

Cultivation of Marine Sponges with Pharmaceutical Value: Status and Future Prospects in India

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ABSTRACT

This article reviews the importance of culturing marine sponges, considering its applications in the field of drug development and pharmaceuticals. Although the biomedical potential of sponges is known, sponge mariculture is an unexplored field in India. Sponges produce bioactive metabolites which have potential applications in drug development, as since sponges yield very low amount of bioactive compounds, mariculture technologies are to be standardized in order to ensure steady supply of sponges in required quantities without disturbing the wild sponge populations. The review also reveals several candidate sponges in India like *Stylissa massa*, *Hirtios erectus*, *Mycale* sp., *Dysidea* sp. and *Plakortis* sp. with reports of high bioactive potential, and can be taken up for mariculture. The possibilities of fish-sponge integrated aquaculture are also discussed as opportunities. With the emergence of rare and uncommon diseases, marine organisms, particularly sponges hold much promise to resolve critical issues in the field of drug development. The review calls on importance in demonstration of feasible mariculture technology of potential candidate marine sponges in India, which could cater to the pharmaceutical needs, without disturbing their wild population.

Keywords

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Introduction

Marine environment hosts innumerable flora and fauna which offers various livelihood and ecosystem services across the globe. Clearly the world's oceans will play an important part in the future control of the global infectious disease burden (Laport *et al.*, 2009). Sponges are one of the most important invertebrates considering its pharmaceutical and drug development prospective, as they are known to produce bioactive secondary metabolites

(Koopmans *et al.*, 2011). The interest in sponges has increased rapidly since the discovery of pharmaceutical compounds produced by many of them (Koopmans 2009). Among the marine organisms, sponges have proved to be the best source of biologically active metabolites for use as drug leads or biomedical tools (Ireland *et al.*, 1993). Microbiologists became fascinated by these unique animals with the discovery of

abundant unusual microorganisms (Thakur and Muller, 2004). Sponges, if propagated sustainably could help to produce several compounds which could play an important role in curing many diseases. With increasing trends of diseases, particularly cancer being a global concern, sponges have the potential to provide drugs against viral diseases, inflammation and malaria (Sipkema *et al.*, 2005a). More than 5300 different products have been recorded from sponges and their associated microorganisms, and every year around 200 new metabolites are reported (Lipton and Shine, 2009). Globally 11,000 sponges have been described of which 8,500 are considered valid (Vansoest *et al.*, 2012).

The first effort for *in situ* aquaculture of marine sponges (bath sponges) was achieved in Adriatic Sea in 1870 (Tommonaro *et al.*, 2015) with no detailed report. Historical details by (Crawshay, 1939) reveal early attempts in sponge culture by Cavolini in 1785 and 1790, followed by Schmidt in 1862, Bucchich in 1864, and Harris in 1897 as none of these experiments yielded any serviceable data (Crawshay, 1939). Detailed studies on sponge culture back in early 1900's by (Moore, 1910; Crawshay, 1939) and detailed review of sponge farming by Osinga *et al.*, (1999), Duckworth (2009), Yi *et al.*, (2005) and Schippers *et al.*, (2012) have given more insights on sponge farming methods and its importance across the world. Macmillan (1996) in his report on setting up of commercial sponge farm describes sponge culture as easy, profitable and environment friendly.

India is one of the rich spots of sponge diversity among 232 marine ecoregions of the world (Vansoest *et al.*, 2012). Though globally sponge aquaculture has been gaining importance owing to its applications, sponge mariculture is relatively an uncharted area in Indian mariculture sector in comparison

with marine fin fishes, shell fishes and bivalves, although small-scale attempts on sponge culture were reported from India during 2009 and 2016. Sponge aquaculture is still at infancy in India (Vinod *et al.*, 2009); though the country is blessed with great diversity of sponges particularly in the Gulf of Mannar, Palk Bay and Andaman Islands, the studies concentrate more on their bioactive compounds. The sponge fauna of India is dominated by species of Demospongia followed by Hyalospongiae and Calciospongiae (Venkataraman, 2005) and the Gulf of Mannar and Palk Bay along the south-east coast account for over 67% of sponge diversity of India (Sivaleela, 2014). In India, 486 species of sponges were reported (Thomas, 1998) wherein the Gulf of Mannar and Palk Bay has the highest number of species (319 species) followed by Andaman and Nicobar Islands (95 species), Lakshadweep (82 species) and the Gulf of Kachchh (25 species) (Venkataraman, 2005). A recent report on the sponge diversity in India by Chandra *et al.*, 2016 updates 476 species among which the Palk Bay and the Gulf Mannar has the highest (329), followed by Andaman and Nicobar (126). Though systematic inventory of sponges in India has been stressed (Wilson and Kitto, 2012), their mariculture potential has not been given due attention. The review highlights the importance of sponge cultivation in India considering its vast applications and to take necessary steps as preparatory action for future as sponge possess metabolites which can be utilized for producing life-saving drugs.

Applications of marine sponges

The incidence of emerging infectious diseases in humans has increased within the recent past or threatens to increase in the near future (Dikid *et al.*, 2013) and sponges hold much promise in developing a potential cure.

Sponges were shown to possess numerous roles as anti-inflammatory, anti-tumour, immuno-suppressive, as cardiovascular agents, neuro suppressive, muscle relaxants, anti-viral, anti-malarial, anti-fouling, antibiotics and as fungicides (reviewed by Sipkema *et al.*, 2005a; Anjum *et al.*, 2016). Sponges have potential as anti-cancer and anti-mitotic (Munro *et al.*, 1999), anti-protozoal activity (Laport *et al.*, 2009), anti-viral and Ara-C (Arabinosyl Cytosine) - an anti-tumour compound marketed by Pharmacia & Upjohn Company in the brand name Cytosar-UR (Thakur and Muller, 2004). They also have potential anti-malarial, anti-microbial and cytotoxic properties (Pedpradab *et al.*, 2010).

The secondary metabolites of some sponges are known to inhibit cancerous growth and diseases (Longakit *et al.*, 2005). They are anti-tumour (Tasdemir *et al.*, 2002; Gordaliza, 2010) have potent antileukemic activity (Muller *et al.*, 1985), inhibitory activity against hepatocellular carcinoma, colorectal carcinoma and breast adenocarcinoma cells (Elhady *et al.*, 2016). They are used for the treatment of psoriasis (Pietschmann *et al.*, 2004), as anti foulant (Pereira *et al.*, 2002; Riberio *et al.*, 2012), in cosmetics (Swatschek *et al.*, 2002), for marine environmental bioremediation in integrated aquaculture practices (Milanese *et al.*, 2003), bioremediation in polluted sea water (Stabili *et al.*, 2006), to clear large volume of water of organic and bacterial loads in polluted sites (Ledda *et al.*, 2014) as their pumping activity might play an important role in water purification. They are used in the biosynthesis of silver nanoparticles (Inbakandan *et al.*, 2012) as silver nanoparticles are being investigated as tools for novel cancer therapeutics (Ong *et al.*, 2013). The sponges serve as pollution bio indicators (Caraballo 1996; Devoogd 2008; Muricy, 1989; Kiruba-Sankar *et al.*, 2016). They are antibacterial

sources for managing shrimp diseases (Selvin and Lipton, 2004a).

Sponges are also known to contribute substantially to the healthy functioning of coral reefs (Diaz and Rutzler, 2001). In India, sponges and associated microbes were studied for their anti-microbial properties (Sonia *et al.*, 2008; Devi *et al.*, 2011; Chairman *et al.*, 2012; Dhinakaran and Lipton, 2012; Suman *et al.*, 2013; Krishnan *et al.*, 2014a, b; Vijayalakshmi, 2015) and mosquito larvicidal properties (Sonia and Lipton, 2012), anti-inflammatory (Kumar *et al.*, 2014), immunomodulatory activity (Krishnan and Keerthi, 2016), anti-tumour (Chairman and Singh, 2013) and anti-cancer properties (Annamalai *et al.*, 2015). Sponge microbe interactions were also discussed in view of bioprospecting and ecological implications (Selvin *et al.*, 2010). Stevely *et al.*, (1978) reports several other uses of sponges by painters, lithographers, janitors, artists, leather workers, window cleaners, in automotive fields, tile setters and in hospitals. Sponges were also shown to have numerous functional roles particularly bioerosion, reef creation, substrate stabilization, carbon cycling, silicon cycling, nitrogen cycling, primary production, secondary production, camouflaging, etc. (reviewed by Bell, 2008). The potential application of sponges are extensive without doubt; however, the actual issue is the supply of requisite biomass (Osinga *et al.*, 1999; Thakur and Muller, 2004) as these invertebrates produce metabolites in trace quantities.

Need for mariculture of sponges

Sipkema *et al.*, (2005a) raised question for future on how to actually prepare the potential novel drugs on a large scale. For instance, the marine sponge *Dysidea avara* produces avarol which is a very important metabolite with various applications. This sponge is known to

contain 2g of avarol per kg wet weight, and therefore a total of 75 tons of sponge would be required to sustain market demand (Sipkema *et al.*, 2005b). Selvin and Lipton (2004) reported recovery of bioactive extracts of marine sponges *Axinella donnani* (8g/kg), *Dendrilla nigra* (6g/kg) and *Clathria gorgonoides* (3.8g/kg).

Sponges produce bioactive compounds as a defence mechanism against fouling, predation and to compete for space (Becerro *et al.*, 1997). Having such potential and numerous applications in various fields, and production of metabolites in trace quantities creates an issue with respect to mass production. Very large quantities of sponges are to be exploited in order to produce considerable quantity of required metabolites. Until mass production is demonstrated, the technologies will not be feasible, particularly when such compounds are required for drug development and pharmaceutical purpose. The available natural population of sponges will not be sufficient enough for utilization as exploitation from the wild could threaten the existing natural stock. Aquaculture of sponges is the only option to address the supply problem (Laport *et al.*, 2009) to produce large quantity of requisite biomass.

Sponges have been experimentally farmed for over 100 years with early attempts done in the sea to supply bath sponges (Duckworth, 2009). In commercial sponge aquaculture, the major requirements include production of required quantities of sponge biomass and to promote or retain high biosynthesis of target bioactive metabolites (Duckworth and Battershill, 2003a). Farming of potential species would also minimize the pressure of over harvesting from wild (Vinod *et al.*, 2009). Due to the difficulty in obtaining steady supply of such metabolites, only few of these compounds have reached clinical trial stage (Hadas *et al.*, 2005).

Sponge mariculture: Global

Commercial sponging originated from the Aegean Islands of eastern Mediterranean Sea as until 1841, world sponge supply was solely derived from Mediterranean Sea (Stevely *et al.*, 1978). Subsequently, it extended to several parts of the world owing to the realization of its importance in commercial market. Sponges can regenerate from small cut pieces making them potential for commercial farming. Their extensive regenerative capabilities play an important role in nature as well as in cultivation methods. Aquaculture from explants is one of the preferred cultivation methods as explants show great capacity to regenerate after fragmentation (Decaralt *et al.*, 2003) and sponges also have quick damage response (Koopmans *et al.*, 2011). Explants generally grow more rapidly than do whole sponge transplants (Kinne, 1977) and explants preparation details are reported by (Macmillan, 1996). Globally, several attempts have been made on sponge culture and Moore (1910) gave detailed description on the importance of sponge culture in one of the earliest studies and expressed concerns on damage of sponge beds due to destructive fishing practices especially in places like Florida, Bahamas, Cuba and in the Mediterranean Sea due to fishing pressure and sponge diseases (Pronzato *et al.*, 1999). He described basic sponge culture methods in sea by using sponge cuttings attached to aluminium wire with artificial substrate in sea. The procedures described by Moore (1910) are still being used worldwide to produce commercial bath sponges (Osinga *et al.*, 1999).

Sponge culture was attempted for several species either *in situ* or *ex situ* or in combinations as demonstrated in *Tethya citrina* (Bari *et al.*, 2014), *Spongia tubulifera* and *S. pertusa* (Oronti *et al.*, 2012), *Stylissa*

massa, *Neopetrosia* spp. (Schiefenhovel and Kunzmann, 2012), *Dysidea avara*, *Chondrosia reniformis* (Nickel and Brummer, 2003; Osinga *et al.*, 2010; Decaralt *et al.*, 2010), *Callyspongia subarmigera*, *Echninodictyum gorgonoides* (Lipton and Shine, 2009), *Negombata magnifica*, *Amphimedon chloros*, *Theonella swinhoei* (Hadas *et al.*, 2005; Bergman *et al.*, 2011) *Crambe crambe* (Belarbi *et al.*, 2003), deep water boreal sponge *Geodia barretti* (Hoffmann *et al.*, 2003), mariculture of fishes (Sea bass) with sponge (Osinga *et al.*, 2010), *Ephydatia fluviatilis* (Francis *et al.*, 1990), *Aaptos suberitoides*, *Amphimedon paraviridis*, *Callyspongia biru*, *Hyrtios reticulatus*, *Ircinia ramosa*, *Pseudoceratina verrucosa* (Devoogd, 2007a), sponge larval culture (Decaralt *et al.*, 2007) early juveniles of *Hymeniacidon perlevis* (Xue and Zhang, 2009) and many other morphologically distinct sponge species. Since sponges are slow growing organisms, a culture period of minimum 1 or 2 years would be required to achieve commercial size. Results of Stevely and Sweat (1985) demonstrate that at least 2 years are required for the surviving sponge base to regrow to a minimum commercial size. Survival rates of 90% are recommended as economic for sponge cultivation (Verdenal and Vacelet, 1990). Higher survival rates of over 90% was recorded in cases of *Dysidea avara* and *Chondrosia reniformes* (Osinga *et al.*, 2010; Page *et al.*, 2005) in New Zealand, 80-96% for *M. hentscheli* in Indonesia (Devoogd, 2007a), 80-100% for Indonesian reef dwelling sponges (Devoogd, 2007b) and 81.1% for *Tethya citrina* (Bari *et al.*, 2014). Close to 100% survival rates were obtained in explant culture of sponges (Decaralt *et al.*, 2003).

Growth rate is also an important factor which determines the culture potential of sponges. As sponges are slow growing organisms, long-term culture methods are prerequisite to

harvest sponges in high volume. Higher growth rates of 5000 % in short term of one month is also achieved in sponge *Lissodendoryx* sp. in New Zealand (Battershill and Page, 1996) whereas *Spongia officinalis* has shown growth of double their weight in one year (Verdenal and Vacelet, 1990) and *Chondrosia reniformis* achieved 800% growth per year (Osinga *et al.*, 2010). Larval culture being one exciting development in sponge culture (Duckworth, 2009) was attempted by Xue and Zhang (2009) and Decaralt *et al.*, (2007) and found that larval culture under controlled conditions was better than open sea culture for preventing biomass loss in early juvenile sponges (Decaralt *et al.*, 2007). Hadas *et al.*, (2005) reports that sea ranching appears to be the most promising and applicable method aimed at production of sponge biomass. Sponge artificial seed rearing could provide a sustainable means of seed supply for sea based aquaculture or controlled biotechnological cultivation of sponge biomass (Xue and Zhang, 2009).

Disease outbreaks in sponge were reported in the Mediterranean and Caribbean Sea (Pronzato *et al.*, 1999). Osinga *et al.*, (1999) reported that increase in temperature makes the sponge susceptible to pathogen infections. Osinga *et al.*, (2003) also discussed the unreliability of natural environment including disease outbreak which may affect productivity. Sponge diseases are catastrophic epidemics (Pronzato, 1999) and increased prevalence of sponge diseases in Papua New Guinea, Great Barrier Reefs and Mexico were reported with evidences of sponge diseases in relation with climate change and agricultural/urban runoff (Webster, 2007).

Factors influencing sponge culture

Farm site selection and identifying favourable environmental conditions that promote

growth and survival are important to promote the commercial success of bath sponge farm (Duckworth *et al.*, 2007). Survival and growth rates of sponges also depend on the season and physical conditions of the site. Several factors might influence the sponge farming as finding the exact requirement could be difficult. Water flow, depth and season are the main environmental factors that could influence the sponge farming (Duckworth *et al.*, 2004). Being filter feeders, water flow could be an important factor for sponge growth and even in case of early juveniles of *Hymeniacidon perlevis*, periodic water flow and light illumination were found to stimulate the growth (Xue and Zhang, 2009). Water flow and food availability could influence sponge growth when farmed in water column (Duckworth, 2009). Duckworth *et al.*, (2004) in culture of transplanted *Latrunculia wellingtonensis* and *Polymastia croceus* found that the survival was lowest in summer when the water temperature was highest and the growth of the transplanted explants was greatest overall at high flow site. Temperature changes were found to have striking effect on juvenile sponge growth (Xue and Zhang, 2009) and is an important factor affecting sponges, though commercial sponges appear to have tolerance between 10°C and 35°C (Stevely *et al.*, 1978).

The survival and growth rates of sponges under controlled conditions could be highly influenced by the food supply. Since sponges are filter feeders, the food availability could be aggravated by increased water flow. Even sponges have the ability to capture enough food during short period to sustain metabolism (Koopmans *et al.*, 2011). Osinga *et al.*, (1999) suggests that an adequate supply of food seems to be the key to successful sponge culture. Osinga *et al.*, (2003) also suggests studying the role of vitamin in the food and its role in sponge metabolism, as its effect on growth and development of

regenerating sponge explants is unknown. Stevely *et al.*, (1978) reports that 'Mallee' a phenomenon caused by heavy growth of fine algae also killed shallow water sponges, as commercial value of sponges can also be greatly affected by the deformities caused by algae.

Cultivation methods used for sponges

Culture of sponges were attempted either in indoor or open sea conditions (Lipton and Shine, 2009; Schifenhovel and Kunzmann, 2012; Osinga *et al.*, 2003). *In situ* and *ex situ* culture methods have its own advantages and disadvantages. Sea-based culture of sponges may be cheaper than land-based culture, since the land-based approach needs infrastructure to manipulate the culture environment. Duckworth (2009) also states that sea-based cultivation is the only commercially viable method. However, monitoring of the culture systems could be easier in the case of controlled conditions, whereas sea-based culture systems are vulnerable to environmental factors which might lead to loss of culture. Open sea conditions remain rough during monsoon with lot of inflow into the sea which also affects the sponge growth due to siltation. The culture system should be monitored periodically to avoid any possible loss of culture as for instance, Osinga *et al.*, (2010) reports loss of culture after one year due to disruption of frame and some of the pins with the explants were found in the sediment around the frame. Duckworth (2009) suggests that land-based aquaculture is not likely to be commercially feasible in the near future in spite of having some positive results. Maintaining such long duration cultivation in indoor systems could be laborious and hence, extensive culture systems should be planned in open sea conditions using ropes (horizontal and vertical), frames, and small cages. However, Koopmans *et al.*, (2009) suggests that apart

from costs, sea-based culture is less desirable than land based culture as sea conditions cannot be controlled and sponges are vulnerable to diseases and parasites.

The sea-based cultivation is advantageous as sponges are known to have bioremediation potential (Milanese *et al.*, 2003; Stabili *et al.*, 2006; Ledda *et al.*, 2014) due to their ability to filter high volumes of water. Kloppel *et al.*, (2008) while conducting experiments on *ex situ* cultivation of *Aplysina aerophoba* found this method to be promising to maintain sponges and obtain their bioactive metabolites.

Substrates for cultivation

Several methods of cultivation were employed globally including *in situ* culture using concrete discs as artificial substratum with sponge pieces attached to aluminium wire (Moore, 1910), threaded rope separated by plastic spacers, pearl panel, mesh array (reviewed by Duckworth, 2009), explants cultured in horizontal polypropylene ropes to coral anchors, Japanese method of hanging sponges on vertical lines extending from bamboo rafts and along lines attached to beer bottle floats (Macmillan, 1996), stainless steel frame and cage, Shish kebab method (Osinga *et al.*, 2010), Metal grids (Schifenhovel and Kunzmann, 2012), horizontal rope, small cage and glue to metallic frame (Decaralt *et al.*, 2010), mesh arrays and rope array (Duckworth and Battershill, 2003 a & b), suspension method (threading sponge fragments on rope) (Hadas *et al.*, 2005), tray batteries moored to sea floor (Muller *et al.*, 1999), lanterns (Scallop lantern 1m in diameter with ten tiers supported by wire hoops and covered in 1.5cm nylon mesh (Munro *et al.*, 1999), iron cages (Sankar *et al.*, 2016), *ex situ* cultivation using rectangular PVC bioreactors (Osinga *et al.*, 2003), aquarium (Lipton and Shine 2009;

Schifenhovel and Kunzmann, 2012; Sankar *et al.*, 2016), FRP tanks (Vinod *et al.*, 2009) and cell culture (Sipkema *et al.*, 2005b). Macmillan (1996) describes that horizontal line method used by most sponge farmers in Micronesia is probably the cheapest, easiest and versatile method to culture sponges.

The method used for culture will determine the growth and survival as these methods has their own advantages and disadvantages. Duckworth *et al.*, (2009) in his experiments on sponges *Coscinoderma* sp. and *Rhopaloides odorabile* cultured in mesh panel and threaded line, found that sponge farmed in mesh panel generally had good shape and oval appearance, whereas sponges farmed on threaded line is of a shape which is not marketable. However, one advantage of farming sponges for metabolite is that the final explant shape is not important (Duckworth, 2009). Munro *et al.*, (1999) cultured sponges in bags, trays, discs and lanterns and found that sponge cultured in trays or on discs did not grow well mainly due to fouling of plastic structures. The best farming method to commercially grow bath sponges will vary between sponge species and regions (Duckworth, 2009). Sponges may also respond differently in growth and survival with respect to the culture method employed as different species require different culture techniques. Interesting observations were made by Stevely and Sweat (1985) with respect to culture of sponges using cut and hooked methods and found that 71% of cut sponges and 41% of hooked sponges were alive after 28 months of study and recommended both cut and hooked sponge culture method to attain commercially harvestable size with higher survival rates.

Measuring growth of sponges

One of the major issues with respect to sponge culture is the measurement of growth

of sponges. There is no ambiguous method to determine the sponge biomass as determining biomass is one of the critical aspects of sponge culture (Osinga *et al.*, 1999; Yi *et al.*, 2005). The growth behaviour of sponges was also poorly understood owing to the fact that it exhibits irregular growth pattern and measuring their growth might be accompanied with certain degree of error. Several methods like underwater weight, film scan, 3D photogrammetry, outline scan, ruler measurement, spicule measurement, and surface area determination are used. Methods such as wet weights (Hoffmann *et al.*, 2003; Hadas *et al.*, 2005), length, width and height using ruler for sponge explants volume (Duckworth and Battershill, 2003b), sponge diameter (Stevely and Sweat, 1985), height measurement (Vinod *et al.*, 2009), estimation of surface area using length and width measurement of sponge explants (Osinga *et al.*, 2010), image analysis to quantify the increase in area (Decaralt *et al.*, 2007), 3D-photogrammetry technique (Koopmans, 2009), mean volume of explants (Schifenhovel and Kunzmann, 2012), underwater weight (Osinga *et al.*, 2003). Measuring wet weight could be destructive to sponges as sponges are filter feeders and if we remove them out of water it could lead to mortality. Also, wet weight of sponges could not be considered as indicator of growth due to irregular water retention by the aquiferous system (Stone, 1970). Measurement using ruler could be simple but the accompanying error could be large (Yi *et al.*, 2005).

Sponge mariculture: India

Only three research studies have been reported in India to cultivate sponges (Lipton and Shine, 2009; Vinod *et al.*, 2009; Sankar *et al.*, 2016) and all the studies were of short-term nature of less than four months. The sponge diversity of India is rich and unique, concentrated mainly in the Gulf of Mannar

and Palk Bay regions. Sponge aquaculture though having high prospects and potential is in very early stage of development in India. Mariculture technologies has been developing at a steady pace in India and technologies for culture of selected species of fin fishes, crustaceans, bivalves, molluscs and sea weeds has been well standardized. Sea weeds cultivated in Mandapam coast of Tamil Nadu has been contributing as significant source of livelihood to the coastal women. Duckworth (2009) suggests that sponge culture could be of great potential to underdeveloped coastal communities as alternative source of income. Lipton and Shine (2009) cultured *Callyspongia subarmigera*, *C. diffusa* and *Echniodictyum gorgonoides* in Kerala coast in recirculatory semi enclosed aquaria and open sea conditions using explants. In open sea, *Callyspongia subarmigera* grew at an average of 88.94mg per day, with an overall growth of 93.37% compared to the initially stocked sponge tissue. In laboratory culture system, the sponges were fed with microalgae *Nanochloropsis* sp. twice a day. The study emphasizes that farming environment is an important factor for survival and growth. *Callyspongia subarmigera* collected locally survived the farming conditions and was alive throughout the culture period whereas the other two species has not survived since transported from elsewhere and cultured. The culture location of sponge *Dysidea avara* in the Mediterranean Sea was also chosen in an area where *D. avara* was found in abundance which was found as good indicator of culture (Decaralt *et al.*, 2010). Osinga *et al.*, (1999) also states that the physical conditions of the culture locations were found to determine the culture success to a great extent. Understanding the physical and biological variables of environment are important (Duckworth *et al.*, 2004) as sponges are suspension feeders and their feeding will be influenced by water current. Also, water temperature will have a significant impact on

growth and reproduction (Huang *et al.*, 2016). Though high water flow has been found to promote growth of sponges, the relationship was not linear, whereas depth influenced the final size of transplanted sponges (Duckworth *et al.*, 2004), and sponges also grew better in sheltered areas (Duckworth *et al.*, 1997). In another study by Vinod *et al.*, (2009), *Spirastrella inconstans* cultured in Kerala coast showed an increase in growth from 149 to 175 mm, 104 to 116 mm, and 121 to 132 mm (in three live specimens) in one month period.

In Andaman Islands, more than 100 sponge species are reported and few works on the antibacterial activities of bacteria associated with *Stylissa* sp. (Krishnan *et al.*, 2014a; anti-microbial activity of bacteria associated with *Ircinia* sp. (Krishnan *et al.*, 2014b) and antibacterial activity of *Pseudoceratina purpurea* (Suman *et al.*, 2013) were carried out. In Andaman Islands, attempts were made to culture marine sponges *Stylissa massa* and *Liosina paradoxain* cages (*in situ*) and in land based aquaria (*ex situ*) over a period of 120 days (Sankar *et al.*, 2016). Growth and survival were evaluated using four substrates *viz.*, tile, block, coral rock and rope under both *in situ* and *ex situ* conditions. *L. paradoxa* in cages recorded significant increase ($p < 0.05$) on day 90 *i.e.*, by 70% compared to initial volume whereas at 120 days there was a significant ($p < 0.05$) decrease (54.22%). *S. massa* showed significant increase ($p < 0.05$) in growth by 95.6% at 120 days compared to initial volume. Negative growth was recorded in *S. massa* under aquarium conditions while *L. paradoxa* recorded good growth as well as survival and performed exceptionally well in aquarium during the entire experimental period of 120 days. In cages, 90.62% survival was recorded for *S. massa* in 120 days. Among the different substrates used, coral rocks gave 100% survival whereas other substrates such as tiles,

blocks and ropes showed 87.5% survival. Under aquarium conditions, *S. massa*, showed an overall survival of 81.25% and among the different substrates, 100% survival was obtained with coral rocks, 87.5% with blocks, 75% with ropes and the lowest survival of 62.5% was recorded with tiles. These studies have given encouraging results on the possibilities of sponge culture in Indian conditions. Measurement of exact growth remains a hurdle in these studies as measuring growth with height, length and breadth might not be accurate. Advanced growth measurement methods are to be followed to monitor their growth pattern. Also, long-term experiments are required, since sponges require a minimum of one or two years to reach the harvestable size. The candidate species which have more applications in pharmaceutical and drug industry should be prioritized for mariculture. Since sponge culture is still in infancy in India, several studies are required to standardize the culture techniques as per species and culture conditions. Considering the future potential, such studies are to be initiated to address the supply issue.

Some of the candidate sponges for mariculture in India

The potential of marine sponge *Dysidea avara* has been thoroughly discussed (Sipkema *et al.*, 2005b; Decaralt *et al.*, 2010; Osinga *et al.*, 2010; Tommanaro *et al.*, 2015) as they produce avarol, an important metabolite which has several potential applications. Their culture practices has been demonstrated and higher survival rates of over 90% has been reported (Osinga *et al.*, 2010). Studies on bioactive compounds from *Dysidea fragilis* are reported from Mandapam coast of Tamil Nadu (Venkateshwarlu *et al.*, 1998) and *Dysidea herbacea* in Andaman Islands (Venkateshwarulu *et al.*, 1994). *Dysidea herbacea* is reported to have new

amino acid Dysiherbaine which is glutamate receptor antagonist (Sakai *et al.*, 1997). Sponges of *Mycale* genus are an important source of several bioactive metabolites (Huang *et al.*, 2016). *Mycale mytilorum* was reported by Vinod *et al.*, (2014) from Ernakulam to Kollam in Kerala coast of India whereas *M. crassissima* and *M. Indica* were reported from Andaman Islands (Pattanayak 2006). *Stylissa massa* is one of the most important sponges concerned with pharmaceutical and drug development. Several compounds like Hymenialdisine, an alkaloid with potential against human neurodegenerative diseases have been found from *S. massa*. Eight alkaloids were derived from these sponges which has potential as anti-tumour (Tasdemir *et al.*, 2002). Their extensive availability in India could be utilized for development of culture technologies. Studies on bioactive metabolite production in cultured sponges were also attempted in *Echinodictyum gorgonoides* and *Callyspongia subarmigerain* India (Lipton and Shine, 2009). *Hyrtios erectus*, another marine sponge from India has been shown to have significant anti proliferative effects against variety of human cancer cell lines (Ramachandran *et al.*, 2013), several alkaloids, Scarlane sesterterpenes (Ashour *et al.*, 2007) and inhibitory activity against hepatocellular carcinoma, colorectal carcinoma and breast adenocarcinoma cells. *Plakortis* sp. are known for the production of cyclic peroxides (Laport *et al.*, 2009) which are effective against parasitic diseases. Marine sponge *Dendrilla nigra* reported from India is a reliable source for the development of shrimp therapeutants and studies suggest that *Dendrilla* medication may form a suitable alternative to replace conventional antibiotics (Selvin and Lipton, 2004a). Despite several growth studies carried out globally, there is only limited understanding on the exact needs of sponges to improve growth (Koopmans *et al.*, 2009). Hence several growth trials will be

required to standardize the culture of sponges in Indian waters. With their proven merits, initially sponges like *Stylissa massa*, *Dysidea* sp. and *Hyrtios erectus* could be attempted on long term (1to 2 years) to study their growth and survival pattern. Since several culture methods were reviewed, trials to standardize the various culture methods (ropes - horizontal & vertical), mesh bags, trays, shish kabab, cages, panels etc. can be explored for standardization. In India, several potential sponges are found distributed in regions like Gulf of Mannar, Palk Bay and Andaman Islands, culture practices should be prioritized in these regions. Selvin and Lipton (2004b) reported Kanyakumari Coast to be an excellent area for collection of diverse species of marine sponges which are landed as by-catch in fishing nets. The sponges caught as by-catch were also utilized as source material for the development of novel shrimp therapeutants (Selvin and Lipton, 2004a). Attempts to culture potential species on large-scale in suitable locations for a longer duration could help to standardize the shortfalls in culture and develop feasible culture technology for the steady supply of metabolites. *In situ* cultivation of sponges can be prioritized in early stages as establishing cultures in land-based cultivation for long-term could be cumbersome. Methods such as rope (vertical and horizontal) culture, mesh culture and cages can be evaluated in early stages and suitable modifications in culture systems can be introduced according to the growth and survival pattern of sponges.

Sponge and fish culture: Possibilities of integrated farming systems

The concept of integrated multitrophic aquaculture is gaining importance now-a-days, as this system combines a number of complementary organisms at farm site to optimise nutrient utilization and reduce solid waste (Granada *et al.*, 2015).Fish-sponge

integrated aquaculture could be one such interesting combination with sponges being filter feeders could act as biofilters. Bath sponge and pearl oyster farms are suggested as feasible natural pollution filtration system in studies on bioremediation mariculture in Zanzibar (Oakland, 2013). Milanese *et al.*, (2003) in his experiments on clearance tests of the sponge *Chondrilla nucula* suggested this species to be suitable for marine environmental bioremediation, as one square meter patch of this sponge can filter up to 14l/h of sea water. Stabili (2006) also demonstrated the high efficiency of *Spongia officinalis var. Adriatica* in removing bacteria and suggested the suitability of this species for bioremediation. Such interesting observations holds much promise for integration of sponge and fish culture as sponges could keep the culture environment clean. Interestingly, Osinga *et al.*, (2010) attempted to combine the mariculture offish (sea bass) with the culture of two Mediterranean sponges, *Dysidea avara* and *Chondrosia reniformis* under floating fish cages and found culturing of *D. avara* to be feasible under floating cages. Large-scale sponge culture could have a profound effect on the water quality in the vicinity of fish farms, with stimulation in sponge growth making more efficient (Granada *et al.*, 2015). Though the concept is discussed, it is not applied on a commercial scale. Marine cage fish farming being a prominent mariculture activity in India wherein fishes like cobia, pompano, are being cultured across the country. Cage culture demonstration activities are being undertaken in Andaman Islands, Mandapam coast (Tamil Nadu), Veraval coast (Gujarat), Kerala and in coastal areas of the country. Places like Andaman Islands, and Mandapam coast hosts several sponge species and they could be ideal sites for preliminary attempts on sponge culture with fishes. The idea of such integration if proven beneficial in Indian waters could popularise the much

deserved attention for sponge culture in the country. Sponges clearly fulfil a number of functional roles across temperate, tropical and polar ecosystems (Bell 2008) and their culture could have beneficial effect on the marine environment apart from the interest on bioactive compounds.

Marine organisms are well known to have specific relationship with numerous microorganisms and sponges are no exception (Thakur and Muller, 2004), as sponges hosts various bacteria, fungi which have been found to possess several bioactive compounds. The association of these microbes with sponges makes them more potential for several applications in drug development field. Hence they need to be harvested sustainably without harming their available natural stock. Sponge farming provides possible solution to the problem of declining wild stocks (Pronzato, 1999) in the era of climate change events which are set to influence the marine world. Considering its potential, sponges could be the future of farming globally because of the demand and the simple methods used for cultivation. Though lack of apparent success in farming methods and production, still they possess enormous scope for mankind. Importance of sponges have been understood globally and countries like the United States of America, New Zealand and parts of Europe have been actively engaged in researches on sponge culture in indoor and outdoor conditions. In India, seaweeds has gained more attention as they possess ample application in various fields of pharmaceuticals, cosmetics and food industry. Seaweed farms are functional in places like Mandapam coast, Tamil Nadu as a source of livelihood for coastal communities. Sponges also possess similar potential, and in fact more in terms of their application in drug development and disease curing capabilities. Diseases like malaria, tuberculosis, HIV and cancer is already claiming thousands of lives in

developing countries like India and marine sponges has proven their potential in developing a cure for such diseases. Methods like chemical synthesis, biotechnological production, cell culture, *in vitro* culture are being explored to produce the sponges and their metabolites in required quantities. Developing culture technologies for mass production of sponges in either indoor or open sea could solve the supply issue. With such high diversity of marine sponges in India, culture attempts of potential species should be initiated to meet the future demand. Attempts on sponge-fish integration could be a viable avenue and more serious attempts are required to assess its feasibility in India. Sponge derived medicines and drugs could help to alleviate the future challenges of developing countries. In Indian conditions, with the increasing population and disease outbreaks, sponge could be seen as future of farming and the study calls for increased attention and research in sponge mariculture for the welfare of mankind and livelihood.

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