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Sea Cucumber Fisheries: Global Status, Culture, Management and Extinction Risks

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Abstract**—**Sea cucumbers are sessile marine invertebrates, usually found in the shallow benthic areas and deep seas worldwide. They have high commercial value coupled with increasing global production and trade. The major products of sea cucumbers, informally named as bêche-de-mer, or gamat, have long been using for food and folk medicine in the peoples of Asia and Middle East. Nutritionally, sea cucumbers have an exciting profile of valuable nutrients such as Vitamin A, Vitamin B1, Vitamin B2, Vitamin B3, and minerals, specifically calcium, magnesium, iron and zinc. A number of distinctive biological and pharmacological activities including anti-angiogenic, anticancer, anticoagulant, anti-hypertension, anti-inflammatory, antimicrobial, antioxidant, antithrombotic, antitumor and wound healing have also been attributed to various species of sea cucumbers due to the presence of valuable bioactive compounds with biomedical applications. We accumulated global aquaculture production, harvestings, economic data, and country-specific assessment and management reports to synthesize global trends in sea cucumber fisheries, evaluate potential drivers, and test for local and global exploitation patterns. Although some sea cucumber fisheries have existed for centuries, catch trends of most individual fisheries followed boom-and-bust patterns since the 1950s, declining nearly as quickly as they expanded. New fisheries expanded five to six times faster in 1990 compared to 1960 and at an increasing distance from Asia, encompassing a global fishery by the 1990s. Global sea cucumber production was correlated to the Japanese yen at a leading lag. Regional assessments revealed that population declines from overfishing occurred in 81% of sea cucumber fisheries, average harvested body size declined in 35%, harvesters moved from near- to off-shore regions in 51% and from high- to low-value species in 76%. Thirty-eight per cent of sea cucumber fisheries remained unregulated, and illegal catches were of concern in half. Nevertheless, development patterns of sea cucumber fisheries are largely expectable, often unsustainable and frequently too rapid for effective management. An ample discussion has been made on the potential ecosystem and human community consequences, appropriate aquaculture management strategies, and urge for better monitoring and reporting of catch and abundance, proper scientific research for stock enhancement and consideration of international trade regulations to ensure sustainable development and utilization of global sea cucumbers fisheries to a greater extent.

Keywords**—**Sea cucumber, bêche-de-mer, status, culture, management, extinction risks.

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I. Status, Culture, Management and Extinction Threats

DURING the last decade, we have witnessed the decline of many traditional finfish fisheries as well as the expansion of existing and the establishment of new invertebrate fisheries [1]. The increase in invertebrate fisheries has been attributed to increasing demand [2, 3], the need for new resources to harvest [4, 5] and the increasing abundance of invertebrates because of their release from predation [6-8]. Is spite of an overall global increase in invertebrate catches and target species [9], many individual fisheries have shown severe depletion or even collapse. For example, sea urchin fisheries have followed a boom-and-bust cycle around the world [3, 10. 11], oysters have been serially depleted along the coasts of the United States of America and eastern Australia [12], and shrimp and crab populations have serially been depleted in the Gulf of Alaska [13].

Sea cucumbers belonging to the class Holothuroidea are elongated tubular or flattened soft-bodied marine invertebrates, typically with leathery skin, ranging in length from a few millimetres to a metre [14, 15]. Holothuroids encompass 14000 known species [16] and occur in most benthic marine habitats worldwide, in temperate and tropical oceans, and from the intertidal zone to the deep sea [17]. The fisheries of sea cucumber have expanded worldwide in catch and value over the past two to three decades [18, 19]. Global sea cucumber production increased from 130,000 t in 1995 to 411,878 t in 2012. Among other aquatic animals, overall production of dried sea cucumbers has increased rapidly (Figure 1). However, sea cucumber fisheries in Asian countries (China, Japan, India, Philippines, Indonesia and Malaysia) have been depleted due to overexploitation as well as lack of effective management and conservation strategies.

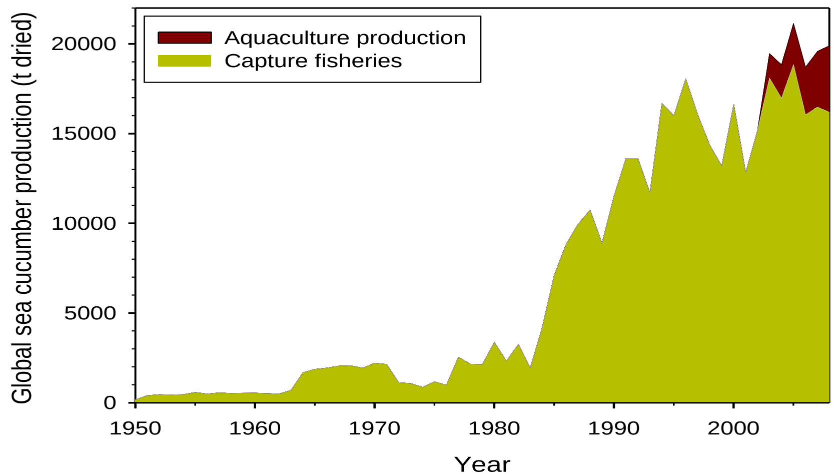

Fig. 1: World sea cucumber fisheries production from 1950 to 2012.

Sea cucumbers in the Indo-Pacific regions have been harvested and traded for over one thousand years, driven primarily by Chinese demand [20]. Harvesters typically capture sea cucumbers by hand, spear, hook, or net while wading or diving with snorkel or SCUBA (Self Contained Underwater Breathing Apparatus) gear. In some regions, and especially for less valuable species, sea cucumbers are trawled [21-23]. They are consumed both reconstituted from a dried form (called trepang or bêche-de-mer) and in a wet form, with muscles cut in strips and boiled [24].

Reports have recently been documented on both the rapid climb in value of traded sea cucumbers and the spread and increase in sea cucumber fisheries around the world [19, 25]. However, sea cucumber populations are particularly vulnerable to overfishing for at least two primary reasons. First, harvesters can easily and effectively capture shallow water holothurians [[26, 27]. Second, their late age at maturity, slow growth and low rates of recruitment make for slow population replenishment [28, 29]. Moreover, at low population densities, their broadcast spawning may induce an Allee effect [11, 30], resulting in population collapse and inhibiting recovery [26, 29]. Owing to these factors, overfishing has severely decreased the biomass of many sea cucumber populations [8, 31, 32]. Thus far, even with harvesting closures, sea cucumber stocks seem slow to recover [28, 33, 34]. Other broadcast spawning invertebrate populations that have been severely depleted, such as pearl oysters in the South Pacific, have not recovered even 50–100 years far onward [35].

Sea cucumbers are important ecologically as suspension feeders, detritivores and prey. In kelp forests [36] and coral reefs [37], they consume a combination of bacteria, diatoms and detritus [38, 39]. Their function as suspension or filter feeders can be substantial. For example, two species of holothurians alone represent nearly half of the filter feeding biomass in South African kelp. As suspension feeders, sea cucumbers regulate water quality by affecting carbonate content and the pH of the water [40]. Deposit feeding sea cucumbers change the size of ingested particles and turn over sediment via bioturbation, thereby altering the stratification and stability of muddy and sandy bottoms [40]. For example, on coral reefs, healthy sea cucumber populations can bioturbate the entire upper five millimetres of sediment once a year (4600 kg dry weight year/1000 m^2), significantly reducing the microalgal biomass in the sediment [41] and playing a substantial role in the recycling of nutrients in oligotrophic environments where nutrients would otherwise remain trapped in the sediment [42]. Bruckner et al. [27] noted that the extirpation of holothurians has resulted in the hardening of the sea floor, thereby eliminating potential habitat for other benthic organisms. Holothurians are also important prey in coral reef and temperate food webs [37, 43] both in shallow and in deep water [40], where they are consumed particularly by sea stars, crustaceans and fishes [3].

In addition to the ecological importance of sea cucumbers, their fisheries are of great social and economic importance to many coastal communities. For example, just a few years after beginning in the Maldives, the sea cucumber fishery became the most highly valued fishery outside the tuna fishing season, representing 80% of the value of all non-fish marine products in 1988 [44]. Sea cucumber fisheries form the main source of income for many coastal communities in the Solomon Islands [45] and for 4000–5000 families in Sri Lanka [46]. Perhaps most importantly, sea cucumber fisheries are economically decentralized. Whereas their total global value is low compared to other higher volume fisheries [47], economic benefits are obtained immediately at the village level [48]. In contrast, other high-value fisheries, such as tuna fisheries, have higher initial cost and bring wealth to a more centralized group of people [8].

Despite the ecological and social importance of sea cucumber populations, the assessment of their global status is challenging. There is generally a lack of abundance data; catch, import and export statistics are often incomplete; and the trade of sea cucumbers is complex [19, 25, 49]. Nonetheless, reports such as FAO [19, 25] and the SPC Bêche-de-mer Information Bulletin have assimilated much of the available knowledge on the status and management of sea cucumber fisheries around the world. So far, there has been discussion of country specific sea cucumber fisheries and insight into the dynamics of the global sea cucumber trade [2, 8, 19, 47, 49, 50]. However, we lack a quantitative analysis of the typical trajectory, potential drivers, and combined spatial and temporal dynamics of sea cucumber fisheries around the world.

Sea cucumbers and their extracts have been well documented for their strong effectiveness against hypertension, asthma, rheumatism, cuts and burns, impotence and constipation [51-56]. Nutritionally, sea cucumbers have an impressive profile of valuable nutrients such as Vitamin A, Vitamin B1 (thiamine), Vitamin B2 (riboflavin), Vitamin B3 (niacin), and minerals, especially calcium, magnesium, iron and zinc [57]. A number of unique biological and pharmacological activities including anti-angiogenic [58], anticancer [59], anticoagulant [60, 61], anti-hypertension [62], anti-inflammatory [63], antimicrobial [64], antioxidant [65], antithrombotic [66], antitumor [67] and wound healing [68] have been attributed to various species of sea cucumbers. Therapeutic properties and medicinal benefits of sea cucumbers can be linked to the presence of a wide array of bioactive compounds, especially triterpene glycosides (saponins) [69], chondroitin sulfates [70], glycosaminoglycan [71], sulfated polysaccharides [72], sterols (glycosides and sulfates) [73], phenolics [74], cerberosides [75], lectins [76], peptides [77], glycoprotein, glycosphingolipids and essential fatty acids [57]. These high-value components and bioactive compounds as well as their multiple biological and therapeutic properties supports to exploring the potential uses of sea cucumbers for functional foods and nutraceutical products [15, 79, 80].

In many Pacific islands, Sea cucumber fisheries have provided an important income source to coastal communities as well as food in some regions for decades if not centuries or millennia but are now worth only a fraction of historical values [78]. Sea cucumbers have been harvested for hundreds of years for trade with Asia and were probably one of the first real 'exports' from the Pacific islands. Unfortunately, the increase in demand and price, combined with the development of cash economies and growing coastal populations in many islands, has led to widespread overfishing of the resource across much of this region. This is particularly severe for countries that depend highly on sea cucumber fisheries and have few alternative income sources, such as the Maldives [44], Sri Lanka [46] and the Solomon Islands [45]. In other regions, sea cucumber fisheries may continue to be just one of many alternative income options (e.g. United States) or may became more important because of the overexploitation or restrictive management of more traditional fisheries (e.g. eastern Canada: [5]). There is a high level of interest in adoption of aquaculture techniques to restore production levels, but different capacity levels require implementation of different techniques. Some Pacific island countries and territories have completed successful research trials of hatchery and release techniques, and now have capacity to scale up this activity. Factors that work in favour of successful aquaculture include pristine marine environments, long familiarity with sea cucumbers as a commodity, and traditional marine tenure systems that in some places can provide a basis for management of released sea cucumbers. However, the challenges include lack of technical capacity, unproven effectiveness of sea cucumber releases, poaching, illegal harvesting and overfishing.

II. Conclusions

Prior to the enforcement of the sustainable management measures, it is vital that stocks are allowed to recover to a near pristine biomass level. Only then can management regimes such as TACs, closed seasons, restricted areas and size limits, be effective in achieving maximum benefits from the resource. Sea cucumber populations have been overexploited, which calls for immediate closure of the fishery to enable stocks to recover to levels where they can be managed sustainably. Whatever management measures are officially enacted, the underlying success of management will depend on effective enforcement. The area where sufficient governance exists, two important steps to manage existing and future holothurian fisheries have been suggested, such as: (i) the expansion rate of new fisheries had best be reduced to a level where management has time to react to early warning signs of resource depletion and (ii) lacking changes in regulation, the catch trajectory and patterns of serial spatial, species and size expansion or depletion are largely predictable. Knowledge of the impending sequence of events can therefore be pre-emptively incorporated into the management of new and existing high-value marine fisheries. In general, this review highlights the urgent need for better monitoring and reporting of harvesting and abundance data, proper scientific stock enhancement and ecosystem impact assessment and appropriate aquaculture and conservation strategies to ensure more sustainable management and effective utilization of global sea cucumber fisheries.

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References

[1] FAO. 2009. The State of World Fisheries and Aquaculture 2008. Technical report, Food and Agriculture Organization of the United Nations, Rome, Italy.

[2] Clarke, S. 2004. Understanding pressures on fishery resources through trade statistics: a pilot study of four products in the Chinese dried seafood market. Fish and Fisheries, 5: 53–74.

[3] Berkes, F., Hughes, T.P., Steneck, R.S. et al. 2006. Globalization, roving bandits, and marine resources. Science, 311: 1557–1558.

[4] Pauly, D., Christensen, V., Guenette, S. et al. 2002. Towards sustainability in world fisheries. Nature, 418: 689–695.

[5] Anderson, S.C., Lotze, H.K. and Shackell, N.L. 2008. Evaluating the knowledge base for expanding low-trophic-level fisheries in Atlantic Canada. Canadian Journal of Fisheries and Aquatic Sciences, 65: 2553–2571.

[6] Heath, M. 2005. Changes in the structure and function of the North Sea fish foodweb, 1973-2000, and the impacts of fishing and climate. ICES Journal of Marine Science, 62: 847–868.

[7] Savenkoff, C., Swain, D., Hanson, J. et al. 2007. Effects of fishing and predation in a heavily exploited ecosystem: comparing periods before

and after the collapse of groundfish in the southern Gulf of St. Lawrence (Canada). Ecological Modelling, 204: 115–128.

[8] Baum, J.K. and Worm, B. 2009. Cascading top-down effects of changing oceanic predator abundances. Journal of Animal Ecology, 78: 699–714.

[9] Anderson, S.C. 2010. Trends, drivers, and ecosystem effects of expanding global invertebrate fisheries. MSc thesis, Dalhousie University, 134 pages.

[10] Andrew, N.L., Agatsuma, Y., Ballesteros, E. et al. 2002. Status and management of world sea urchin fisheries. Oceanography and Marine Biology: An Annual Review, 40: 343–425.

[11] Uthicke, S., Schaffelke, B. and Byrne, M. 2009. A boombust phylum? Ecological and evolutionary consequences of density variations in echinoderms. Ecological Monographs, 79: 3–24.

[12] Kirby, M.X. 2004. Fishing down the coast: historical expansion and collapse of oyster fisheries along continental margins. Proceedings of the National Academy of Sciences of the United States of America, 101: 13096–13099.

[13] Orensanz, J., Armstrong, J., Armstrong, D. and Hilborn, R.W. 1998. Crustacean resources are vulnerable to serial depletion – the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Reviews in Fish Biology and Fisheries, 8: 117–176.

[14] Lawrence, J. 1987. A Functional Biology of Echinoderms. Croom Helm, London & Sydney.

[15] Rahman, M.A. 2014. Global sea cucumber fisheries: Their culture potentials, bioactive compounds and sustainable utilizations. International Journal of Advances in Chemical Engineering and Biological Sciences, 1(2): 193-197.

[16] Pawson, D.L. 2007. Phylum echinodermata. In: Z.Q. Zhang and W. Shear (Eds.), Linnaeus Tercentenary: Progress in Invertebrate Taxonomy, volume 1668 of Zootaxa. Magnolia Press, Auckland, New Zealand, pp. 749–764.

[17] Hickman, C.P., Roberts, L.S., Larson, A., l'Anson, H. and Eisenhour, D.J. 2006. Integrated Principles of Zoology, 13th Edn. McGraw-Hill, New York, NY, USA.

[18] Conand, C. 2004. Present status of world sea cucumber resources and utilisation: an international overview. In: A. Lovatelli, C. Conand, S.W. Purcell, S. Uthicke, J.F. Hamel and A. Mercier (Eds.), Advances in Sea Cucumber Aquaculture and Management, FAO Fisheries Technical Paper 463. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 13–23.

[19] FAO. 2008. Sea Cucumbers: A Global Review of Fisheries and Trade. Technical Report 516, Food and Agriculture Organization of the United Nations, Rome, Italy.

[20] Conand, C. and Byrne, M. 1993. A review of recent developments in the world sea cucumber fisheries. US National Marine Fisheries Service Marine Fisheries Review 55: 1–13.

[21] Aumeeruddy, R. and Payet, R. 2004. Management of the Seychelles sea cucumber fishery: status and prospects. In: A. Lovatelli, C. Conand, S.W. Purcell, S. Uthicke, J.F. Hamel and A. Mercier (Eds.), Advances in Sea Cucumber Aquaculture and Management. FAO Fisheries Technical Paper 463. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 239–246.

[22] Kumara, P.B.T.P., Cumaranathunga, P.R.T. and Linden, O. 2005. Present Status of the Sea Cucumber Fishery in Southern Sri Lanka: A resource Depleted Industry. SPC Beche-de-mer Information Bulletin, 22: 24–29.

[23] Choo, P. 2008. Population status, fisheries and trade of sea cucumbers in Asia. In: Sea Cucumbers: A Global Review of Fisheries and Trade. Fisheries and Aquaculture Technical Paper 516. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 81–118.

[24] Sloan, N.A. 1984. Echinoderm fisheries of the world: a review. In: B.F. Keegan and B.D.S. O'Connor (Eds.), Proceedings of the Fifth International Echinoderm Conference. A.A. Balkema, Rotterdam, Netherlands, pp. 109–124.

[25] FAO. 2004. Advances in Sea Cucumber Aquaculture and Management. Technical Report 463, Food and Agriculture Organization of the United Nations, Rome, Italy.

[26] Uthicke, S. and Benzie, J. 2000. Effect of beˆche-de-mer fishing on densities and size structure of *Holothuria nobilis* (Echinodermata: Holothuroidea) populations on the Great Barrier Reef. Coral Reefs, 19: 271–276.

[27] Bruckner, A.W., Johnson, K. and Field, J. 2003. Conservation strategies for sea cucumbers: Can a CITES Appendix II listing promote sustainable international trade? SPC Beche-de-mer Information Bulletin, 18: 24–33.

[28] Uthicke, S., Welch, D. and Benzie, J. 2004. Slow growth and lack of recovery in overfished holothurians on the Great Barrier Reef: evidence from DNA fingerprints and repeated large-scale surveys. Conservation Biology, 18: 1395–1404.

[29] Bruckner, A.W. 2005. The recent status of sea cucumber fisheries in the continental United States of America. SPC Beche-de-mer Information Bulletin, 22: 39–46.

[30] Courchamp, F., Clutton-Brock, T. and Grenfell, B. 1999. Inverse density dependence and the Allee effect. Trends in Ecology & Evolution, 14: 405–410.

[31] Skewes, T., Dennis, D. and Burridge, C. 2000. Survey of *Holothuria scabra* (sandfish) on Warrior Reef, Torres Strait. 2000. CSIRO Divison of Marine Research, Cleveland, Queensland, Australia.

[32] Lawrence, A., Ahmed, M., Hanafy, M., Gabr, H., Ibrahim, A. and Gab-Alla, A.F. 2004. Status of the sea cucumber fishery in the Red Sea – the Egyptian experience. In: Advances in Sea Cucumber Aquaculture and Management. FAO Fisheries Technical Paper 463. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 79–90.

[33] D'Silva, D. 2001. The Torres Strait beˆche-de-mer (sea cucumber) fishery. SPC Beche-de-mer Information Bulletin 15: 2–4.

[34] Ahmed, M.I. and Lawrence, A.J. 2007. The status of commercial sea cucumbers from Egypt's northern Red Sea Coast. SPC Beche de Mer Information Bulletin, 26: 14–18.

[35] Dalzell, P., Adams, T. and Polunin, N. 1996. Coastal fisheries in the Pacific islands. Oceanography and Marine Biology: An Annual Review, 34: 395–531.

[36] Harrold, C. and Pearse, J.S. 1989. The ecological role of echinoderms in kelp forests. In: M. Jangoux and J.M. Lawrence (Eds.), Echinoderm Studies 2. A.A. Balkema, Rotterdam, Netherlands, pp. 137–233.

[37] Birkeland, C. 1989. The influence of echinoderms on coral-reef communities. In: M. Jangoux and J.M. Lawrence (Eds.), Echinoderm Studies 3, volume 3. A.A. Balkema, Rotterdam, Netherlands, pp. 1–79.

[38] Massin, C. 1982a. Food and feeding mechanisms: Holothuroidea. In: M. Jangoux and J. Lawrence (Eds.), Echinoderm Nutrition. A.A. Balkema, Rotterdam, Netherlands, pp. 43–55.

[39] Moriarty, D.J.W. 1982. Feeding of *Holothuria atra* and *Stichopus chloronotus* on bacteria, organic carbon and organic nitrogen in sediments of the Great Barrier Reef. Australian Journal of Marine and Freshwater Research, 33: 255–263.

[40] Massin, C. 1982b. Effects of feeding on the environment: Holothuroidea. In: M. Jangoux and J. Lawrence (Eds.), Echinoderm Nutrition. A.A. Balkema, Rotterdam, Netherlands, pp. 494–497.

[41] Uthicke, S. 1999. Sediment bioturbation and impact of feeding activity of *Holothuria* (*Halodeima*) *atra* and *Stichopus chloronotus*, two sediment feeding holothurians, at Lizard Island, Great Barrier Reef. Bulletin of Marine Science, 64: 129–141.

[42] Uthicke, S. 2001. Nutrient regeneration by abundant coral reef holothurians. Journal of Experimental Marine Biology and Ecology, 265: 153–170.

[43] Francour, P. 1997. Predation on holothurians: a literature review. Invertebrate Biology, 116: 52–60.

[44] Joseph, L. 2005. Review of the Beche de mer (Sea Cucumber) Fishery in the Maldives. Technical Report 79, Food and Agriculture Organization of the United Nations, Madras, India.

[45] Nash, W. and Ramofafia, C. 2006. Recent developments with the sea cucumber fishery in Solomon Islands. SPC Beche-de-mer Information Bulletin, 23: 3–4.

[46] Dissanayake, D., Athukorala, S. and Amarasiri, C. 2010. Present status of the sea cucumber fishery in Sri Lanka. SPC Beche-de-mer Information Bulletin, 30: 14–20.

[47] Ferdouse, F. 2004. World markets and trade flows of sea cucumber/beche-de-mer. In: Advances in Sea Cucumber Aquaculture and Management. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 101–116.

[48] Kinch, J., Purcell, S.W., Uthicke, S. and Friedman, K. 2008. Population status, fisheries and trade of sea cucumbers in the Western Central Pacific. In: Sea Cucumbers: A Global Review of Fisheries and Trade. Fisheries and Aquaculture Technical Paper 516. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 7–55.

[49] Baine, M. 2004. From the sea to the market place: an examination of the issues, problems and opportunities in unravelling the complexities of sea cucumber fisheries and trade. In: Advances in Sea Cucumber Aquaculture and Management. FAO Fisheries Technical Paper 463.

Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 119–131.

[50] Uthicke, S. and Conand, C. 2005. Local examples of beche-de-mer overfishing: an initial summary and request for information. Beche-de-mer Information Bulletin, 21: 9–14.

[51] Weici, T. 1987. Chinese medicinal materials from the sea. Abstracts of Chinese Medicine 1(4): 571–600.

[52] Anderson, E.N. 1988. The Food of China. Yale University Press, New Haven, CT, USA.

[53] Jilin, L. and Peck, G. 1995. Chinese Dietary Therapy. Churchill Livingstone, London, UK.

[54] Yaacob, H.B., Kim, K.H., Shahimi, M., Aziz, N.S. and Sahil, S.M. 1997. Malaysian sea cucumber (Gamat): A prospect in health food and therapeutic. In Proceeding of Asian Food Technology Seminar, Kuala Lumpur, Malaysia, p. 6.

[55] Chen, J. 2003. Overview of sea cucumber farming and sea ranching practices in China. SPC Beche-de-mer Information Bulletin, 18: 18–23.

[56] Wen, J., Hu, C. and Fan, S. 2010. Chemical composition and nutritional quality of sea cucumbers. Journal of the Science of Food and Agriculture, 90: 2469–2474.

[57] Bordbar, S., Anwar, F. and Saari, N. 2011. High-value components and bioactives from sea cucumbers for functional foods—A review. Marine Drugs, 9: 1761–1805.

[58] Tian, F., Zhang, X., Tong, Y., Yi, Y., Zhang, S., Li, L., Sun, P., Lin, L., Ding, J. 2005. PE, a new sulfated saponin from sea cucumber, exhibits anti-angiogenic and anti-tumor activities *in vitro* and *in vivo*. Cancer Biology & Therapy, 4: 874–882.

[59] Roginsky, A., Singh, B., Ding, X.Z., Collin, P., Woodward, C., Talamonti, M.S., Bell, R.H. and Adrian, T.E. 2004. Frondanol(R)-A5p from the sea cucumber, *Cucumaria frondosa* induces cell cycle arrest and apoptosis in pancreatic cancer cells. Pancreas, 29: 335.

[60] Nagase, H., Enjyoji, K., Minamiguchi, K., Kitazato, K.T., Kitazato, K., Saito, H. and Kato, H. 1995. Depolymerized holothurian glycosaminoglycan with novel anticoagulant actions: Antithrombin III and heparin cofactor II-independent inhibition of factor X activation by factor IXa-factor VIIIa complex and heparin cofactor II-dependent inhibition of thrombin. Blood, 85: 1527–1534.

[61] Chen, S., Xue, C., Yin, L., Tang, Q., Yu, G. and Chai, W. 2011. Comparison of structures and anticoagulant activities of fucosylated chondroitin sulfates from different sea cucumbers. Carbohydrate Polymers, 83: 688–696.

[62] Hamaguchi, P., Geirsdottir, M., Vrac, A., Kristinsson, H.G., Sveinsdottir, H., Fridjonsson, O.H. and Hreggvidsson, G.O. 2010. *In vitro* antioxidant and antihypertensive properties of Icelandic sea cucumber (*Cucumaria frondosa*). Presented at IFT 10 Annual Meeting & Food Expo, Chicago, IL, USA, 17–20 July 2010; presentation no. 282-04.

[63] Collin, P.D. 2004. Peptides having anti-cancer and anti-inflammatory activity. United State Patent 6,767,890.

[64] Beauregard, K.A., Truong, N.T., Zhang, H., Lin, W. and Beck, G. 2001. The detection and isolation of a novel antimicrobial peptide from the echinoderm, *Cucumaria frondosa*. Advances in Experimental Medicine and Biology, 484: 55–62.

[65] Althunibat, O.Y., Ridzwan, B.H., Taher, M., Jamaludin, M.D., Ikeda, M.A. and Zali, B.I. 2009. *In vitro* antioxidant and antiproliferative activities of three Malaysian sea cucumber species. European Journal of Scientific Research, 37: 376–387.

[66] Mourao, P.A.S., Guimaraes, B., Mulloy, B., Thomas, S. and Gray, E. 1998. Antithrombotic activity of a fucosylated chondroitin sulphate from echinoderm: Sulphated fucose branches on the polysaccharide account for its antithrombotic action. British Journal of Haematology**,** 101: 647–652.

[67] Zou, Z., Yi, Y., Wu, H., Wu, J., Liaw, C. and Lee, K. 2003. Intercedensides A–C, three new cytotoxic triterpene glycosides from the sea cucumber *Mensamaria intercedens* Lampert. Journal of Natural Products, 66: 1055–1060.

[68] San Miguel-Ruiz, J.E. and García-Arrarás, J.E. 2007. Common cellular events occur during wound healing and organ regeneration in the sea cucumber *Holothuria glaberrima*. BMC Developmental Biology, 7: 1–19.

[69] Kerr, R. and Chen, Z. 1995. *In vivo* and *in vitro* biosynthesis of saponins in sea cucumbers (Holothuroidea). Journal of Natural Products, 58: 172–176.

[70] Vieira, R.P., Mulloy, B., and Mourão, P.A. 1991. Structure of a fucose-branched chondroitin sulphate from sea cucumber. Evidence for the presence of 3-*O*-sulfo-β-D-glucuronosyl residues. Journal of Biological Chemistry, 266: 13530–13536.

[71] Pacheco, R.G., Vicente, C.P., Zancan, P. and Mourão, P.A.S. 2000. Different antithrombotic mechanisms among glycosaminoglycans revealed with a new fucosylated chondroitin sulfate from an echinoderm. Blood Coagulation & Fibrinolysis, 11: 563–573.

[72] Mourao, P.A.S. and Pereira, M.S. 1999. Searching for alternatives to heparin: Sulfated fucans from marine invertebrates. Trends in Cardiovascular Medicine, 9: 225–232.

[73] Goad, L.J., Garneau, F.X., Simard, J.L., ApSimon, J.W. and Girard, M. 1985. Isolation of Δ9(11)-sterols from the sea cucumber. Implications for holothurin biosynthesis. Tetrahedron Letters, 26: 3513–3516.

[74] Mamelona, J., Pelletier, E.M., Lalancette, K.G., Legault, J., Karboune, S. and Kermasha, S. 2007. Quantification of phenolic contents and antioxidant capacity of Atlantic sea cucumber, *Cucumaria frondosa*. Food Chemistry, 104: 1040–1047.

[75] Sugawara, T., Zaima, N., Yamamoto, A., Sakai, S., Noguchi, R. and Hirata, T. 2006. Isolation of sphingoid bases of sea cucumber cerberosides and their cytotoxicity against human colon cancer cells. Bioscience, Biotechnology, and Biochemistry, 70: 2906–2912.

[76] Mojica, E.R.E. and Merca, F.E. 2005. Isolation and partial characterization of a lectin from the internal organs of the sea cucumber (*Holothuria scabra* Jäger). International Journal of Zoological Research, 1: 59–65.

[77] Rafiuddin, A.M., Venkateshwarlu, U. and Jayakumar, R. 2004. Multilayered peptide incorporated collagen tubules for peripheral nerve repair. Biomaterials, 25: 85–94.

[78] [78] Anderson, S.C., Mills-Flemming, J., Watson, R. and Lotze, H.K. 2011. Serial exploitation of global sea cucumber fisheries. Fish and Fisheries, 12: 317–339.

[79] Rahman, M.A. 2014a. Global sea cucumber fisheries: their culture potentials, bioactive compounds and sustainable utilizations. International Journal of Advances in Chemical Engineering & Biological Sciences, 1(2): 193–197.

[80] Rahman, M.A. 2014b. Sea cucumbers (Echinodermata: Holothuroidea): their culture potentials, bioactive compounds and effective utilizations. In: J.C.M. Kao and M.A. Rahman (eds.), Proceedings of the International Conference on Advances in Environment, Agriculture & Medical Sciences (ICAEAM'14), International Academy of Arts, Science & Technology, Kuala Lumpur, Malaysia, pp. 23–27.