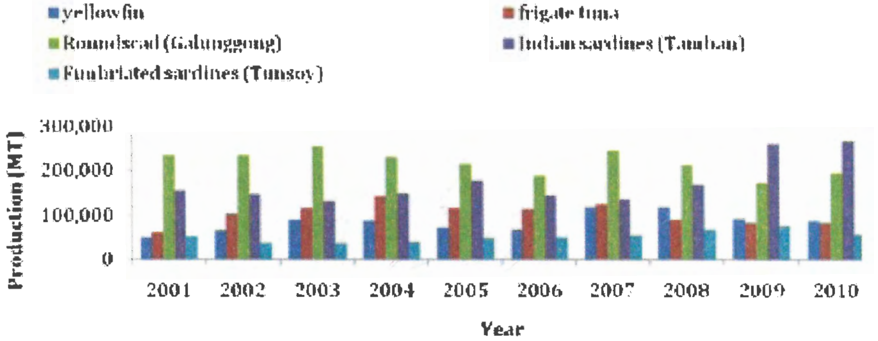


Figure 4. Major commodities from the Capture Fisheries sector (Data from BAS).

In general, fish by-products have been industrially utilized in the manufacture of fishmeal, silage, and fertilizers. Fishmeal contains digestible proteins, essential vitamins and oils, and is largely used in both agriculture and aquaculture to promote the growth of plants and livestock. However, there are higher value products that can be derived from discards of pelagic fishes, which contain a great amount of oils. Nguyen et al. (2011) reported that tuna by-products could be utilized because it notably exhibited proteolytic and enzymatic activities. Fish oil (e.g., from tuna) is mainly composed of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These two fatty acids, classified as omega-3, are known to reduce the risk of coronary heart problems and other heart-related dysfunctions, and have been found to improve brain development (Severus et al. 2000).

Fish by-products can also be used to produce chymotrypsin (Zhou et al. 2011), an endopeptidase secreted by the pancreatic tissues of vertebrates and invertebrates. Chymotrypsin has various applications in many industries including the food industry, leather production industry, chemical industry, and medical industry.

Fish discards could be a potential source of biofuel. Fish oil from discarded fish parts was catalyzed by *Carica papaya* lipase to produce biodiesel (Pinyaphong et al. 2011). Biodiesel from refined fish oils have a higher cloud point and cetane number, and better stability. Moisture content was far below the values that could cause biodiesel yield to decrease. In Iran, extracted oil from fish waste is utilized to produce biofuel. Yahyaee et al. (2012) reported that 11% of the total weight of fish waste is oil, which can be utilized to produce biodiesel fuel after a chemical reaction called transesterification. Important fatty acids such as palmotoleic acid, palmitic acid, stearic acid, oleic acid, linoleic acid, and linolenic acid were identified from the extracts, and such fatty acids affect the magnitude of the cetane number of biodiesel fuel.

Fish by-products contain valuable protein and lipid fractions, as well as vitamins and minerals, but are also a significant source of environmental contamination (Nguyen et al. 2011). Hence, environmental regulations now require new methods for managing fish discards. Thus, apart from additional economic benefits, production of high-value products from fish discards will help reduce environmental pollution.

Seaweeds

Seaweeds comprise a high proportion of the species diversity of marine flora and thus represent a huge potential of renewable raw materials for biofactories. Seaweeds are cultivated for food, feed, and fertilizer in many portions of the world. These marine plants are generally low-calorie and are rich in vitamins, minerals, and dietary fiber. In addition, seaweeds are a potential source of protein and a small amount of unsaturated lipids, which provide protection against cardiovascular pathogens. Seaweeds are also a source of bioactive compounds that exhibit cytostatic, antiviral, antihelminthic, antifungal, and antibacterial activities (Vallinayagam et al. 2009). Moreover, seaweeds have been recognized to provide chemically and functionally novel metabolites that demonstrate a wide range of antioxidant, anti-inflammatory, anti-cancerous, anti-proliferative, and anti-obesity activities (Sachindra et al. 2010). For these reasons, marine plants have been screened globally to isolate life-saving drugs or biologically active substances.

As of the most recent inventory of seaweed diversity, there are 949 recorded species in the Philippines (Ganzon-Fortes 2012). About 350 species of the species found in the country are considered economically important (Trono 1999). The Philippines is considered as one of the world's leading producers of seaweeds by quantity, after China and Indonesia (FAO 2010). Two species that comprise the sources of kappa-carrageenan are *Kappaphycus alvarezii* (Doty) Doty ex Silva and *Kappaphycus striatum* (Schmitz) Doty ex Silva, and a source of iota-carrageenan is *Eucheuma dendiculatum* (Burman) Collins et Harvey (Ganzon-Fortes et al. 2012). Seaweed farming is considered the most successful local mariculture industry. It is mostly a small grower industry at the production side, which provides alternative livelihood in poor coastal areas. Seaweeds are produced in all regions except CAR, with ARMM as the largest producer (Velayo NAST RTD 2013) (Figure 5). In 2004, the total national production of highly valued seaweeds reached 1.2 million metric tons, of which 56.9% came from Mindanao. The 2004 production generated $158 million, a 10% increase from the production in 2003.

While the growth of the seaweed production has declined in recent years, the Philippines is still the top worldwide producer of carrageenan. In 2010, the Philippines produced 34, 500 MT of carrageenan followed by Indonesia (17, 000 MT). In the same year, the worldwide market price reached $1,500 per metric ton and P60 per kilogram (SIAP data 2010). Major carrageenan markets include meat, dairy, water gels, toothpaste, and pet food, among others; it has also slowly made progress in pharmaceuticals (e.g., excipient formulations and drug capsules) and cosmetics (Bixler and Porse 2011).

Less than 5% of commercially important species are presently utilized as food species and as sources of phycocolloids and other natural products used in various applications, ranging from agricultural, medical, pharmaceutical, neutraceutical, or bioremediation/biofiltration (Trono NAST RTD 2013). The vast potentials of the seaweed diversity of the country remain a major area for expansion of seaweed-based industries not only in farming, but also in other industries for highly valued natural products. For example, the industrial potentials of *Sargassum* spp., *Gracilaria* spp., and *Caulerpa* spp. are just being explored.

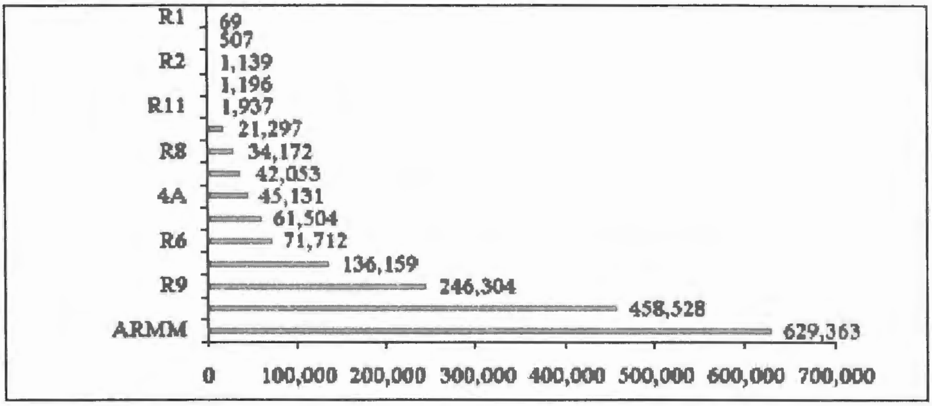


Figure 5. Seaweed production by region, 2012 (Velayo NAST RTD, 2013).

Sargassum, a genus of brown algae, is common in rocky intertidal and shallow subtidal areas of the Philippines. It is often cast up in large quantities on shores and beaches after storms. Thinh et al. (2013) isolated and purified fucoidan fractions, potential antitumor agents, from the brown alga, *Sargassum mcclurei.* Crude and diethyl ether extracts from *Sargassum polycistum* collected from Batangas, Philippines were also found to be effective as an insecticide, a possible plant hormone, and a basic emulsifier for soap. In the study conducted by Samee et al. (2009), two *Sargassum* species exhibited effective anti-allergy activities.

In addition to the development of seaweed-based food and natural products industries, attention has been directed towards the production of energy. Seaweeds have a high sugar content, which are converted to advanced biofuels and ethanol, have no lignin, can more easily be harvested compared to microalgae, and can be harvested up to six times a year in warm climates. Moreover, seaweeds absorb more airborne carbon than land-based plants (Mitra 2013), and require no pretreatment for ethanol production. Other prospective advantages of seaweed biofuels relative to terrestrial plants include the lack of competition with arable lands and limited or no need for the use of freshwater and external fertilizers or phytosanitary products. Because of these, investments from petrochemical majors and governments in Asia, Europe, and the United States have emerged (Thormund 2010). While the expansion of seaweed culture can conceptually be more environmentally friendly, it can also exclude other users, especially in multiple-use near shore areas that may cause socio-economic conflicts (Phillips 1990). This is already an emerging issue in some areas in Mindanao where small fishers are excluded from traditional fishing areas by seaweed farming, and where the lack of planning (e.g., farm site selection, use rights) and management of seaweed areas have also contributed to the degradation of coral reefs and seagrass meadows.

Invertebrates

Marine Invertebrates are important components of marine ecosystems. Apart from predator-prey roles, invertebrates have more diverse ecological functions compared to finfish and provide essential ecosystem services, such as maintenance of water quality, regeneration of nutrients, oxygenation of sediments and prevention of algal overgrowth through grazing (Anderson et al. 2011). Invertebrates are also important fishery commodities and are considered important raw materials for a wide range of marine natural products with significant potential for drug development, clinical treatments, and nutraceuticals. Bioactive compounds extracted from marine invertebrates (e.g., sponges and sea cucumbers) have also been widely used in medicine as anti-inflammatory, anti-hypertension, anti-tumor, and anti-cancer drugs. Chitin and chitosan oligomers obtained from shellfishes and crustaceans have also been found to possess antitumor and wound healing properties (see reviews of Sipkema et al. 2015; Se-Kwon and Mendis 2006; Bordbar et al. 2011; Forghani et al. 2012). For taxa that are not abundant and cannot be cultured in commercial quantities, prototype culture systems such as a greenhouse covered tank culture system and in-sea aquaculture process for bryozoans, and a closed-cycle aquaculture system for sponges are being designed and developed (Mendola 2003).

Aside from bioactive compounds, some invertebrates served as experimental models for studies on tissues or organ regeneration, and their physiological processes have inspired engineering innovations. For instance, a Nickel catalyst to capture carbon dioxide from the atmosphere was developed based on the discovery that sea urchins use nickel to convert CO_2 to calcium carbonate for their exoskeleton (Bhaduri and Siller 2013).

The Philippines is the epicenter of diversity of major invertebrate taxa (e.g., corals, mollusks, crustaceans). Marine invertebrates also make up a considerable volume of the marketable fishery resources that are a primary source of income and sustenance (i.e., various shellfish gleaned from intertidal areas) of artisanal fishermen in the country. Shrimps, cephalopods (squid, cuttlefish, and octopus), crabs, and sea cucumbers are high-value export commodities. Because of the lack of management coupled with high market demand, many wild populations of commercially important species are overexploited and invertebrate capture fishery production has decreased. While the aquaculture production of the four widely cultured invertebrates (i.e., oysters, mussels, shrimps/prawns, mud crab) in the country has steadily increased in the past decade, culture production of invertebrates is still generally low relative to the fisheries production.

Research on marine drug discovery from marine invertebrates started in the 1980s with the pioneering work on the marine snail *Conus* (e.g., Olivera et al. 1985; Cruz et al. 1985). Studies on conotoxins from various species led to the development of the drug Prialt, which is an alternative to morphine. Another group of very diverse gastropods, the turrids, are part of a major drug discovery program (PHARMASEAS). Many different bioactive compounds can be derived from a single species. Given the hundreds of species of cone and turrid shells, thousands of potential bioactive compounds can be derived just from these two groups (Olivera 2008). Aside from these gastropods, screening of bioactive compounds that come from a variety of Philippine species of marine sponges and tunicates have been undertaken (reviewed by Juinio-Meñez 2012).

Bioactive compounds from echinoderms have received less attention from local researchers (Juinio-Meñez NAST RTD 2013). Biologically active compounds isolated from sea cucumbers, sea urchins, and starfish have been evaluated for their biomedical applications, specifically on their cytotoxity against tumor or cancer cells, as well as their antiviral, antifungal, and antimicrobial activity, among many others. Culture and management technology for commercially important species of sea urchins (*Tripneustes gratilla*) and sea cucumbers (*Holothuria scabra, Stichopus cf. horrens*) were developed at the UP Marine Science Institute's Bolinao Marine Laboratory to help rebuild depleted natural populations and help sustain the livelihood of small fishers. The culture and management technology of these high-value species also provides an opportunity to add economic value to current traditional fishery products (i.e., sea urchin roe/"uni" and dried sea cucumbers). For *T. gratilla*, crude extracts of its different organs exhibit anti-microbial activity, and peroxysterol isolated from this urchin was found to be effective against tumor cell lines, while not detrimental to normal human hepatocytes at given therapeutic dosages (Liu et al. 2011). The tests of sea urchins, which are discarded, also contain important bioactive pigments (Shankarlal et al. 2011). Carotenoids in *H. scabra* were found to be a potential source of natural antibiotics (Ibrahim 2013). Other medically important bioactive compounds, such as glycosaminoglycan, lectin, and steroidal sapogenins are also present in *H. scabra* (reviewed by Bordbar et al. 2011). In Malaysia, gamodulin extracts from different species of *Stichopus spp.* are used in various health supplements and cosmetic products. In addition, enzyme hydrolysates of *S. horrens* have been found to be a potential source of functional Angiotensin-Converting Enzyme (ACE) inhibitor peptides (Forghani et al. 2012).

Opportunities for adding value to coral reef protection in the case of outbreaks of the sea star *Acanthaster plancii* (crown-of-thorns) are also worth mentioning. *A. plancii* outbreaks are a major threat to our coral reefs, and occurrences have become widespread. The high biomass of this species collected from reefs can be converted to local agricultural products. The protein content of the crown of thorns starfish was found to be within range of protein content in fish, and possess a good profile of amino acids, as well as a rich variety of fatty acids, with 60% composed of unsaturated fatty acids. It also has higher asaxanthin content than most shrimps. In addition, it was found non-toxic to mice when used as feed, making it a potential ingredient for animal feeds (Luo et al. 2011).

Responsible culture-based management of marine invertebrates (e.g., sea urchins and sea cucumbers) can help rebuild depleted fishery stocks, increase the value of the harvest of small fishers, and increase the raw materials for development of pharmaceutical and nutraceutical products. In the case of the removal of crown-of-thorns starfish to protect reefs, value can be added by utilizing them as fertilizers and feeds to enhance local agricultural and livestock production.

Incentives and Investments

Global demand for bio-based raw materials is expected to grow with emerging carbon markets and increasing environmental consumerism. Companies around the world are investing in technologies to identify, develop, and process reliable and sustainable sources of these materials. The opportunities for the Philippines are immense, as illustrated by the examples presented in this paper. Fish discards from capture fisheries and aquaculture, the high diversity of seaweeds and invertebrates, both cultured and wild, provide raw materials for the development of manufacturing industries based on high-value products such as pharmaceuticals, nutraceuticals, biofuels, and other industrial materials (Table 1).

Development of biodiversity-based industries will optimize economic returns that generate direct socio-economic benefits to the households of poor fishers (i.e., increase value of harvests per unit volume, livelihood diversification) and the private sector (e.g., development of biotechnology based companies, commercial aquaculture and capture fisheries), and thus contribute to inclusive growth.

These benefits should serve as incentives for greater public (national and local government) and private investments in research and technology development to develop sustainable manufacturing industries for high-value marine products. Interdisciplinary R&D will include basic research, such as integrative taxonomy, biology and ecology of seaweed and marine invertebrate species, molecular and biochemical mechanisms, and interactions with environmental factors (e.g., regulation of production of bioactive compounds), as well as technological and engineering innovations (e.g., cost-effective culture systems, biodiesel production systems, bioprocessing).

The growth of these industries will also require greater investments in environmental and natural resources management to sustain the country's marine biodiversity. Effective marine conservation (e.g., through protected areas) coupled with responsible fishery and mariculture practices will increase and ensure long-term production to support the development of marine biotechnology-based industries.

Table 1. Examples of high-value products and corresponding ecological benefits from finfish discards, seaweeds, and invertebrates.

Raw Materials		High-Value Products	Ecological Benefits
1. **Finfish Discards**	Capture (tuna, etc.)	Fish oil, biofuel, etc.	Impede environmental degradation
	Culture (bangus, tilapia)	Leather, pearl essence, etc.	
2. **Seaweeds**	Wild (*Sargassum*)	Fucoidan, fucoxanthin, biofuel, etc.	Carbon sinks
	Culture (*Kappaphycus, Eucheuma*)	Carrageenan, etc.	
3. **Invertebrates**	Wild (starfish, etc.)	Animal feed, etc.	Conservation of corals
	Culture (sea urchin, sea cucumber)	Bioactive compounds, antibiotics, etc.	Rebuilding of depleted stocks

Philippine marine biodiversity is a strategic national asset that needs to be harnessed and developed within an integrated and holistic framework to generate multiple benefit streams for different stakeholders (Figure 6). The result would be the enhancement of municipal and commercial fishery industries, diversification of industries and livelihood, additional revenues, conservation of marine biodiversity, sustainable and equitable aquaculture and production, and a higher return of investment. The multifarious potentials and supplemental benefits will influence all levels of organization, such as the fishers, private aquaculture companies, local government units, academic and research institutions, investors, and the national government.

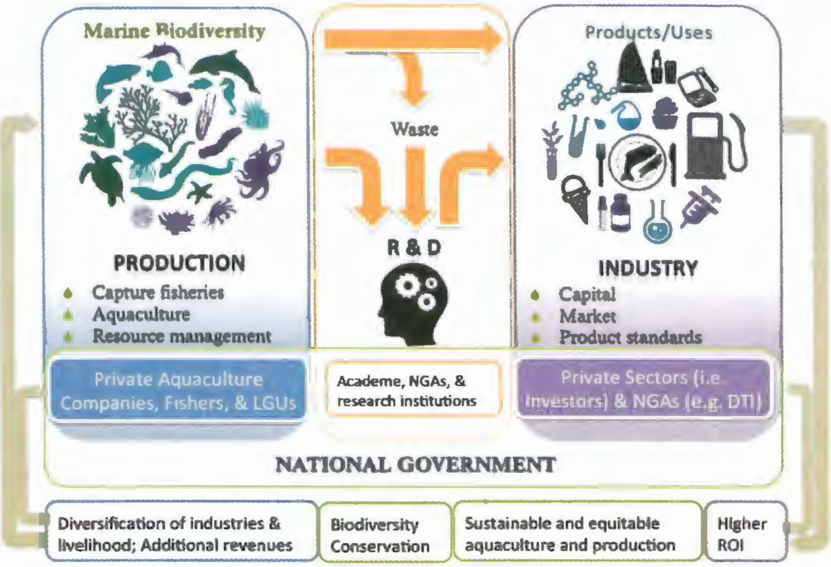


Figure 6. Integrated framework for the development and sustainability of marine biodiversity-based industries.

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