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ADVANCING THE BLUE ECONOMY THROUGH SUSTAINABLE MARICULTURE: THE PROSPECT OF PEARL OYSTER AND SPONGE CULTIVATION IN ST. VINCENT AND THE GRENADINES

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Abstract: The Blue Economy is estimated to be worth over USD 2.5 trillion annually, or almost 3% of the world's GDP in 2020. St. Vincent and the Grenadines (SVG) in the Caribbean region has a vast and rich marine space that is underutilized. This study aimed to explore the feasibility of pearl oyster and sponge farming to advance the country's Blue Economy through sustainable mariculture. A qualitative approach was applied, using a literature review and thematic analysis of data gathered through semi—structured interviews and focus group discussions with relevant stakeholders. Among several species evaluated, the result of the study revealed that the *Pinctada imbricata* oyster species and *Hippospongia lachne* sponge species are the most suitable for cultivation in SVG coastal waters, specifically in the Ashton Lagoon of Union Island. The study concluded that while there is strong support from the stakeholders in SVG for pearl oyster and sponge farming in the country, challenges still exist. Nevertheless, it has been found that by learning and adopting the strategies of the leading Small Island Developing States (SIDS) in the Blue Economy development combined with the critical enablers such as meticulous planning, stakeholder collaboration, establishment of legal frameworks, and ecosystem—based management, pearl oyster and sponge mariculture in the identified location in SVG could potentially aid the expansion of the country's Blue Economy.

Key words: pearl oyster farming, sponge farming, sustainability, Small Island Developing States

Introduction

The emergence of the "Blue Economy" concept has garnered increasing attention globally, marking a pivotal shift in the understanding of oceanic resources (Midlen 2021). It encapsulates the intersection of sustainability, economics, and the oceans, as highlighted by various professionals, regional organizations, and international entities like the World Bank (2017) and the United Nations (2022). Significantly, the United Nations (UN) has underscored the Blue Economy's role in achieving Sustainable Development Goal (SDG) 14 — "Life Below Water," which focuses on the conservation and sustainable use of marine resources.

The Blue Economy is a major contributor to global Gross Domestic Product (GDP), with the value of ocean—based trade estimated at USD $2.5 trillion annually according to United Nations Conference on Trade and Development (UNCTAD 2022). This figure underlines the sector's economic significance, encompassing diverse activities from maritime trade to ecosystem services. However, the definition of the Blue Economy varies, with some emphasizing its role in employment and national financial gains, while others focus on integrating maritime activities and Ocean Management (Blažauskas et al. 2015, Fernández—Macho et al. 2016). This variance in definition underscores the need for a nuanced understanding of the Blue Economy, particularly in relation to mariculture.

Mariculture, also known as marine aquaculture, is a distinct type of aquaculture that is performed at inshore and offshore areas of tropical, subtropical, and temperate regimes of various nations, and involves bottom culture as well as raft and cage culture (Tacon and Halwart 2007). Unlike the typical aquaculture which involves growing aquatic plants and animals in either natural or controlled freshwater or marine environments, mariculture specifically focuses on cultivating these organisms in marine and estuarine (brackish) waters (Mmochi 2016). Mariculture is a component of the Blue Economy, which represents the fastest—growing food system globally (Phillips 2009) and contributes to economic growth, food security, sustainable resource management, and climate change resilience (United Nations 2022).

The cultivation of pearl oysters and sponges through mariculture represents a key approach for advancing a nation's Blue Economy. Pearl cultivation presents a substantial opportunity for economic growth in coastal communities across the spectrum of valuable species (Gervis and Sims 1992). Over 30 countries have been producing cultured pearls in the past decades (Zhu et al. 2019), with China accounting for 98% of global output; freshwater pearls comprised 99.5% (FAO 2022) by 2014 or 800–1,000 tons, whereas only 2.6 tons of marine pearls were produced (Cartier 2014). Japan, the leading marine pearl producer, contributes around 20 tons per year (Zhu et al. 2019). Other countries producing marine pearls include the Federal States of Micronesia and French Polynesia (Cartier et al. 2012), Venezuela (MacKenzie et al. 2003), Vietnam, Australia, Myanmar, Indonesia, Philippines, Cook Islands, Fiji, Mexico, and the United Arab Emirates (Cartier 2014). In fact, the United Nations Department of Economic and Social Affairs (2021) recognizes that cultivating pearls from oysters can be seen to enhance sustainability, benefiting coastal communities and promoting environmental conservation in biodiversity—rich areas of the Pacific. However, global pearl production has decreased by 60% and output value by 39% in the past decade due to over—saturation of low—quality pearl production (FAO

2022).

The economic significance of sea—based sponge farming is likewise acknowledged (Osinga et al. 1999). Notably, Zanzibar and Tanzania sponge farmers earn USD 15—30 / £ 12—24 per sponge (Makoye 2023), emphasizing the economic viability of sponge farming. In addition, Cuba has a thriving sponge farming industry with an estimated international market value of over USD 40 million annually (Betanzos—Vega et al. 2019). Sponge farming can be a profitable business but requires time and expertise for successful implementation (Aguilo—Arce et al. 2023).

Sponge farming combats decreasing biodiversity loss and poverty, using marine resources sustainably, and encouraging environmentally sustainable economic development (Aguilo—Arce et al. 2023, Makoye 2023). Moreover, the combined farming of pearl oysters and sponges has been done in Tanzania and reported no indication of any detrimental effects to the environment, animals or human life, and has displayed strong pollution filtration abilities (Oakland 2013). Aligned with the UN SDG 14, marine pearl oyster and sponge farming thus promote scientific growth, diversify Blue Economy production, and contribute to aquaculture supply.

In Saint Vincent and the Grenadines (SVG), a small archipelagic state spanning 389 km^2 in the southeastern Caribbean, the heavy dependence on coastal and marine resources contrasts sharply with the untapped economic potential these resources present, despite their rich biodiversity (Howell et al. 2019). Moreover, the nation faces high rates of unemployment and poverty, with small—scale fisheries being a primary source of livelihood (Howell et al. 2019). This underscores the urgent need for sustainable economic development strategies.

As such, this study aimed to investigate the feasibility of cultivating oyster pearls and sponges through mariculture, thus contributing to the advancement of the Blue Economy in SVG. This research endeavors to shed light on pathways to unlock the economic potential of marine resources while ensuring long—term environmental and social sustainability by addressing the following key research questions surrounding perceptions, suitability, viability, and impacts within SVG's unique national context:

1. What species of pearl oysters and sponges would be suitable for mariculture in SVG?;
2. Which areas could sustain viable pearl oysters and sponges?;
3. What are the perceptions of the emerging Blue Economy and the potential for mariculture in SVG?;
4. How will pearl oyster cultivation and sponge farming affect local fisherfolk and coastal stakeholders?

Materials and Methods

A 2—stage qualitative research method was applied in this study, as presented in Figure 1. The first stage was a thorough literature review, whereas the second stage involved semi—structured interviews and focused discussion groups.

Literature Review

The first stage of the study was conducted through a literature review following the steps proposed by Templier and Paré (2015) to determine the pearl oyster and sponge species that are suitable for mariculture in SVG (research question 1) and to identify specific areas in SVG that could

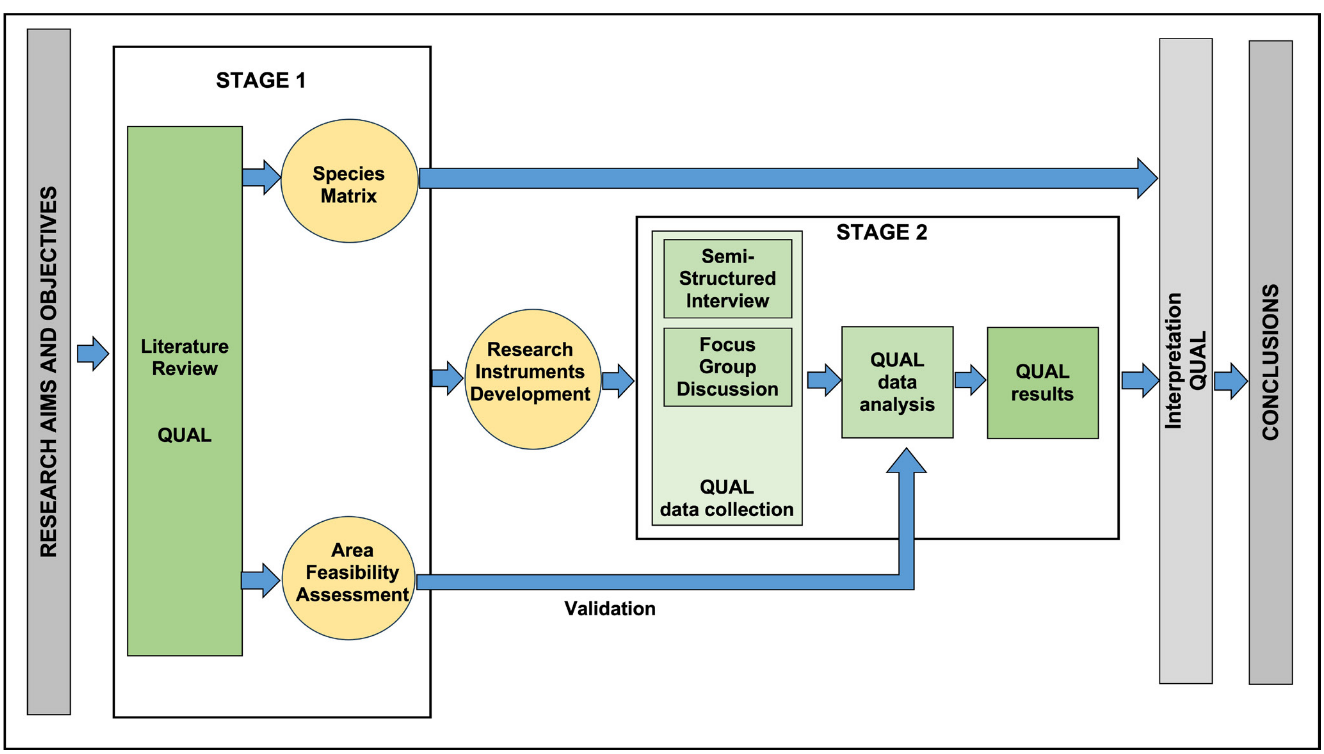


Figure 1. *General overview of the methodological framework of the study. QUAL—qualitative*

sustain its farming (research question 2). The literature only included articles that were published between the years of 1990 and 2024. The literature search was conducted from 06 April 2023 to 26 May 2024, through websites hosted by government organizations, non—governmental organizations (NGOs), inter—governmental organizations (INGOs), and Google Scholar, using pre—identified keywords “pearl oysters biology”, “sponges biology”, “pearl oysters mariculture”, “sponges mariculture”, “Saint Vincent and the Grenadines”, “Blue Economy in Saint Vincent and the Grenadines”. The criteria for inclusion were peer—reviewed articles or publications from official websites that are related to pearl oyster and sponge cultivation, and Blue Economy or mariculture in SVG; and written in the English language. Publications that did not fall within the criteria were not considered in the study.

The initial Stage 1 search yielded a total of 109 literature citations. These publications were screened based on predefined inclusion criteria. Specifically, abstracts from peer—reviewed journal articles and content from official websites were reviewed to determine their relevance to the topic for subsequent analysis. Following this process, 78 publications were excluded, resulting in a final selection of 31 publications for further analysis. These 31 publications were extracted and analyzed to establish the biological information about different pearl oyster and sponge species, including the environmental conditions necessary for the survival and culturing of the organisms.

There were only limited sources found regarding the different environmental conditions of different islands in the SVG. Of the 24 publications in the initial literature search, only 9 sources were found to be reliable and related to the study. Data were then extracted and analyzed to compare the different environmental conditions of SVG islands with the environmental requirements of the sponge and pearl oyster species. Characteristics considered in selecting the most suitable area for sponge and pearl oyster mariculture included the transportation availability, the competing usage from tourism and fishing, development costs, and other environmental consideration including water depth, currents, and shelters.

Overall, the literature review resulted in the contextualization of information regarding the pearl oysters and sponges as well as the understanding of suitable areas of its cultivation. This information is presented in species matrices and the proposed area in SVG for its cultivation in the results section. All results of Stage 1 informed the development of the semi—structured interview questions used in Stage 2 of the study.

Semi—Structured Interview and Focus Group Discussion

Semi—structured interviews were conducted online from 1 June to 8 July 2023, and face—to—face focus group discussions from 13–15 November 2023. Purposive sampling was employed to gather rich insights (Palinkas et al. 2015) from stakeholders with expertise in Blue Economy management in SVG and the people who will possibly be affected by the potential Blue Economy expansion. The aim was to determine and analyze their perception regarding Blue Economy and the viability of sponge and pearl oysters in SVG (research question 3), determine the possible effect on local fisherfolk and coastal communities (research question 4), and validate findings from the area feasibility assessment in Stage 1.

There were 29 stakeholders who participated in the study: 5 in semi—structured interviews and 24 in the focus group discussion. Semi—structured interviews were individually conducted with the SVG national ministries and relevant NGOs. The questions focused on their perceptions of SVG’s Blue Economy, with specific questions on possible pearl oyster and sponge mariculture, social, environmental, and economic perspectives, and regulatory framework. Moreover, the responses of stakeholders from the governmental organizations and NGOs were used to validate the result of the literature review to determine the most suitable location in SVG for mariculture use.

Four focus group discussions were conducted, involving 6 fishermen and 18 other residents of Union Island, SVG, to gather their perceptions about pearl oyster and sponge farming on the island. The stakeholders were asked about the activities that they do at sea and other livelihoods, their regular income, their perceptions about mariculture, and their views about the possible sponge and pearl oyster farming in SVG. The profile information of stakeholders can be accessed in Supplemental Table S1 to support the credibility of the interviews and focus group discussions. Codes were assigned to the stakeholders to maintain the confidentiality of their identities. Interviews and group discussion methodologies were approved by the university’s Research Ethics Committee before data collection. When gathering data, the researcher obtained informed consent from individuals who participated in the study.

Both the interview and focus group discussions were recorded through Zoom application, transcribed using Otter.ai and then analyzed using NVivo software (Release 1.7.1). An inductive thematic analysis was applied where no preconceived themes were used throughout the analysis (Braun and Clarke 2006). A 6—phase approach to thematic analysis outlined by Braun and Clarke (2006) was adopted in the study, comprising familiarization with the data, generating initial codes, searching for themes, reviewing potential themes, defining and naming themes, and producing the report.

First, all transcripts were uploaded into NVivo software and systematically annotated to gain familiarity and identify elements pertinent to research questions 2, 3 and 4. Following this initial review, the transcripts were coded using a hierarchical structure of parent and child nodes. Phrases were coded multiple times as needed, depending on their contextual relevance to the research questions. Subsequently, the codes were reviewed to detect and address any overlaps or redundancies, leading to the clustering of related codes to facilitate theme identification.

The potential themes identified were reviewed for their relevance to the codes and the research questions. This iterative process resulted in the identification of four overarching themes, which are detailed in the results section. Each theme is supported by corresponding sub—themes derived from the clustered codes. The findings from this thematic analysis are visually represented via a mind map using Xmind software application.

Results and Discussion

Literature Review and Application of that Knowledge

Marine Pearl Oysters

In general, cultured pearl farming involves 7 major steps: farm selection, oyster selection, nucleus implantation, nurturing, harvesting, pearl processing, and pearl marketing (Cartier et al. 2012, Haws 2002, Zhu et al. 2019). After around 2 years of maturation, young pearl oysters undergo grafting, which kicks off the nurturing of a pearl. Following a 40—day inspection, pearl oysters remain on the farm for 12 to 24 months before harvesting (Haws 2002).

There are several environmental factors that affect the growth and quality of oyster pearls, which include water temperature, depth, salinity, pollution, currents, and spawning season. Temperature thresholds differ between species and are the primary factor affecting species distribution. The tolerance range across commercially viable species is 18–32°C, which varies across each type of pearl oyster. Cold water can inhibit growth, reproductive development, and increase susceptibility to illness (Gervis and Sims 1992). Salinity tolerance ranges from 28–35 (Gervis and Sims 1992), but rapid changes in salinity can harm pearl oysters (Haws 2002). The depth of the water is crucial during the nurturing phase impacting mortality, quality, color, and growth of pearl oysters (Gervis and Sims 1992). It is suggested that pearl oysters have to be placed in a calm area of the ocean 2—3 m deep after nucleus implantation (Wang et al. 1993 as cited in Zhu et al. 2019). Clear, unpolluted waters are preferred, as contamination from sewage, oil, chemicals, and other types of pollutants is detrimental (Haws 2002). Currents also play a role; weak currents are generally favored (Haws 2002), although some species such as *Pinctada maxima* and *Pinctada margaritifera galtsoffi* prefer strong currents (Gervis and Sims 1992). Moreover, spawning is influenced by temperature extremes or abrupt changes in the environment (Gervis and Sims 1992), with pearl oysters typically spawning in warmer water (Haws 2002). In addition, every species has different spawning seasons (Gervis and Sims 1992).

The environmental requirements of 4 commercial marine pearl oysters, *Pinctada imbricata, Pinctada fucata/martensii, Pinctada maxima,* and *Pinctada. margaritifera* are shown in Table 1. This study did not assess commercial species other than the aforementioned ones due to a lack of credible and complete data in the existing literature.

Pinctada imbricata, commonly used for various purposes, is found in the Western Atlantic region, including the Caribbean region and Gulf of Mexico (GOM) (OBIS 2021a, SeaLifeBase 2023a). *Pinctada fucata/martensii*, employed in commercial pearl production, is typically harvested from the Western Atlantic region (Caribbean region, GOM), Western Pacific Ocean (Korea, Japan, southern China, and Australia), and the Indian Ocean, including the Red Sea and Persian Gulf (SeaLifeBase 2023b). *Pinctada maxima*, the largest and most valuable, is prevalent in Indonesia, Northern Australia, the Philippines, Malaysia, and Myanmar (SeaLifeBase 2023c). Lastly, *Pinctada margaritifera*, the second—largest pearl oyster producing black pearls, is found in the Indo—Pacific region, ranging from Mexico to Tanzania and the Red Sea to French Polynesia (SeaLifeBase 2023d, OBIS 2023b).

All species fall within the sea surface temperature range of 17.9—33°C. Except for *P. fucata/martensii*, the 3 other species can be farmed <1 m below the seawater surface. Regarding tolerance of depth, all subjects can be farmed within 3—20 m,

TABLE 1. *A list of the main commercial oysters for marine and round pearl cultivation, their environmental tolerance, and the source of the information. *indicates preferred species for cultivation in St. Vincent and the Grenadines.*

Scientific Name/ Commercial Name	Water Temperature (°C)	Depth Interval (m)	Growth Duration (months)	Diameter (cm)	Salinity	Source
*Pinctada imbricata**	20.5–29.1	0–23	–	7.7–8.8	–	SeaLifeBase 2023a
(Atlantic Pearl Oyster)	20–30	0–30	–	–	30–35	OBIS 2021a
	–	–	12–24	–	–	Haws 2002
Pinctada fucata/martensii	17.9–28.9	3–46	–	8	–	SeaLifeBase 2023b
(Akoya pearl oyster	20–30	20–40	–	–	30–35	OBIS 2017
or Japanese pearl oyster)	–	–	12–24	–	–	Haws 2002
Pinctada maxima	24.4–29.1	0–60	–	20–30	–	SeaLifeBase 2023c
(the gold or silver–	20–30	20–30	–	–	30–35	OBIS 2023a
lip pearl oyster)	–	–	12–24	–	–	Haws 2002
Pinctada margaritifera	26–33	0–20	–	9.8	–	SeaLifeBase 2023d,
(black–lip pearl oyster)						OBIS 2023b
	20.30	0–30	–	–	30–35	OBIS 2023b
	–	–	12–24	–	–	Haws 2002

TABLE 2. *List of main commercial sponges, their environmental tolerance, and the source of information. *indicates preferred species for cultivation in St. Vincent and the Grenadines.*

Scientific Name/ Commercial Name	Water Temperature (°C)	Depth Range (m)	Harvest Time (months)	Diameter (cm)	Salinity	Source
Hippospongia communis	15.2–21.6	5–80	–	30	–	SeaLifeBase 2023e
(Horse Sponge,	15–25	–	–	–	30–35	OBIS 2014
Honeycomb)	–	–	1.5–3	–	–	Ellis et al. 2008
Hippospongia gossypina	26.1–28.3	14–15	–	–	–	SeaLifeBase 2023e
(Velvet)	25–30	0–20	–	–	30–35	OBIS 2023c
	–	–	1.5–3	–	–	Ellis et al. 2008
*Hippospongia lachne**	–	2–10	–	30	–	FAO 1990
(Wool, Sheepswool)	26.3–28.1	5–15	–	28.7	–	SeaLifeBase 2023f
	–	–	–	–	30–35	OBIS 2023d
	–	–	1.5–3	–	–	Ellis et al. 2008
Spongia agaricina	14.3–21.6	5–60	–	50	–	FAO 1990
(Elephant ear)	–	4–60	–	100max	–	SeaLifeBase 2023g
	15–20	–	–	–	30–35	OBIS 2023e
	–	–	1.5–3	–	–	Ellis et al. 2008
Spongia barbara	–	2–15	–	25	–	FAO 1990
(Yellow sponge)	–	7–45	–	–	–	SeaLifeBase 2023h
	25–30	1–10 & 40–50	–	–	30–35	OBIS 2023f
	–	–	1.5–3	–	–	Ellis et al. 2008
Spongia graminea	–	2–5	–	12–25	–	FAO 1990
(Glove, glass)	–	1–20	–	–	–	SeaLifeBase 2023i
	20–30	–	–	–	30–35	OBIS 2023g
	–	–	1.5–3	–	–	Ellis et al. 2008
Spongia officinalis adriatica	–	0.5–40	–	35	–	FAO 1990
	15–30	0–50	–	–	30–35	OBIS 2021b
(Bathing sponge) (Other name:	–	1–100	–	–	–	Pronzato and Manconi 2008
Spongia officinalis Linnaeus, 1759)	–	–	1.5–3	–	–	Ellis et al. 2008
Spongia officinalis mollissima	15–25	10–30	–	15–20	–	FAO 1990
(Turkey solid)	15–25	0–10 & 40–50	–	–	30–35	OBIS 2019
	–	–	1.5–3	–	–	Ellis et al. 2008

however, *P. maxima* can be farmed in water depth up to 60 m. All species have a similar growth duration of 12–24 months.

The environmental requirements of the 4 pearl oysters evaluated in this study were cross–referenced with the environmental conditions of the identified islands in SVG based on existing literature. The analysis showed that the area feasibility assessment of environmental conditions in SVG meet all the necessary conditions required for the successful cultivation of all the aforementioned pearl oyster species. The pearl oyster species *P. imbricata* was identified as endemic to SVG and the Caribbean region (SeaLifeBase 2023a, OBIS 2021a). In addition, to avoid out–competing natural species, the use of a naturally occurring species rather than introduce an invasive one is necessary since invasive species possess the capacity to induce extinctions of indigenous flora and fauna, diminish biodiversity, engage in competition with native creatures for finite resources, and modify environments (National Oceanic and Atmospheric Administration (NOAA) 2023). Due to these reasons, one species (*P. imbricata)* was identified from the 4 as the most ideal species for pearl oyster cultivation in SVG.

Sponges

The wellbeing of sponges is influenced by temperature, salinity, light, oxygen, food availability, depth, and water currents. They grow slower in cold temperatures and are more resilient in warmer temperatures (Makoye 2023). Low salinities disrupts their water content balance (Osinga et al. 1999 as cited in Friday 2011). Light benefits sponges with photosynthetic endosymbionts (Yi et al. 2005), and sufficient dissolved oxygen is essential for their productivity (Dobson 2003, Yi et al. 2005). Food availability affects sponge growth as they filter the nutrients from water (Yi et al. 2005; Schippers et al. 2012). A minimum depth of 1.52 m protects them from sun exposure and damage (Friday 2011). Water currents regulate feeding, reproduction, and gas exchange (Wu 1995 as cited in Yi et al. 2005).

Eight main commercial sponges and their ecosystem requirements for optimal survival were found in the literature, as presented in Table 2. *Hippospongia communis* is typically found in the Mediterranean (FAO 1990) and the Eastern Central Atlantic (SeaLifeBase 2023e). *Hippospongia gossypina* is commonly harvested in the Western Central Atlantic, including the USA, Belize, and Honduras (SeaLifeBase 2023f). *Hippospongia lachne* is typically caught in the GOM and the Caribbean region (FAO 1990). *Spongia agaricina* is commonly harvested in the Northeast Atlantic and the Mediterranean (SeaLifeBase 2023g), and *Spongia barbara* is found in the Florida Keys (FAO 1990) and the Western Central Atlantic, ranging from Belize south to Panama, north to the Bahamas, and east to the British Virgin Islands (SeaLifeBase 2023h). *Spongia graminea* is harvested in the GOM, the Caribbean region (FAO, 1990), and the Western Central Atlantic, including the USA, Cuba, and Honduras (SeaLifeBase, 2023i). *Spongia officinalis adriatica* is found in the Mediterranean, specifically in Greek Waters (FAO 1990). Lastly, *S. officinalis mollissima* is typically harvested in the Mediterranean (FAO 1990, OBIS 2019). All the species are used as bath sponge (FAO 1990, SeaLifeBase 2023e) except for *S. agaricina* which is used for decoration and as a polisher (FAO 1990).

Most of the commercial sponges can be found in the Mediterranean, Caribbean region, and GOM. Their temperature range is 14.3—30°C. The literature outlines varying depth tolerance for the assessed species of sponges. For instance, for *H. communis,* a range of 0.5—30 m was observed in FAO (1990) while SeaLifeBase (2023e) gave a range of 5—80 m. The diameter of the sponges varies in a range of 12—100 cm. Most are within the range of 25—30 cm, while *S. officinalis mollissima* and *S. graminea* are 15—20 cm and 12—25 cm respectively, and *S. agaricina* with a diameter range of 50—100 cm. All species can comfortably survive a salinity range of 30—35.

Of the 8 sponge species that were evaluated in this study, 3 species demonstrated potential suitability for mariculture farming in SVG. Literature indicated that both *H. gossypina* and *S. barbara* require a minimum temperature of 25°C, which falls below the minimum average sea surface temperature of SVG by 1.3 °C. They both require a maximum of 30°C, which is within the scope of the average sea surface temperature of SVG. They are found particularly in the Caribbean region and GOM, areas that are known to have similar environmental conditions to SVG. However, the minimum required temperature for *H. lachne* is 26.3 °C, which is the closest to the minimum average sea surface temperature of SVG (27.2°C) of all the assessed species. The maximum temperature for *H. lachne* is 28.1°C, which falls below the maximum sea surface temperature of SVG (29°C). Additionally, *H. lachne* is identified as endemic to SVG and Grenada. This makes it a priority as opposed to introducing an invasive species that may out—compete natural sponge species found in SVG. Notably, the literature also highlights the flexibility of lowering sponge lines into deeper water during warmer months or adverse weather conditions to achieve cooler temperatures and provide protection (Friday 2011).

Potential Locations for Mariculture

The literature review revealed that there has never been any form of oyster pearl or sponge farming assessment or cultivation in St. Vincent and the Grenadines. Notably, there is no available information on potential locations for this form of mariculture. As a result, based on the environmental requirements for both groups of sponges and oyster pearl species 4 possible locations were initially identified (Figure

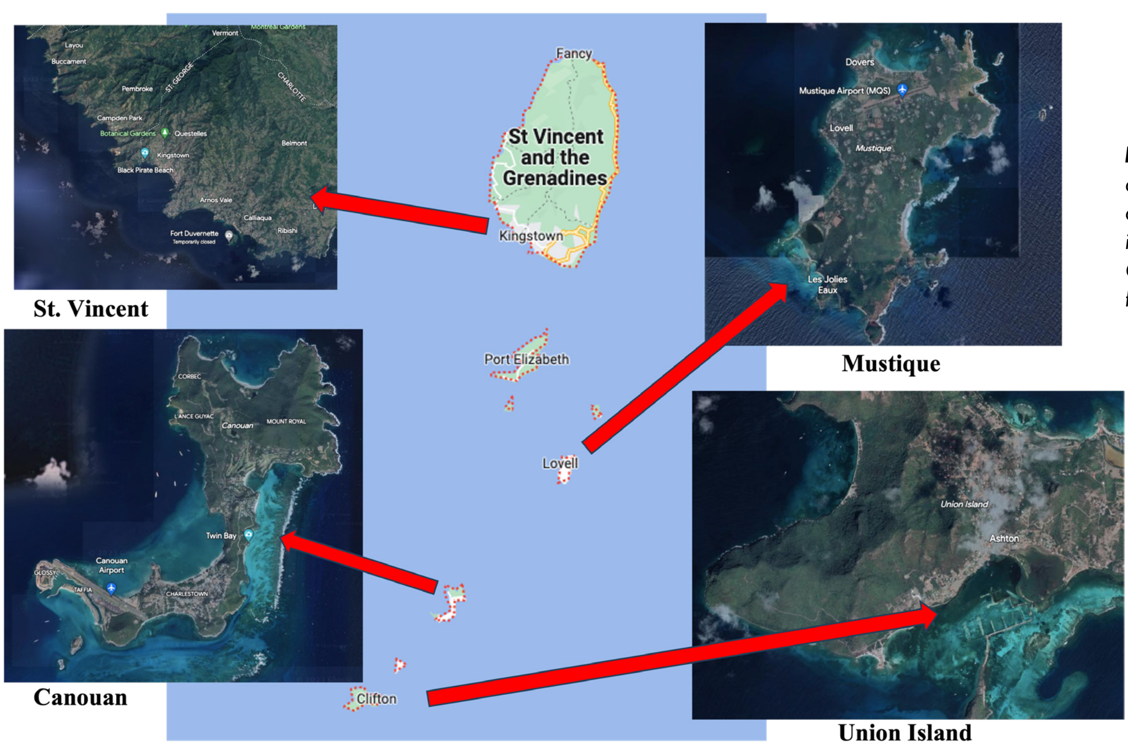


Figure 2. *Four locations assessed for pearl oyster and sponge mariculture in St. Vincent and the Grenadines. Photos are from Google Earth, 2023.*

2): St. Vincent, Mustique, Canouan, and Union Island. The environmental conditions of the islands were determined from the literature, such as the population densities (Statistical Office 2022), area usage (St. Vincent and the Grenadines Tourism Authority (SVGTA) 2022), salinity (National Aeronautics and Space Administration (NASA 2015), temperature (SeaTemperature 2023), currents, depth, shelter from hurricanes and storms, and security against theft (Howell et al. 2019). This information was then compared with the environmental requirements of both the sponges and pearl oyster farming as outlined in Tables 1 and 2 and validated through stakeholders' interviews.

All stakeholders agreed on the 4 identified possible locations, expressing concerns about other coastal areas nationwide due to high activity levels, limited mariculture space, vulnerability to looting, and hurricane–related damage. All suggested locations have similar temperature ranges from 27.2–29°C (SeaTemperature 2023) and salinity of 30–35 (NASA 2015).

Figure 3. *The Ashton Lagoon site at Union Island identified as most feasible for mariculture. From Google Earth, 2023.*

St. Vincent, which is the mainland of SVG, has 90.72% of the total 110,784 population of SVG as of 2021 living on the mainland where most of the population is concentrated along its coastal areas (Statistical Office 2021). Mustique Island is a private island with 1% of the total SVG population (Statistical Office 2022). Although the entire island is a conservation area, surrounded by pristine white beaches, and has the lowest population in SVG, this island has significant coastal activities such as mooring of yachts and beachgoers (SVGTA 2022). In addition, Mustique is the second largest employer in SVG after the government of St. Vincent (GoBeach 2024). and the island is exposed to strong winds and currents (Howell et al. 2019).

Canouan Island is another small island in SVG, measuring 1,251 km^2 (SVGTA 2022) which is surrounded by white beaches and untouched nature, with 1.5% of SVG's total population (Statistical Office 2022). One side of the island is covered with a coral reef in shallow water for over a mile while the other side caters to high yacht traffic (SVGTA 2022). In addition, strong winds and currents are also present around the island and there are few sheltered sites suitable for mariculture (Howell et al. 2019).

Union Island is in the southernmost part of the Grenadines and has a surface area of 9 km^2, with 1.9% of SVG's total population (Statistical Office 2022). Despite having beaches, it is designated as a Marine Protected Area (MPA) (Kentish 2022), with some areas sheltered from storms, strong currents, and wave action. The island supports various transportation modes for passengers and goods. In 1994, a foreign investor initiated a hotel, marina, and golf course within the MPA and Ashton Lagoon, but structural failure led to tidal obstruction, increased mangrove mortality, and water contamination. The once biodiverse lagoon became a mosquito–breeding site. Following the bankruptcy of the Valdetaro Construction Company, local conservation efforts led by SusGren have successfully rehabilitated Ashton Lagoon, with mangrove survival rates now exceeding 90% (Kentish 2022).

Union Island emerged as a potential site that needs further exploration. Union Island has an MPA, sheltered areas, and diverse transportation options. The rehabilitated Ashton Lagoon (part of Union Island) provides protection from heavy weather conditions and structural support for aquaculture through the still–standing foundational pillars from the past development project, dating back to 1995 (Kentish 2022). Figure 3 depicts the identified 204,030.56 m^2 area in Union Island where the parallel pillars from the failed development project can be observed. The site aligns with literature promoting low–impact cultivation in protected areas, offering essential structural support and cost savings for sponge and pearl oyster cultivation, with the pillars serving as anchorage points for farming lines in the sheltered lagoon, effectively mitigating weather–related risks.

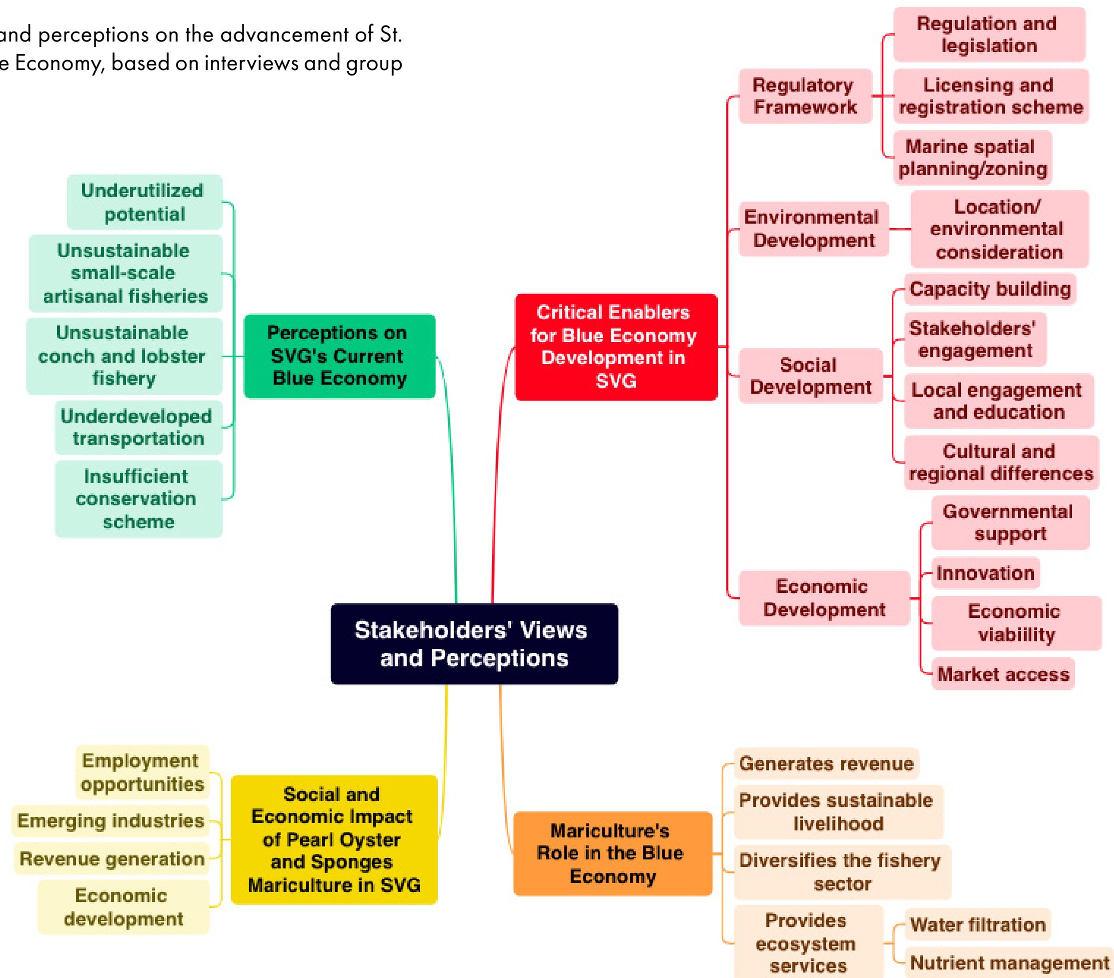
Interviews and Focus Group Discussions

Figure 4 illustrates the overall results of the interviews and the focus group discussions about the stakeholders' views and perceptions of Blue Economy. Four overarching themes emerged in the thematic analysis which include: 1) Perceptions on SVG's current Blue Economy, 2) Critical enablers for Blue Economy Development in SVG, 3) Social and economic impact of pearl oyster and sponge mariculture in SVG, and 4) Mariculture's role in the Blue Economy.

Stakeholder Views and Perceptions on SVG's Current Blue Economy

All stakeholders emphasized the SVG's underutilized Blue Economy. Aside from small–scale artisanal fisheries, conch and lobster aquaculture, and marine tourism, there is potential

Figure 4. Stakeholders' views and perceptions on the advancement of St. Vincent and the Grenadines' Blue Economy, based on interviews and group discussions.



in areas that could be explored such as oil, gas, and minerals in the seabed. However, concerns were raised about the sustainability of large—scale conch and lobster industries due to increased fishing efforts to attain the same amount of catch. During the focus group discussion, stakeholder FF3 mentioned *"We have to go further than normal to get conch these days."* Nevertheless, stakeholders NGO2 and FA1 expressed that there is potential for mariculture development including sea moss, sponges, sea cucumbers, and pearl oysters. Meanwhile, underdeveloped transportation infrastructure in SVG was highlighted by 100% of stakeholders from governmental organizations and NGOs (n = 5), advocating faster and more efficient inter—island boats to sustain Blue Economy promotion in the country. The stakeholders from the local community did not raise this as a concern. However, they noted awareness of the MPA implemented in the SVG islands although they highlighted challenges in monitoring and management of current MPAs resource and scientific capacity limitations. Stakeholder FA2 explained that *"...there is the Caribbean challenge initiative...I think MPA was supposed to be originally 20% by 2020 and I think [it was adjusted to] 20% by 2030"* while stakeholder FA1 shared that *"... the National Parks, Rivers, and Beaches Authority would have had the national parks and protected areas system plan. I think they're currently reviewing it this year trying to update it"* Further exemplary quotes supporting the results can be viewed in Table S2.

Stakeholder views on critical enablers for Blue Economy development in SVG

Stakeholders and NGO's from the governmental organizations emphasized the necessity of a regulatory framework and holistic environmental, social, and economic strategies. Stakeholders NGO2 and FA2 specifically stressed the importance of regulations, licensing schemes, and marine spatial planning and zoning. Stakeholder NGO2 shared *"Number one would be the zoning of that. So, coming up with a zoning scheme that allows and sets aside space to allow for it [sustainable mariculture]."* However, the lack of specific legislation, registration schemes for mariculture farmers in SVG, technical capacity, infrastructure and funds were identified by stakeholders FA1, NGO1 and NGO2. For instance, stakeholder FA1 mentioned *"We currently don't have legislation... and also, at least some sort of zoning and plan for best areas that could sustain mariculture moving forward."*

In addition, stakeholders FA1, FA2, and NGO1 noted that balancing entrepreneurship with environmental conservation is deemed crucial for environmental sustainability. Social development, including capacity building, stakeholder engagement, education, and recognition of cultural and regional recognition, was highlighted to foster public trust and support local mariculture. Stakeholder NGO1 highlighted the importance of having the right stakeholder and human capacity— "*So, I think Blue Economy also has to do with having the right stakeholder involved and the human capacity to really propel it.*" Moreover, the involvement of youth and integration of local knowledge were emphasized, alongside governmental support, innovation, economic viability, and market access, as key factors for mariculture in SVG. Other exemplary quotes for this overarching theme can be seen in Table S3.

Stakeholder views on social and economic impact of pearl oyster and sponge mariculture in SVG

All stakeholders expressed that pearl oysters and sponge mariculture in SVG will create employment opportunities, new industries, and generate additional income for fisherfolk and other residents, while fostering overall economic growth within the Blue Economy expansion. Notably, when asked about the possible pearl oyster and sponge mariculture in SVG, particularly in Union Island, stakeholder NP1 mentioned that *"It's something that we should definitely look at, personally, growing up and being on an island and knowing what sea moss farming has done for a lot of livelihoods, especially for families, single parent families, female and households, and those things are important. So, I think there's a huge potential for it.".* Further, stakeholder FA1 stressed that *"... the benefits far outweigh the cons... it will literally develop a new industry for the nation... even on a tourism base...".* Moreover, stakeholder NP1 stated, *"I personally believe that mariculture as a whole can play an important role for the economic growth and development in SVG and also for food security."*

Stakeholders viewed pearl oyster and sponge mariculture as a pathway to sustainable livelihoods, particularly for local communities. They stressed the importance of skill acquisition through certified diver training and recognized the benefits of job opportunities, skills training, and financial returns for locals. Other illustrative quotes can be viewed in Table S4. Similarly, examples from Zanzibar, Tanzania (Msuya 2013, Makoye 2023), and French Polynesia (Johnston et al. 2019) showcased economic gains and employment opportunities in seaweed and sponge farming and the cultured pearl sector. The stakeholders envisioned these new industries contributing to economic development, revenue generation, and the emergence of related sectors such as marine tourism, fisheries and aquaculture advancement, renewable energy, marine biotechnology, and enhanced marine conservation and research.

Stakeholders Views on mariculture's role in the Blue Economy

The respondents indicated that mariculture generates revenue, diversifies the fishery sector, provides sustainable livelihood, and provides ecosystem services, underscoring its diverse role in the Blue Economy. For instance, stakeholder NP1 explained that mariculture can produce new industries, *"You're opening locals to a whole new avenue of revenue earnings in terms of the Blue Economy and not just only fishing, tourists, tours ..."* and generates revenue in the country "*The cultivation of aquatic animals and plants in a natural control environment, specifically marine environment, I believe that this would help to increase revenue generation in SVG ...*" Fishermen and other locals also supported this idea. Specifically, stakeholder OL7 mentioned "*More money can come into the country with this idea*" and stakeholder FF5 stated that "*It would give our family additional income ... So, I'd be glad if this idea would come into reality ...*"

When asked about the potential mariculture of sponges and pearl oysters in SVG, stakeholders stressed that it diversifies the fishery sector. Stakeholder NP1 specifically responded "*... it also helps with the diversification of the fishery sector in St. Vincent and the Grenadines*". In addition, this stakeholder compared it with the benefits of sea moss farming in SVG, especially to single parent households, as it provides sustainable livelihood. Moreover, stakeholders FA2 and FA1 stressed that mariculture provides ecosystem services such as water filtration and nutrient management.

Perceptions of the Emerging Blue Economy and Mariculture Potential in SVG

Stakeholders involved in the study perceived that there is much potential in SVG's Blue Economy expansion, particularly in sectors like fishing, transportation, renewable energy, mariculture and marine tourism, which is aligned with Howell et al.'s (2019) findings. However, the Blue Economy in SVG suffers from inadequate management, poor zoning, lack of workforce availability, technical skills, and funds. Challenges in marine transportation were also highlighted, emphasizing the need for improvements to support the nation's Blue Economy. The insufficiency of environmental conservation schemes was identified as a primary factor contributing to inadequate monitoring and administration of existing MPAs.

Despite these drawbacks, the underutilized potential of SVG's Blue Economy aligns with existing literature in the Caribbean region, indicating room for its further expansion (Department of Maritime Administration (DMA) 2013, Howell et al. 2019, Oxenford and McConney 2020). Mariculture, recognized for its social, environmental, and economic contributions, was viewed as a revenue generator, provider of sustainable livelihoods, and contributor to ecosystem services. All stakeholders in the study acknowledged the growth potential of mariculture in SVG, consistent with the perspectives of Phillips (2009), the World Bank (2016), and FAO (2022).

The multifaceted contributions of pearl oyster and sponge mariculture underscore their potential as drivers of economic, social, and environmental wellbeing in SVG. Environmental benefits of pearl oyster and sponge farming were highlighted, offering an alternative to fishing, reducing pressure on natural resources, and contributing to climate change mitigation through carbon cycle control and greenhouse gas reduction (Makoye 2023). Pearl oyster and sponge farming in an MPA zone of Union Island appears to pose no adverse environmental effect. For instance, the small—scale pearl farming near Pakin Island in Micronesia, which is an MPA, promotes the well—being of the ecosystem by protecting local fish stock as fry thrive around pearl oyster environments, bioremediation of contaminated coastal environments as a result of sponges' high filtration rates and the propensity to absorb heavy metal contaminants (including nutrients) and bacteria (Gervis and

Sims 1992, Zhu et al. 2019). Notably, this notion aligns with the principles of marine conservation (Brodbeck 2010 as cited in Cartier et al. 2012). Additionally, no evidence of adverse effects on the environment, animals, or human well—being were seen in Zanzibar Tanzania from the coexistence of oyster and sponge farming (Oakland 2013).

However, as revealed in the study, pearl oyster and sponge farming in SVG needs a lot of consideration. Aside from environmental conditions identified in the study, the establishment of a regulatory framework for mariculture in SVG is necessary. The government plays a crucial role in the success of mariculture within the country. In addition, although the stakeholders showed awareness about the activities that can be done within the MPA zone, the education and continued engagement by the government sector and the relevant non—governmental organizations with the fisherfolks and other locals are necessary for the expansion of the Blue Economy in SVG.

The best practices of other Small Island Developing States (SIDS) related to the development of the Blue Economy were analyzed to determine which may be taken into consideration for adoption by SVG. The Public—Private Partnership (PPP) has been recognized as key enabler for the Blue Economy expansion. Collaboration among governments, intergovernmental organizations, academic institutions, civil society and other entities was found to be effective in technology and funds mobilization, thereby driving solutions to Blue Economy development issues (Manikarachchi 2022).

To safeguard its maritime resources and foster economic development, Seychelles, a Pacific SIDS, has placed a high priority on sustainable fisheries management and marine conservation (Clifton et al. 2012). The nation has put laws into place to stop illicit fishing, create marine protected zones, and advance environmentally friendly travel (FAO 2019). The idea of "debt—for—nature swaps," in which foreign debt is swapped for pledges to support marine conservation, was also used by Seychelles in 2015, allowing the nation to fund sustainable development and marine protection initiatives (Benzaken et al. 2024). Mauritius has diversified its Blue Economy through investments in offshore aquaculture, marine biotechnology, and ocean—based renewable energy, notably wave energy (Srinivasan et al. 2022). These efforts have expanded economic prospects while encouraging long—term development. Mauritius also prioritized capacity building and skills development in the maritime industry, preparing a competent workforce to support the expansion of its Blue Economy industries (Srinivasan et al. 2022). Finally, the blue ocean diplomacy in both Seychelles and Mauritius has been significant for advancing their Blue Economy initiatives (Hisyam et al. 2022).

Among other Caribbean SIDS, Barbados has prioritized sustainable coastal and marine management, which includes coral reef protection, marine spatial planning, and sustainable fishing methods. The country has also invested in maritime research and monitoring to help with decision—making and conservation initiatives. Barbados has pushed sustainable tourism projects, such as marine eco—tours and dive tourism, to create revenue while reducing environmental damage and assisting local people (Phang et al. 2023). The importance of a sustainable Blue Economy as a crucial component in building a climate—resilient economy is highly recognized by the Government of Barbados (UNDP 2020).

These examples show how SIDS can maximize their Blue Economy by balancing economic growth and environmental sustainability, encouraging responsible management of marine resources, and investing in creative solutions for sustainable development. SIDS may maximize the potential of their Blue Economy while protecting maritime ecosystems for future generations by focusing on conservation, sustainable practices, and community engagement.

However, it should be recognized that there are threats to developing a sustainable Blue Economy. These threats encompass space competition, population growth, changing political cycles, climate change, and global market dynamics. Nevertheless, coordinated and innovative actions are essential to addressing such threats within SIDS, specifically in the Caribbean nations (Phang et al. 2023). Notably, many SIDS have large exclusive economic zones (EEZs) that are far vaster than their land cover. This benefit allows them to engage in harnessing diverse ocean services ranging from a wide array of marine life, fishing, aquaculture, tourism, oil and gas mining, and shipping (Phang et al. 2023).

Effect of Pearl Oyster Cultivation and Sponge Farming on Local Fisherfolk and Coastal Stakeholders

Notably, for the sector of marine tourism, implementing pearl oyster and sponge mariculture in SVG could stimulate and enhance visitor experiences, support local economies and promote conservation efforts in the coastal areas. Like the strategies of Barbados in promoting marine tourism (Phang et al. 2023), SVG can provide one—of—a—kind experiences for travelers who are enthusiastic about sustainable tourism and marine life. Touring farms, learning about the growing process, and even partaking in close—up activities like diving or snorkeling may entice visitors. Additionally, tourists can be provided with educational opportunities to learn about the value of sustainable practices, the function these animals play in the ecosystem, and the importance of marine conservation. This may result in a greater understanding and admiration of maritime habitats and can encourage visitors to support businesses that prioritize sustainability and environmental protection. Furthermore, sponge and pearl oyster farming can contribute to the local economy as it creates job opportunities and new small businesses such as souvenir shops and restaurants. This can help support sustainable livelihoods for communities in coastal areas.

Other related industries like fisheries, aquaculture, renewable energy, and marine conservation, can also benefit and be developed sustainably. Overall, promoting mariculture is seen as enhancing economic growth and coastal community well—being, contingent upon robust business strategies and effective operational and marketing plans. This aligns with findings in Cuba, where sponge farming played a significant role in sustainable fishery alternatives, job creation, and community revenue (Betanzos—Vega et al. 2019).

Moreover, stakeholder participation is crucial for sustainable management. It involves informing and involving stakeholders in decision—making processes for reciprocal economic, environmental, and social benefits (FAO 2014). In environmental and development sectors, engaging local stakeholders is vital for democratic and equitable objectives, addressing marginalization, enhancing trust, acknowledging diverse values, and fostering social learning (Reed 2008, Fritsch and Newig 2012, Young et al. 2013a, and Birnbaum et al. 2015 as cited in Sterling et al. 2017). Capacity building is essential for the sustainable sponge and pearl oyster farming in SVG as aligned with the practice of Mauritius (Srinivasan et al. 2022).

Conclusion

While there is strong support from the stakeholders in SVG for pearl oyster and sponge farming in the country, challenges such as technical expertise, startup capital, lack of regulation and legislation, and long—term commitment exist within the Caribbean Island nation. Nevertheless, national, regional, and international collaborations, innovative financing, capacity building, and investment in maritime research have been the key to Blue Economy development in other SIDS like Barbados, Mauritius, and Seychelles. By embracing these proven strategies and focusing on the critical success factors identified such as meticulous planning, stakeholder collaboration, establishment of legal frameworks, and ecosystem—based management, the pearl oyster and sponge mariculture in SVG could potentially help the expansion of the country's Blue Economy. Furthermore, the conducive environmental parameters identified in the research are essential for the successful expansion of this industry.

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