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Assessing the feasibility of sponge aquaculture as a sustainable industry in The Bahamas

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Abstract Sponge harvesting was a significant part of the Bahamian economy until the late 1930s when disease, hurricanes, and unsustainable harvesting practices reduced the viability of the sponge industry. Current international demands for natural products, increasing regional needs for economic diversification, and the historical foundation of sponging in The Bahamas makes sponge aquaculture a desirable candidate as a sustainable industry. To determine the feasibility of sponge aquaculture in The Bahamas, we deployed growout arrays between February 2006 and September 2009 at two sites off South Eleuthera to examine the survival and growth rates of grass sponge (*Spongia tubulifera*) and hardhead sponge (*Spongia pertusa*) cuttings. Complete skin regeneration occurred for both species by the second week following deployment. Following 43 months of growout, both grass and hardhead sponges showed significant positive growth, with cuttings of both species exhibiting faster growth trajectories at the more protected site (Site A) when compared with the site further from shore (Site B). The proportion of sponge cuttings lost during the course of the study was also considerably less for both species at Site A, as was the amount of required maintenance for the arrays. The initial deployment of larger sponge cuttings could help reduce the overall growout period, as would the selection of sites that offered more protection for growout. Based on these results, sponge aquaculture could

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prove to be a sustainable low-cost industry in The Bahamas; however, further research on site selection, regulations, and market acceptability remains to be done.

Keywords Sponge aquaculture · Grass sponge · Hardhead sponge · Eleuthera · Bahamas

Introduction

Sea sponges have been used for their unique absorptive properties dating back to the ancient Greeks and other Mediterranean cultures (Casson 1991). The practice of commercial harvesting of sponges also began in the Mediterranean and was conducted exclusively in this region until the 1840s when French explorer Hayman noted the presence of sponge beds in the Caribbean (Corfield 1938; Storr 1964; Pronzato 1999). Following this discovery, sponges from the tropical and subtropical western Atlantic were introduced to the European market, thus encouraging the commercial harvest of sponges in places such as the Caribbean, Florida, and The Bahamas (Corfield 1938; Casson 1991).

In The Bahamas, the sponge industry became an established part of the economy circa 1843, with production reaching its peak in 1917 (Knowles 1974). The sponge-harvesting industry at that time involved one-third of the Bahamian work force and dealt with the harvesting, processing, and trading of sponges. Other industries in The Bahamas such as shipbuilding and repair also thrived during this time largely because of the commercial sponge industry (Buchan 2000). The commercial sponging industry was a major economic force in The Bahamas until the late 1930s when a series of hurricanes damaged a large proportion of sponge stocks (Knowles 1974). In 1938, a fungal blight further decimated the remaining 70–95% of natural sponges in The Bahamas (Storr 1964; Knowles 1974; Smith 1941; Craton and Saunders 1998). These major disturbances, in conjunction with the unsustainable harvest practice of tearing sponges from the sea floor (rather than cutting to allow for regrowth), greatly affected the availability of viable sponges for commercial trade. In addition, synthetic sponges developed in the 1940s were less expensive and more readily available than natural sponges. As such, the decline in demand further reduced the importance of the commercial industry for natural sponges in The Bahamas (Storr 1964).

The boom and bust of the commercial sponge industry is typical of other cycles in natural resource exploitation that have affected the strength of the Bahamian economy in the last few centuries (Albury 1975; Craton and Saunders 1998; Danylchuk 2005); for example, many economic trends in small island developing states are rooted in the overuse of resources, fluctuating international market demands, and a lack of integrative local and regional management strategies that focus on sustainable development (Buchan 2000; Albury 1975). On the island of Eleuthera specifically, commercial agriculture and livestock production was very common in the early 1900s until thin soils, intensive growing practices, and advancements in shipping technology reduced agriculture back to a subsistence level (Knowles 1974; Danylchuk 2005). Currently, tourism is the largest single contributor to the Bahamian economy, representing more than 50% of the annual gross domestic product (Buchan 2000; BEST 2005). Given that tourism itself is also sensitive to changes in international market demands, such as the decline in tourism following terrorist attacks on US soil (Bonham 2006), the development of alternative industries that can help diversify sources of revenue in The Bahamas could help reduce economic uncertainty.

Given the historical context of sponging in The Bahamas and the growing demands for natural sponges for the cosmetic, biomedical, and aquarium trades (Osinga et al. 1999; Duckworth and Battershill 2003, Belarbi et al. 2003), sponge aquaculture could be a low-cost, low-risk economic opportunity if done sustainably. In fact, sponge aquaculture could prove to be a very lucrative and important industry for the acquisition of secondary metabolites for the purposes of biomedical research (Osinga et al. 1999; Belarbi et al. 2003; Duckworth and Battershill 2003). In addition, the culture of sea sponges could increase production of natural sponge products while reducing the need to intensively harvest natural sponge beds (Pronzato 1999; Cotte 1908; Moore 1908; Duckworth et al. 1997). Because sponges have a unique regenerative capacity (Wiedenmayer 1977), wild sponges can be cut away from the base that attaches them to the substrate, and both the raw edges of the base as well as the raw edges of the cutting will regenerate. Cutting sponges is thus a more sustainable practice of sponge biomass production than tearing wild sponges from their holdfast since the original cuttings can be used as a source for the next harvest, while the 'donor' sponge can regrow and perform key ecological functions (Duckworth and Battershill 2003; Belarbi et al. 2003). Given that sponges are filter feeders and have relatively few natural predators, the growout of sponges for commercial production may be a low capital and low-risk industry.

Before sponge aquaculture is promoted as a viable industry, however, information is required on optimal culture techniques that maximize the survival and growth of sponge cuttings while minimizing cost and risk (Duckworth and Battershill 2003; MacMillan 1996). Sponge farming has been developing through land or sea-based means using various methods over the last 100 years (reviewed by Duckworth 2009). Studies have focused on developing good farming structures and identifying the optimal environmental conditions that promote production of bath sponges or bioactive metabolites. As such, we conducted a long-term growout experiment using grass sponge (*Spongia tubulifer*a) and hardhead sponge (*Spongia pertusa*) cuttings to examine their regeneration, survival, and growth rates. Grass sponges are commonly used in the cosmetic and artisan industries, while hardhead sponges potentially possess secondary metabolites that are desirable to the pharmaceutical industry (Osinga et al. 1999). Secondarily, we tested a relatively low-cost deployment system for sponge cuttings that could make sponge aquaculture more affordable and economically sustainable, especially in developing countries such as The Bahamas.

Materials and methods

Study site

Our study occurred off the north coast of Cape Eleuthera, Eleuthera, The Bahamas (N 24 50 05 and W 76 20 32) between February 2006 and September 2009. Sponges were grown out at two different sites that varied in their proximity to shore. Site A was located 15 m from shore in a 3-m-deep dredged channel at the mouth of a small protected bay with substrate dominated by turtlegrass (*Thalassia testudinum*). Site B was located in a more exposed location 750 m directly offshore from Site A. Although further from shore, Site B also had a water depth of 3 m while the substrate was a mosaic of turtlegrass, benthic macroalgae, and sand. Tidal currents at both sites were bidirectional depending on the tidal cycle, and maximum flow rates were approximately 1 m/s at peak flows.

Aquaculture array

Structures or arrays used for the growout of sponges were made out of low-cost materials readily available on Eleuthera. Support structures for the arrays consisted of concrete

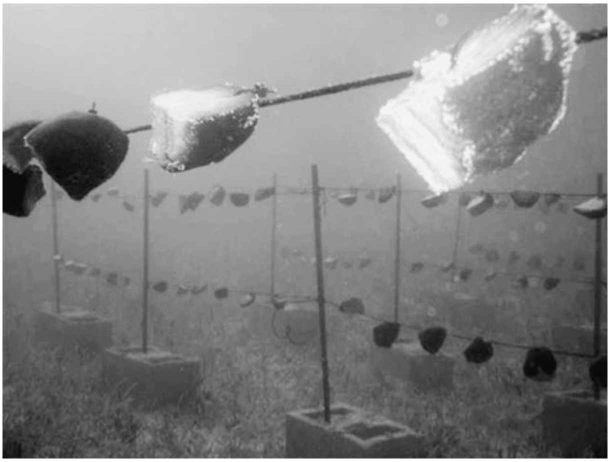

Fig. 1 Sponge cuttings deployed on low-cost growout arrays located near Eleuthera, The Bahamas

blocks, each with a 1 m length of 19 mm (¾″) steel rebar cemented vertically in the center hole of the block (Fig. 1). Each array consisted of five support structures placed in a line running parallel to the direction of the current to reduce hydrodynamic drag. Spanning horizontally between each support structure were two rows of tarred nylon twine (24 gauge, Nylon Net, Memphis, Tennessee) 105 cm in length, spaced 15 cm and 45 cm from the top of the steel rebar posts. Arrays were constructed underwater using SCUBA prior to harvest and attachment of sponge cuttings to the tarred nylon twine.

Sponge harvesting

Donor grass and hardhead sponges were harvested from within a 3 km radius of the growout sites. Sponges were cut using a freshly sharpened knife and handled gently to minimize stress and damage to each sponge. One-third of each donor sponge was left attached to the substrate to allow for regrowth (Duckworth and Battershill 2003). The remaining two-thirds of the donor sponge were kept in the water throughout the harvesting period. Once sufficient sponge biomass was collected, it was then transported to a carrying tank where it could be divided into numerous smaller sub-spherical cuttings. A sharp knife was used to subdivide the donor sponge into smaller pieces approximately 160–190 cm^3 in size for grass sponges and 60–67 cm^3 for hardhead sponges, ensuring that a minimum of one side of the cutting had intact pinacoderm (Duckworth and Battershill 2003). Each sponge cutting was measured on three sides using vernier calipers (to the nearest mm) from which a cutting volume was determined.

Sponge cuttings were attached at 15-cm intervals to tarred twine (24 gauge, Memphis Net and Twine, Memphis, Tennessee, USA) that was strung horizontally between each pair of support structures for each array (Fig. 1). A plastic cable tie was threaded through a small cut made on the sponge cutting or through an osculum, and then the cable tie was threaded through the strands of the tarred twine and tightened. With each array having eight horizontal lines, a total of 48 sponge cuttings were affixed to each array and three arrays were deployed at each site for each species ($n = 144$ cuttings/species/site).

Data collection

Sponge cuttings were monitored weekly for the first 2 weeks of the study to document regrowth of the pinacoderm. Monitoring then occurred monthly for 2 months, approximately every 2 months for the first year and then approximately every 6 months thereafter. For each monitoring session, ten cuttings were randomly selected from each of the three arrays for each species ($n = 30$ for each sample period for each species at each location). Each cutting was measured on three sides using a vernier caliper (to the nearest mm), and the mean volume of each species was determined for each monitoring period. Survival of all cuttings on each array was also recorded, as was the complete loss of cuttings from the arrays. Linear regression was used to determine the growth trajectories for each species at each site and a Student's t-test to determine the effect of location on growth rates.

Results

Growth

Sponge cuttings were grown out for a total of 43 months following deployment, and monitoring was conducted 11 times during this period. The pinacoderm of all sponge cuttings for both species regrew within 7–10 days following deployment. The mean volume of grass sponge cuttings at Site A increased from 190 cm^3 (±59.3 cm^3 SD) at the time of deployment to 1,404 cm^3 (±190.4 cm^3 SD) after 43 months, while the mean volume of grass sponge cuttings at Site B increased from 160 cm^3 (±48.3 cm^3 SD) to 638 cm^3 (±102.3 cm^3 SD) during the same period (Fig. 2a). Grass sponge cuttings at both sites displayed significant positive growth over the course of the study (Site A, $r^2 = 0.97$, $P = 0.004$; Site B, $r^2 = 0.98$, $P = 0.001$). The mean growth rate of the cuttings, however, at Site A was faster (27.5 cm^3/month, ±4.3 cm^3 SD) than the mean growth rate of cuttings at Site B (12.3 cm^3/month, ±2.3 cm^3 SD). After 43 months, grass sponges at Site A were approximately seven times larger than their size at deployment, whereas grass sponges at Site B were four times larger then when initially deployed.

The mean volume of hardhead sponge cuttings at Site A increased from 67 cm^3 (±29.1 cm^3 SD) to 324 cm^3 (±40.9 cm^3 SD) during the growout period, while hardhead sponge cuttings at Site B increased from 60 cm^3 (±26.4 cm^3 SD) to 199 cm^3 (±36.8 cm^3 SD) during the 43-month growout period (Fig. 2b). Hardhead sponge cuttings at both sites displayed significant positive growth over the course of the study (Site A, $r^2 = 0.94$, $P = 0.001$; Site B, $r^2 = 0.94$, $P = 0.001$). Again, the mean growth rate of cuttings at Site A (6.2 cm^3/month, ±0.9 cm^3 SD) was faster than the growth rate of cuttings at Site B (2.9 cm^3/month, ±0.8 cm^3 SD). At the end of the growout period, hardhead cuttings were 4.8 and 3.3 times greater in volume then when initially deployed at Sites A and B, respectively.

Mortality and loss

Following 43 months of growout, 12.5% of the grass sponge cuttings were lost from Site A (18 out of 144 total cuttings, mean 6 ± 2.5 SD among arrays), of which a total of 2 cuttings (11% of those lost or 1% of the total number of cuttings) were observed to have suffered mortality prior to being lost from the arrays. For grass sponges at Site B, 68% were lost after 43 months (98 out of 144 total cuttings, mean 32.6 ± 4.0 SD among

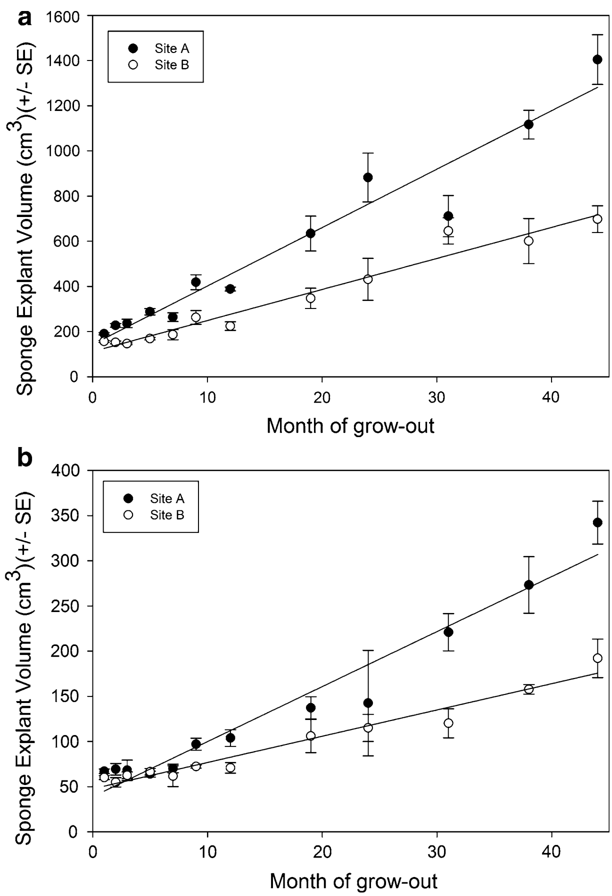

Fig. 2 Mean volume of **a** grass sponge cuttings and **b** hardhead sponge cuttings, at Site A and Site B during the 43-month growout period. *Best-fit lines* represent simple linear regressions

arrays); however, the proportion of those lost that showed earlier signs of mortality was similar to Site A (10 out of 98, or 10% of those lost).

For hardhead sponges at Site A, 12.5% were lost over the 43-month growout period (18 out of 144 total cuttings, mean 6 ± 1.7 SD among arrays), and 2 of these cuttings showed signs of mortality (11% of those lost or 1% of the total number of cuttings). For Site B, 55% of hardhead cuttings were lost (79 out of 144 total cuttings, mean 26.3 ± 3.5 SD among arrays), of which 24 cuttings (30% of those lost or 17% of the total number of cuttings initially deployed) suffered mortality prior to being lost from the arrays.

Discussion

The purpose of our study was to determine whether the growout of sponges could be feasible for the development of a low cost, alternative industry in The Bahamas. Cuttings of both grass and hardhead sponges grew considerably during the 43 months of our study; however, site-specific differences in growth were particularly evident for grass sponges.

Environmental factors are critical to the survival and growth of individual sponge cuttings (Duckworth et al. 1997). Variation in exposure to light, current, temperature, nutrients, and depth are likely to affect the ability of an individual sponge to maximize filtration and growth (Duckworth et al. 1997). Differences in nutrient input are also important factors when considering growth since a sponges primary source of food are nutrients suspended in the water column that are available for filtration (Duckworth and Battershill 2003). Differences in exposure and the influences of nutrient runoff from land could help explain why grass sponges grew more quickly in Site A since this location was nearshore in a protected channel. The influence of stress related to physical disturbances could have also resulted in the greater loss of sponges located at Site B, which was further from shore and potentially exposed to greater wave action. Arrays at Site B also needed considerably more maintenance as support structures were often found tipped on their sides, likely the result of more turbulent waters. As such, site selection for the growout of sponge cuttings is an important consideration that could increase production rates and the success of a sponge aquaculture program.

Grass sponge cuttings in our study, particularly from Site A, reached the legal harvestable size in The Bahamas based on current regulations (14 cm diameter). For Site B, however, extrapolated growth trajectories indicated that it would take approximately 7–8 years for these grass sponge cuttings to reach the legal size limit. Although initially starting the growout cycle with larger cuttings may significantly reduce the time to harvests, site selection is also an important factor that could help optimize growth. For hardhead sponges, because of their relatively small size in the wild (i.e., the size of the donor sponges), the size of many of the initial cuttings used in our study was greater than the legal harvestable size in The Bahamas (2.5 cm diameter). Since the growout of hardhead sponges would potentially be for the pharmaceutical rather than the cosmetic market, sponge quality might be more of a concern rather than final sponge size (Munro et al. 1999).

The success of sponge aquaculture depends on the regrowth of parent/donor sponges as well as the survivorship of cuttings. A concurrent small-scale study conducted on Eleuthera showed that donor grass and hardhead sponges demonstrated regrowth at 16.1 and 12.6% of post-cutting size per year, respectively (Tyrrell, unpublished). Moreover, this work showed that mortality of donor sponges after cutting was <3%). Reports of sponge disease since the outbreak of 1938 have increased only in recent years (Webster 2007) with the increased attention to this biological issue correlating with increased environmental change. The only report of disease in cultured sponges occurred at British Honduras in 1941 (Smith 1941); however, wild sponge population densities have been shown to influence disease dynamics in wild sponges (Wulff 2007). The low rates of mortality in the cuttings of both species suggest that disease was not an issue within the small culture array or in the donor sponges. Regrowth and mortality of donor sponges should, however, be monitored in all sponge aquaculture projects.

One benefit to the implementation of sponge aquaculture is the relative low cost of establishing the infrastructure for production. The total cost of the twelve arrays plus incidental materials (e.g. knives) used in our study was approximately $150 USD for the potential production of 576 sponge cuttings. With proper sighting of arrays where sponge loss would be minimal, and given that local sponge harvesters can earn anywhere from $1.00–$4.00 USD for a legal sized grass sponge depending on its quality, the potential gross revenue could be as high as $2,300 USD based on the scale of growout used in our study. During our study, maintenance costs, especially for the sponge arrays in Site A, were negligible and the cost of consumables, such as commercial feed, were eliminated since sponges are filter feeders. During the growout cycle, it was also evident that many more sponge cuttings could have been affixed to the horizontal lengths of tarred twine that were suspended between support structures, plus additional horizontal lines could have been added to each array. As such, the total number of sponge cuttings per array could be increased considerably as a way to augment production and increase the margin between capital costs and profit for entrepreneurs in local communities. The potential revenue could also vary depending on the species of sponges to be grown out and their potential market, since sponges produced for their secondary metabolites, for instance, could prove to be more lucrative (Osinga et al. 1999; Munro et al. 1999). In addition, growth rates and overall production of sponges could be increased by combining their growout with other forms of aquaculture as a way to capitalize on waste streams and create a multitrophic integrated system (Wurts 2000), such as within offshore aquaculture systems.

Although our study was relatively simple, the results are important for determining the feasibility of sponge aquaculture in The Bahamas. Before sponge aquaculture is advocated as a viable economic industry, it will be important to determine the most efficient avenues to connect local entrepreneurs with wholesale brokers and other market representatives to ensure that there is a stable endpoint for the products. While domestic use is the most common market for some species, new emerging markets such as the aquarium and pharmaceutical industries could prove to be important targets for sponge aquaculture (Osinga et al. 1999; Munro et al. 1999). In spite of the low capital costs, it may still be important for regional governments to provide financial aid and other support to entrepreneurs who wish to potentially supplement their income by becoming sponge farmers. Given the historical context of sponge harvesting in The Bahamas, the combination additional scientific research, market analyses, and government support may ultimately help sponge aquaculture become a viable option for increasing economic stability while conserving wild stocks of natural sea sponges.

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References

Albury P (1975) The story of the Bahamas. Macmillan Education Ltd, London

Bahamas Environment, Science, and Technology Commission (BEST) (2005) State of the environment. Government of the Bahamas

Belarbi EH, Gómez AC, Chisti Y, Camacho FC, Grima EM (2003) Producing drugs from marine sponges. Biotechnol Adv 21:585–598

Bonham C (2006) The impact of 9/11 and other terrible global events on tourism in the United States and Hawaii. J Trav Res 45:99–110

Buchan KC (2000) The Bahamas. Mar Pollut Bull 41:1–6

Casson L (1991) The ancient mariners. Princeton University Press, Princeton

Corfield GS (1938) Sponge industry of the Caribbean area. Econ Geog 14:201–206

Cotte J (1908) Sponge Culture. Fourth International Fishery Congress, Washington

Craton M, Saunders G (1998) Islanders in the stream: a history of the Bahamian people, vol 2. University of Georgia Press, Georgia

Danylchuk AJ (2005) Fisheries management in South Eleuthera: can a marine reserve help save the 'holy trinity'. Proc Gulf Caribb Fish Inst 56:169–177

Duckworth A (2009) Farming sponges to supply bioactive metabolites and bath sponges: a review. Mar Biotechnol 11:669–679

Duckworth A, Battershill C (2003) Sponge aquaculture for the production of biologically active metabolites: the influence of farming protocols and environment. Aquaculture 221:311–329

Duckworth AR, Battershill CN, Berquist PR (1997) Influence of explant procedures and environmental factors on culture success of three sponges. Aquaculture 156:251–267

Knowles LJ (1974) The sponge industry. The Exhibition of Historical Documents Held at the Public Records Office, Ministry of Education and Culture. Nassau, Bahamas, pp 5–34

MacMillan SM (1996) Starting a successful commercial sponge aquaculture farm. Center for Tropical and Subtropical Aquaculture, University of Hawaii, Publication no. 120

Moore HF (1908) A practical method of sponge culture. Fourth International Fishery Congress, Washington

Munro MHG, Blunt JW, Dumdei EJ, Hickford SJH, Lill RE, Battershill CN, Duckworth AR (1999) The discovery and development of marine compounds with pharmaceutical potential. J Biotech 70:15–25

Osinga R, Tramper J, Wijffels RH (1999) Cultivation of marine sponges. Mar Biotech 1:509–532

Pronzato R (1999) Sponge-fishing, disease and farming in the Mediterranean Sea. Aquat Conserv Mar Freshw Ecosyst 9:485–493

Smith FGW (1941) Sponge disease in British Honduras, and its transmission by water currents. Ecology 22:415–421

Stevenly J, Sweat D (1985) Survival and growth of cut vs hooked commercial sponges in the Florida Keys. Florida Sea Grant College Technical Paper 38

Storr JF (1964) Ecology of the Gulf of Mexico commercial sponges and its related fishery. US Fish and Wildlife Service, Special Scientific Report, Fisheries No. 466

Webster NS (2007) Sponge disease: a global threat? Environ Microbiol 9(6):1363–1375

Wiedenmayer F (1977) Shallow-water sponges of the western Bahamas. Naturalhistorisches Museum, Basel

Wulff JL (2007) Disease prevalence and population density over time in three common Caribbean coral reef sponge species. J Mar Biol Assoc UK 87:1715–1720

Wurts W (2000) Sustainable aquaculture in the twenty-first century. Rev Fish Sci 8:141–150