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Looking Back Before Moving Forward: Learning From History to Develop Aquaculture and Mariculture in Barbados

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Abstract

To meet local demands, Barbados currently imports much more fish and fish products than it produces. In recent years this disparity has worsened by the significant reduction in catches of flyingfish and dolphinfish resulting from the mass influxes of *Sargassum* spp. into traditional fishing grounds. Against this background, the Barbados Fisheries Policy (BFP) 2023-2033 requires Government to support the contribution of sustainable aquaculture to economic growth, food security and income diversification. At this juncture, it is prudent to critically review and assess the island's past aquaculture and mariculture ventures with the objective of discerning any lessons learnt and applying these to the formulation of sound policies and plans for the development and management of viable and sustainable aquaculture and mariculture in Barbados. This is the main objective of this paper.

Scarcity of available land and water resources significantly limits opportunities for large-scale, land-based aquaculture ventures in Barbados. As such, the island's few commercial-scale ventures have necessarily utilized Recirculating Aquaculture Systems (RAS). However, most of these businesses have not been sustainably profitable for various reasons, with most not progressing beyond the pilot-phase. Small-scale "backyard" ventures often rearing primarily Tilapia in small tanks as well as in aquaponics arrays, have emerged as the predominant forms of aquaculture on the island. Options for mariculture are also constrained by the island's densely populated land area and limited and crowded coastline. It is emphasized that it is the duty of government through cogent legislation to ensure that all aquaculture and mariculture ventures are financially sustainable and redound to the benefit of Barbados without damaging the environment. To this end, a new policy framework for aquaculture and mariculture and regulations were approved by Cabinet on 9th June 2023. Regular consultation with stakeholder experts is necessary for implementation and to chart the way forward for the sector.

KEYWORDS: Barbados, aquaculture, mariculture, history, lessons learnt

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1. INTRODUCTION

Barbados is a small island with a land area of 432 km (166.6 sq. mi), with a coastline of 97 km (60 mi) in length and a total maritime area of 186,898 km^2 (72,162 sq. mi) or 430 times its land area. By the mid-20th century Barbados had moved from an agro-based economy to one in which tourism and light industry were the dominant economic drivers. With an estimated population of 269,806 people at the end of 2021 (Barbados Statistical Services), Barbados is the 16th most densely populated country in the world (UNEP, 2012).

Barbados is relatively flat with the highest point being a minimal mountain, Mt. Hillaby (340 m or 1,120 ft. above sea level). The island is in fact the tallest point of the Barbados Ridge, an accretionary prism composed of sedimentary rock scraped off from the oceanic crust of the South American Plate as it is sub-ducted under the Caribbean Plate. Eighty-six percent of the island is composed of a limestone cap comprising ancient corals laid down on the rising sedimentary prism during the late Pleistocene and early Holocene epochs. In the remaining 14% of the island, the cap is eroded exposing the basal sandstone and clays in the east of the island known as the Scotland District. This arrangement of a porous limestone cap (an average thickness of 70 m) atop the compact basement of clay rich sedimentary rocks gives Barbados a fairly unique hydrogeology whereby rainwater percolates through the limestone until reaching the impervious sedimentary basement where it collects underground as sheet or stream water. Some surface springs do form along the edges of the Scotland District, at the junction of the Scotland Series and the coral cap (Wilson, 1989). The volume of water in the streams and pools varies greatly between the dry and wet seasons and Barbados is ranked as the 15th most water scarce country in the world (UNEP, 2012).

A survey conducted in 1992 identified 45 streams and 14 ponds on the island (Mahon, 1994). It should be noted that the volume of water in these streams and pond is seasonally variable, carrying significant quantities of water only during periods of heavy rainfall and may even completely dry out during periods of low rainfall. By the late 20th century at least two of the island's most significant rivers, the Constitution and Indian River had been reduced significantly in size from their original state. The remaining significant coastal wetland areas are Long Pond in St. Andrew, Chancery Lane, and Graeme Hall Swamps (Fig. 1) both in Christ Church. The Graeme Hall Swamp is Barbados's Ramsar site and includes the last stand of red mangroves (*Rhizophora mangle*) on the island and a 12-acre artificially created lake that is the largest body of fresh water on the island (Fig. 1). More than 20 fresh and brackish water fish species have been found in the lake. The scarcity of available land and water resources, both in relation to the occurrence of few permanent natural bodies of water and in recent years, the underground water reserves as well, significantly limits options for land-based aquaculture ventures in Barbados.

Figure 1. Aerial view of Graeme Hall Swamp in Christ Church. The lake in the swamp is the largest remaining body of freshwater on the island. Source: Image from Google Earth.

To satisfy local demand, Barbados traditionally imports much more fish and fish products than it produces. For example, in 2016, 6,234 tons of fish and fish products were imported into the island (CRFM, 2018), compared to local production, exclusively from capture fisheries, of 1735 tons for the same year (FAO). In addition, the mass influxes of *Sargassum* sp. into the region in recent years have resulted in significant declines of particularly traditional mainstay species such as flying fish (primarily *Hirundicthys affinis*) and associated large pelagic species such as dolphinfish (*Coryphaena hippurus*), which has in turn resulted in a reduction in the overall supply of wild caught fish (see Oxenford et al., 2019). Against this backdrop, it has become even more urgent to explore the potential of aquaculture and mariculture in augmenting the island's fish supply. The Barbados Fisheries Policy (BFP) 2023-2033 notably requires Government to support the contribution of sustainable aquaculture to economic growth, food security and income diversification. It should be noted that as part of its efforts to support the development of aquaculture, from 2014 concessions have been offered to people registered as aquaculturists with the Fisheries Division. While several aquaculture and mariculture ventures have been undertaken in Barbados in the past with markedly different success, few have lasted to become what could be considered commercially successful with most not being sustained beyond the "pilot" phase. For this reason, it is considered prudent to critically review and assess these ventures with the objective of identifying their failures and corrective actions, where possible. The lessons learned will then inform the formulation of sound policies and plans for the development and management of viable and sustainable aquaculture and mariculture in Barbados.

2. METHODS

The body of contemporaneous information used for chronicling the history of aquaculture in Barbados was drawn from a variety of sources. These ranged from academic publications, the print media, articles in the popular press, web resources, as well as information extracted from official files of the Fisheries Division, including internal correspondence among government officials and regular monthly and annual reports submitted by the Fisheries Officer on the island's fisheries. Selected supplemental information was obtained through unstructured interviews with key informants. A thematic analysis was conducted to highlight major issues recurring over the years and the potential solutions for addressing these challenges.

3. RESULTS

In simplest terms, aquaculture is the production of aquatic organisms under controlled conditions throughout part or all their lifecycle. The earliest recorded involvement of Barbados in what could loosely be referred to as aquaculture, was the pantropical exportation of a species of small larvae-eating fish endemic to the island known locally as "millions" or guppies (*Poeciloides reticulatus*) as an attempt to control populations of the *Anopheles* mosquito, the animal vector of malaria, a disease that was notably not present in Barbados. In this regard by 1909 "millions" had been sent to several destinations throughout the Caribbean, South America, West Africa, the London Zoo as well as the Panama Canal construction zone ((Barbados. Agricultural. News. 1909; The Canal Record, Vol. II. No.43.).

3.1 Tilapia

A major component of the British government's post Second World War strategy to improve the social and economic conditions in its neglected Caribbean Colonies was the development of local fisheries to augment food supply while reducing imports of fish products. To this end from

1949, the then Colonial Fisheries Officer, C. F. Hickling promoted introduction of the Mozambique Tilapia *Oreochromis mossambicus* from Malaysia to St. Lucia and subsequently to other British territories in the Caribbean (Ramnarine, 2000). The first introduction of the species to Barbados occurred in early 1952 with 120 fish imported from St. Lucia and released into the Graeme Hall Swamp with the assistance of members of the swamp's Bird shooting Club. By 1954 the fish had also been released into several other water bodies across the island. However, Hickling himself recognized that while the introduced populations could supply the wider public with a small quantity of fish, freshwater and brackish water fisheries would not supplant the potential production from marine fisheries for the island (Hickling in a Memo to the Fisheries Officer, 1954). As such all efforts in the 1950's through the 1970's were focussed on developing the marine wild fisheries. Although harvest of the naturalised tilapia was limited, some people have, over the years, taken some of the tilapia to stock their own small-scale aquaculture operations.

By the early 1980's the then Fisheries Officer Robert Hastings pressed government to explore options to develop freshwater aquaculture on the island, and from early 1982 he started in earnest to organize a pilot fish farming project with the collaboration of a Professor from the University of the West Indies with expertise in aquaculture, the U.S. Peace Corps for sourcing and funding an expert volunteer fish farmer and the United States Agency for International Development (USAID) for providing funding for the project in general. Local government support included the provision of land for the farm at the government owned Greenland Agriculture Research Station and labour and equipment for construction of the farm's infrastructure.

The objectives of the project were to establish a small experimental hatchery and distribution centre for the Scotland District; establish suitable techniques needed for the successful cultivation of a variety of species under local conditions; train locals in basic aquaculture techniques; determine the economics of the various species and culture systems and explore market reaction to the various aquaculture products.

In April 1983, USAID granted funds for the purchase of materials, equipment etc. for the farm and by September of the same year the aquaculture expert from the Peace Corps arrived. The development of the farm was however beset with challenges and problems that delayed its completion and commencement of operations. In July 1984, the Peace Corps expert resigned. While work was continued on the construction of the farm's infrastructure, the FAO was approached to provide technical assistance through a short-term deployment of Jamaican-based aquaculture consultants. Under the FAO Technical Cooperation among Developing Countries (TCDC) programme, 3 consultants were provided on short term assignments (3 months) from the Jamaica Inland Fisheries Unit (JIFU). The first consultant arrived on in February 1985 bringing 500 male Nile Tilapia (*Orechromis nilotica*) fingerlings which was the start of production at the farm.

In Barbados the consultants provided training in aquaculture to the Fisheries Division's Marine Biologist. They were also involved in some extension work including offering technical advice to persons interested in setting up their own aquaculture facilities, which included site visits to their properties and conducting soil tests for those planning to use ponds. The lead consultant also produced a training manual for fish farming by small farmers in Barbados (MooYoung, 1985). In July 1985 another aquaculture expert from the Peace Corps arrived to manage the farm. By late 1985, 100 red tilapia hybrids (species mix uncertain) were imported from Jamaica and added to the farm's fish stock. The completed infrastructure of the fish farm comprised a 0.13-acre non-drainable brood pond for fingerling production, a 20 ft. by 4 ft. concrete raceway and a 0.6-acre green water production pond as well as fish-tanks for the hatchery and nursery of the fry. While the *O. nilotica* stock were raised in the ponds, the raceway was reserved for the hybrid red tilapia.

The farm was beset with other operational challenges. The first major problem was the supply of water that was piped in from a natural stream. Unfortunately, the stream also supplied water to the Agriculture Research Station's dairy farm and a nearby brick factory. The stream was subject to very low water levels during the annual dry season at which time it could not adequately supply the demands of all three dependent enterprises. In addition, the water demand at the aquaculture farm was greater than planned as although the ponds were in an area of clay soils there was still some limestone outcrops arising from deep in the subsoil through which water leaked. This problem was further exacerbated by the male Tilapia burrowing into the substrate to make their nests. Additionally, lack of security of the farm facilitated a high rate of theft of the fish. Finally, the market demand for adult Tilapia was low.

In July 1985, of an expected first harvest of 500 lbs only 101 lbs of fish (average individual weight of 9 oz.), was harvested. Most of the production losses was attributed to a combination of theft and damage to the drainage system and only a small proportion due to natural mortality. Nevertheless, the farm did manage to produce and market a few more crops of Tilapia up until December 1986 when the fish in the grow-out pond were culled and the pond drained for fear that the water may have become contaminated with a chemical used to spray the cattle in the dairy.

Given the limited market potential of the adult Tilapia at the time, the recommended actions that included lining the leaky ponds with plastic and the installation of fencing around the entire property to prevent theft was considered too costly for the farm to be a financially viable entity. However, the venture was successful in its role of supplying fingerlings to the, albeit slow-growing, group of locals interested in small-scale production of Tilapia and as such the farm continued in this limited capacity until it was completely closed in 1989. By 1987, an aquaculture research building funded under Lomé II was built at the Cave Hill Campus of the University of the West Indies. It was used as a teaching and research facility and a hatchery for red hybrid tilapia fingerlings.

In 1997 a local family-owned company in St. George set up an intensive Recirculating Aquaculture System (RAS) as part of a pilot project for intensive culture of hybrid red tilapia. The system comprised 4 circular 600-gallon tanks, 2 rectangular 700-gallon raceways, a settling tank and two bio-filtration columns along with the requisite water and air pumps. The system was enclosed in a shed. Tilapia brood stock was imported from Canada in early 1997 but were only successfully bred once. The fish were fed imported commercial catfish feed. Due to the failure of the brood stock, two batches of fry were imported from Canada in November 1997 and March 1998. Between August 1998 and March 1999 around 800lbs in weight were produced and sold to a local supermarket. Despite the success in producing and marketing the fish, the costs associated with importing fingerlings proved too high for the farm to be commercially profitable and it was then closed.

On 14th, November 1995 an Australian-born farmer, who had been residing in Barbados for many years, incorporated Natures Produce Inc., an agriproducts company that focussed on organic production practises. The six-acre farm was commercially very successful and by 2010 the rearing of Tilapia and Australian red claw crayfish was included into the integrated-farming network. By 2012 the farm planned to ramp up production but after a protracted legal battle, in late 2015 the company lost its bid to purchase the land on which it operated.

In November 2013, another young entrepreneur trained in aquaculture opened her farm, Adams Aqualife, located on the grounds of Hopewell plantation in St. Thomas. The farm utilized intensive recirculating green water technology in six fibreglass 25m^3 circular grow-out tanks each accommodating between 500 and 1000 male Hybrid Red Tilapia. The water in the tanks was aerated and recirculated through a drum filter and a bio-filter. The valuable brood stock was

kept at the owner's home. The farm was commercially viable but in 2020 the lease for the land was not renewed and the owner made the decision to focus only on continuing to breed the fish from her home at another location in St. George while the grow-out tanks were sold.

3.2 Decapod Species

In the early 1960's, research on the feasibility of culturing the native big claw river shrimp *Macrobrachium Carcinus* (L) was conducted at the Bellairs Research Institute (BRI) in Barbados. Wild caught juveniles and adults were stocked in both shallow (1 ft. water depth) and deep (6 ft. water depth) concrete tanks through which freshwater was continuously run. The shrimp were fed a diet of the freshwater algae *Cosmarium* sp. that was introduced into the tanks and allowed to proliferate naturally. The study showed that the cultivation of these shrimp was feasible, but more work was needed to identify suitable feeds especially for the larger market-size cohort as high levels of cannibalism occurred at these sizes under the culture conditions. In the late 1980's a Ph. D. student at the University of the West Indies studied the ecology and culture of native freshwater shrimps. However, no commercial aquaculture of any *Macrobrachium* species of shrimp ever materialised.

In 1998, a local agro-business company used an intensive RAS to raise Specific Pathogen Free Pacific white shrimp (*Penaeus vannamei)* from post larvae imported from Florida. A closed recirculating concrete raceway 70 ft. long by 20 ft. wide was constructed by placing a central dividing wall down the centre of the tank that created a circular water flow. Water was supplied from a well on the estate used for irrigation. The tank water was aerated and filtered through a large bead filter and then a biological filter before being returned to the system. The shrimp post larvae were first acclimatized in a 600-gallon nursery tank before transfer to the raceway. Given that the farm was located miles away from any natural watercourses and the species can only reproduce in sea water the potential environmental risks to the island were negligible. Unfortunately, the survivorship of the post larvae shrimp was too low to produce a commercially viable stock and since the importation costs associated with restocking were high, the project was abandoned. Instead, the proponents switched to raising Koi that proved to a more profitable alternative (Barry Gale, Managing Director of Gale's Agro Products Ltd. Pers. Com).

Starting with a brood stock of 14 imported from the USA in July 1997, the small family-owned Tilapia farm in St. George (previously mentioned) cultured Australian red claw crayfish (*Cherax quadricarinatus*) in 6 concrete tanks. The crayfish were originally to be sold as food, however a more profitable offer to market the animals for the aquarium trade in England was made. This presented an interesting legal dilemma as tax concessions had been granted to the farm on the basis that the crayfish were to be utilised as food. In the end the animals did not attain the physical features that would have made them suitable for the aquarium trade and they were eventually disposed of locally as food. This was the only example of commercial aquaculture of a decapod species in Barbados. As noted earlier, Australian red claw was also successfully reared at the Nature's Produce farm before its abrupt closure in 2015.

3.3 Sea Moss Mariculture

Of the five extant *Gracilaria* species in Barbados only the agar from *G. debilis* has a high gel strength without additional treatment with alkali (Duckworth et al., 1971). As such G. *debilis* was the choice species for the sea moss products. An M. Phil. student at the University of the West Indies noted that the abundance of wild stocks of native sea moss had declined by the early 1980's compared to the levels in the 1920's through the 1960's. Nevertheless, she identified 29 sites located along the island's coast, except the West Coast, where natural stands

of *G. debilis* were still present in 1981-1982. Sea moss was still a popular product and she identified 20 locations including one major supermarket around the island where sea moss products were sold. Given that a ready market still existed and the decline in the abundance of the wild stocks, she assessed the feasibility of restoring native *Gracilaria debilis* as a commercial enterprise in Barbados through testing various culturing methods and conditions. She concluded that the best culture method was by vegetative propagation on polypropylene ropes at depths of between 10 and 70cm at sea (St. Hill, 1986).

Cultivation of sea moss for commercial species was started in St. Lucia in 1981 (Smith et al., 1984). The most popular cultivation method was the rope culture also used by St. Hill (1986). This involves weaving bunches seamoss cuttings between the strands of polypropylene rope (8 to 10mm diameter), which is then anchored to the seafloor at both ends. Sealed empty 2 L PET soda bottles used as floats, are placed at intervals (around 3 ft.) along the length of the rope, which is itself naturally buoyant. Apart from inspecting the lines periodically to ensure their integrity and to remove any drifting sea moss (such as *Sargassum*) or other flotsam entangled in them, the plants are simply left to grow (Smith, 1986).

The first attempt to culture sea moss for commercial purposes in Barbados was in February and March 1996 at Consett Bay using the process of vegetative propagation on ropes just described. The seamoss grew well for six weeks but then suddenly disappeared from the lines, undoubtedly stolen. From 1994 a private entrepreneur operating at Half Moon Fort St. Lucy started cultivating a non-native unidentified terete verrucosoid type known as *Gracilaria* GT, a species that grows quickly, sourced from St. Lucia, on rafts constructed of PVC pipe, each 10 x 10 x 1.5 ft. with 8 parallel lines into which the sea moss was woven. The sides and bottom of the rafts were covered with netting to prevent grazing by reef fish. A maximum number of 35 rafts were deployed by the end of 1998. Each raft produced about 10 lbs. of dried seamoss with 1800 and 700 pounds (dry weight) produced in 1998 and 1999 respectively. This cottage industry was a clear financial success, with the product being marketed through many of the island's supermarkets and even being included in the manufacture of ice cream. However, eventually the demands of the operation that was being conducted on a part-time basis forced the businessman to cease operations. This project remains the most successful sea moss aquaculture venture overall recorded for the island and the owner is now involved in a pilot project with Export Barbados where the processed seamoss is being used in a line of condiments marketed under the brand name 'Landship'.

In September 1998 the government, through a demonstration project of the Coastal Zone Management Unit, again embarked on developing a community-based sea moss cultivation project at Consett Bay, St. John. The raft culture method just described was first tried using *Gracilaria* GT. However, the sea conditions in the area proved to be too rough and the rafts were eventually destroyed. By December 1998 about 200 pounds (wet weight) was harvested from the four remaining rafts. In 1999, another similar community-based sea moss rearing project was undertaken using the rope technology again but although the farmers managed to harvest one crop (Fig. 2) interest and participation in the on-going operations had waned and without the commitment of the community the project had to be eventually abandoned.

Figure 2. Sea moss (Gracilaria GT) on culture rope at Consett Bay, 1999. Photo Angela Watson.

3.4 Finfish Mariculture

In 1994, the first mariculture project in Barbados was started by an American-based company in partnership with a Barbadian Fish Processing company to culture dolphinfish (*Coryphaena hippurus*). The company, Caribbean Aquafarms, planned to implement the venture in 2 phases starting with growing out fingerlings sourced from a hatchery in Florida in four circular 40 ft. net pens located off the Northwest Coast of the island. The production yield for the first year was estimated at 12,500 8-lb fish (or a total of 100,000 lbs.). The second phase of the project included construction of a hatchery on land and additional pens to produce 250 tons of fish. (BRI, 1994).

The pens were eventually placed 600 meters offshore Half Moon Fort, St. Lucy and 2 were stocked with 2,800 and 940 fingerlings respectively. The fingerlings were fed a formulated, high-protein, vitamin-enriched pellet food, occasionally supplemented with frozen fresh fish. Initial mortality rates in both pens were high reaching maximum daily rates of 33% and 43%. Although the mortality rate later decreased, by the time of harvesting (after 150 and 80 days respectively) few surviving fish remained (Prescod and Hunte, 1996). Farm reports indicate that the fish in the pens were prone to high levels of parasite infestation, which may account for the high mortality rate.

Despite the low production rates the proponents of the project tried to continue implementing Phase 2 of their proposal by first seeking permission to increase the number of net pens in increments of 4 over 1996, so that a total of 12 pens would be in place by the end of 1996, and to build the hatchery. By early 1996 the hatchery was in place and by the end of March 1996 the first shipment of dolphinfish eggs had arrived. Although the farm continued to operate, its success with dolphinfish production remained very poor. By late 1997 a large European fish farming country offered to invest in the farm on the conditions that other fish species were reared, specifically red drum (*Sciaenops ocellatus*) and sea bass (species not identified), and that the hatchery be expanded and the number of offshore cages be increased to 60. This was not tenable and the farm remained inactive throughout most of 1997 and 1998.

Local investors partnered with a successful fish farming company in Martinique to form a new company in June 1999. Commercial culture of Red drum in Martinique began in 1996. Red drum (*Sciaenops ocellatus*) imported at the fertilised egg stage were being successfully reared in the hatchery by August 1999. The hatchery consisted of a series of 6 small tanks that held the rotifers and Artemia to be used as food at various stages of the larval development of the red drum, a series of 8 small tanks in which the larvae were raised and a series of 4 round $5m^3$ weaning tanks for the fingerlings. Water for the hatchery was pumped from the sea and passed through a sand filter before being sent to any of the tanks in the hatchery. However, the water supplied to the larval tanks was then also first passed through a paper core filter and finally a UV lamp filter column, while the water supplied to the weaning tanks was not given this extra filtering and sterilization treatment to allow the fish to acclimate to the ambient sea water. The water flow into the weaning tanks was continuous, draining from the tank through a central pipe that was perforated at a height that maintained the desired water volume. The discharged water was passed through a UV lamp filter before draining onto the land outside the hatchery. Iodine was the only disinfectant reported to be used at the hatchery.

The company divested ownership of the grow-out pens to a wholly locally owned company registered in May 2000. In the first half of 2000 around 67,000 fingerlings were exported to farms in Martinique and Mexico and between May 2000 and February 2001 nearly 24,000 lbs of the fish raised in the net pens was sold locally. The remaining stock was prematurely harvested and put in cold storage on the approach of a tropical Storm in September 2000. Operations at neither the hatchery nor the offshore facility were resumed after this.

3.5 Aquaponics

Aquaponics is the integration of recirculating aquaculture and hydroponics in one production system. Simply put, fish are grown in tanks using the normal fish husbandry protocols such as adequate aeration, proper feeding regimes etc., and the nutrient-rich water produced by the fish culture is pumped into hydroponic (soilless) beds to irrigate and fertilize plants. The plants absorb the nutrients, and the purified water is returned to the aquaculture tank. Hardy fish species such as Tilapias are usually used while a wide variety of plants (except root crops) can be grown but to optimize productivity the types of plants grown should be matched with the specific aquaponics system used.

In March 2009, a young entrepreneur who had been experimenting with aquaponics since childhood teamed with other residents of his home village located in the parish of St. George to form the Baird's Village Aquaponics Association (BVAA). Recirculating systems are used for all the production arrays with solar power used to run the water and air pumps. The original production array was comprised of 1 fish tank to 4 plant grow beds composed of a bed of coconut coir laid over a raft frame. The coconut fibre acts as both a growing medium for the plants being cultivated and as a filtration system to trap sediments and prevent them from re-entering the fish tanks. More recently the farm has used the Nutrient Film Technique (NFT) which uses horizontal PVC pipes that are perforated at the top through which the plants are placed allowing their roots to contact the thin film of nutrient-rich water flowing through the pipes. The species of fish cultured are Tilapia and Pacu (*Piaractus mesopotamicus*), which are fed a low-cost, high protein feed. A variety of vegetables and herbs are grown including tomatoes, lettuce, sweet peppers. The BVAA engages in significant extension work, including on social media platforms, to promote aquaponics and offer training to interested people. The project has attracted developmental grants from the Global Environment Facility Small Grants Programme as well as co-funding from McGill University, the Inter American Institute for Cooperation on Agriculture, and the Ministry of Agriculture in Barbados.

From late December 2017 the government participated in an FAO funded project entitled "*Towards a Caribbean Blue Revolution*" (TCP/SLC/3601), the main objective of which was the establishment of a functional demonstration aquaponics farm on the island to be used for the hands-on training of interested persons to successfully establish and run an aquaponics farm.

The demonstration farm was set up at Adams Aqualife. Two common aquaponics systems were used, namely the deep-water culture method, also known as the raft method or floating system, and the nutrient film technique (NFT) (Fig. 3). In the deep raft arrangement, nutrient-rich water is circulated through long canals at a depth of about 20 cm while rafts (usually polystyrene) float on top. The plants are supported within holes in the rafts in net pots such that the roots hang down in the oxygenated and nutrient rich water (FAO, 2015). The fish (Tilapia) are held in 3 tanks and the plants grown are lettuce, chives, mint, and basil which are sold to local restaurants.

Figure 3. Aquaponics arrays at Adams Aqualife. The Deep Raft arrangement is in the foreground and the Nutrient Film Technique (NFT) arrangement is in the background.

The wider objective was to promote aquaponics as a feasible subsistence-level or commercial-scale enterprise that redounds to the benefit of Barbados in general by increasing alternative livelihood options, contributing to food security and perhaps even reduction of the food import bill. This objective has been achieved as to date, in addition to the original project target of training 40 persons (including 10 teachers), Adams has privately trained at least 80 people as well as some school children. Her collaboration with TVET council has led to a Level 1 certification in Aquaponics which will be delivered this year (2023) in collaboration with the Fisheries Division. It is estimated that at least 75 units based on the demonstration model have been built by people to provide food for their families, while between 20 and 30 have been built and are operated as small businesses (Kristina Adams, Owner Adams Aqualife, Pers. Com.). After the loss of access to the land at Hopewell, Adams now operates the aquaponics farm from her home in St. George.

3.6 Aquaculture in stock rehabilitation programs

Laboratory culture of larvae has long been proffered as a potential tool in an "artificial restocking" programme for the Barbados White Sea urchin *Tripneustes ventricosus* (known locally as the sea egg) population (see Duerden, 1901). The idea was supported by at least one other contemporaneous scientist, Dr. Caswell Grave of Johns Hopkins University who reported that he had successfully reared other species of urchins under laboratory conditions and suggested that his methods could be used to rear *T. ventricosus* larvae to the point of settlement as well for such a restocking exercise (The Agricultural News, May 10, 1902). It is noteworthy that *T. ventricosus* larvae were reportedly successfully reared to the early pluteus stage by David Tennent (1910) and to at least the age of 22 days by Theodor Mortensen (1921) during a field trip to Tobago. By the early 1980's the alarming decline in the sea egg stock renewed interest in the potential use of laboratory rearing of sea egg larvae for stock rehabilitation. To this end, Anne Hickey (1982) reared some sea egg larvae to just over two weeks of age and in 1987, working at the Bellairs Research Institute, Canadian scientists, Robert Scheibling and Philip Mladenov again unsuccessfully attempted the artificial rearing of sea-egg larvae for a potential restocking project.

4. DISCUSSION

Based on the historical summary presented, several aquaculture and mariculture ventures were attempted in Barbados with varied success. Species choice is of course a major factor in both the success of an aquaculture venture and impacts on native ecosystems. *Poecilia reticulata* and *Oreochromis mossambicus* are among the nine most Invasive Alien Species (IAS) in freshwater ecosystems in every continent except Antarctica (Sultana and Hashim, 2016). It is therefore ironic that, with the best of intentions, during the first half of the 20th century, Barbados acted as a major contributor to the pantropical spread of *P. reticulatus* (for mosquito control) and a recipient of *O. mossambicus* (for food supply augmentation).

Aquaculture efforts after 1980 in general followed more environmentally prudent guidelines especially in relation to the selection protocols for culture species whereby native species were first considered or tried (e.g., freshwater shrimp, naturalized *O. mossambicus* and local sea moss species). Introduced species were chosen only after careful consideration of their potential invasiveness and deleterious impacts on native ecosystems in the event of escapement into the wild. For example, in the case of the New Caribbean Aquafarms venture, importation of the culture species, red drum, was allowed as it was deemed highly unlikely that an escapee could successfully reproduce given the absence of estuaries in Barbados (or similar areas) that serve as spawning and then nursery habitats for the species. Nevertheless, legislation specific to controlling the introduction of non-native species in general, and not just focused on preventing the introduction of pests and diseases into the island, is lacking and this increases

the risk for the introduction of harmful Invasive Alien Species, for any reason, including aquaculture.

Fields and Taylor (1995) suggested that while limited land and water resources constrained commercial-scale aquaculture there was limited potential for medium to small-scale aquaculture ventures in Barbados. Indeed, nearly 30 years later, low-tech small-scale "backyard" ventures often rearing hardy fish species that are of modest market value, primarily Tilapia spp., have emerged as the predominant and arguably more sustainable model for Barbados. Although in this regard it should be noted that while investment in these ventures may seem trifling by industry-standards it may be significant at the personal level. In this context, the significant increase in the number of aquaponics ventures observed in recent years suggests that this cottage-scale culture is becoming a noteworthy component of the island's food production sector. However, it should be noted that most of the profits from aquaponics is derived from the plant production component and not the fish production, as the quantity of fish raised is necessarily limited. A potential avenue for increasing the overall profitability of these systems is to grow the most valuable crops that will be advised by contemporary market intelligence, as well as rearing more intrinsically valuable hardy aquarium fish species, such as Koi (*Cyprinus rubrofuscus*). However, given the limited local market for high-end ornamental fish, access to export markets is critical for this option to be sustainably profitable. It should be noted that there are several ornamental fish breeders on the island and, as such, rearing less valuable readily available species is not recommended.

In the contexts of larger-scale aquaculture ventures, the option for pond-based aquaculture should not be dismissed, although the costs of constructing the ponds will be costly. In this regard, the construction of earthen ponds is a viable option in the clay soils of the Scotland District. However, such ponds would have to be excavated to a depth at which all outcrops of limestone are completely scraped away with the entire floor of the pond composed of a thick layer of unadulterated compacted clay. However, plastic-lined ponds are the most economically feasible option for the majority of the island composed of porous limestone soils. Nevertheless, it is the dearth of permanent natural bodies of water, and in recent years, the decline in underground water reserves that significantly limits the reliable supply of clean water and by extension the options for large-scale land-based aquaculture ventures in Barbados. Terrestrial run-off is not a suitable source of water in the ponds to produce aquaculture products for food given the chances of the water and sediments transporting environmental contaminants into the pond system, such as occurred in the case of the Greenland Tilapia experiment. Indeed, aquaculture ponds should be surrounded by levees to prevent the incursion of land run-off.

Given the limited land space and scarcity of water, commercial-scale ventures are usually restricted to RAS technologies for which water demand is much less. However, to date the level of production from these ventures has been comparatively small by industry standards. Such modest yields compared to the high capital and operational costs of these relatively small RAS ventures results in a commensurately limited Return on Investment and a lengthier period to reach the financial break-even point. This is simply not a practicable business model and as such historically such ventures have not made it beyond what is often described as the "Pilot phase". In addition to the expected technical production problems, a range of fundamental flaws in long-term business planning, ranging from inaccurate projections of inputs and production costs to market access limitations and poor marketing strategies for the final products, have been the major downfall for the ventures. Simply, as for any other business, a sound long term business plan is essential for any aquaculture venture to be financially feasible let alone sustainable.

In addition to the physical limitations in areas where larger-scale aquaculture ventures can operate owing to the small size of the island as well as the very high population density, there is often fierce competition for access to land. In this context, it is unfortunate to note that the two hitherto most promising and successful commercial-scale aquaculture ventures were forced

to close because of the loss of access to the land on which they operated. As such long-term right of access to the land on which the enterprise operates must be definitively established before investing in any commercial-scale aquaculture venture if it is to be economically sustainable.

Although Barbados has jurisdiction over a substantial maritime area of 186,898 km2, the options for mariculture are still constrained by the island's densely populated small land area and commensurately modest and crowded coastline of 97 km (60 mi) in length. Under these circumstances direct access to needed onshore support facilities for mariculture enterprises is significantly limited. In addition, given the spatial requirements of conventional commercial-scale mariculture pen or cage installations, there are few locations within Barbados's coastal space for such ventures. In this context the prevailing rough sea conditions on the island's Atlantic coast would continuously imperil the structural integrity of these installations and thus, not only increase the costs of maintenance and replacement of significantly damaged or lost equipment but will increase the chances of escapements in incidences of such structural failures. The added physical burden of Sargassum mats becoming enmeshed in the walls of the cages or pens will also increase physical pressure on the structures. In this context it is only along the calmer waters on the western and southwestern coasts that such structures could be more safely installed. Unfortunately, these areas comprise what has been described as Barbados' main coastal urban corridor, which includes the island's main tourism belt. As such, a multiplicity of economic activities occur in these areas which would directly compete with both the presence of the mariculture installations and associated operational activities. Added to this, most the island's living coral reefs are located in the western and southwestern coasts and as such great care will be necessary to ensure prudent site selection for the mariculture facilities, so that the ventures do not add to the environmental stress on these already degraded critical habitats.

Finally, the negative impact of these installations on the area's aesthetic appeal and value particularly in the context of tourism, the main economic engine of the island, must also be considered. To mitigate several of the problems associated with surface-based mariculture including rough sea conditions especially during extreme weather events, poor surface water quality, and conflicts with other coastal users, one promising option is the use of submersible cages (see review by Sievers, M. et al., 2021). However, this technology is still in its infancy and costlier than conventional surface mariculture systems. As such it would only be deemed feasible based on careful cost-benefit analyses that would include an evaluation of the risks (both financial and existential) that would be incurred from a conventional mariculture venture impacting on the myriad environmental, social, cultural, and economic factors including those just described.

Aquaculture and mariculture can undoubtedly play a major role in the rehabilitation of depleted stocks of marine species that are of direct significant commercial importance. In this context, the successful laboratory culture of *T. ventricosus* from fertilization to exotrophic juvenile (Wolcott and Messing, 2005; Moe, 2014, Williams, 2023) raises hopes that *T. ventricosus* may also be successfully raised in the numbers required for practicable use in restocking programs such as has been achieved for the congeneric species *T. gratilla* (see https://manoa.hawaii.edu/news/article.php?aId=11168). Another species, of direct commercial value, for which aquaculture or mariculture is rapidly becoming a feasible method for rehabilitation of depleted stocks is the queen conch (*Alger gigas*). (see https://conchaquaculture.org/labs-%26-farms).

However, aquaculture can also play an important role in the rehabilitation of depleted stocks of species that serve in pivotal roles in maintaining ecosystem health and function. For example, the black sea urchin *Diadema antillarum* is a keystone grazer species in coral reef ecosystems of which local populations have still not recovered to their strength after being decimated by a

still poorly understood disease that spread throughout the Caribbean region in the early 1980's and which resulted in the loss of more than 93% of the population. It is noteworthy that promising work on laboratory culturing *D. antillarum* for use in population restocking is being conducted (Pilnick et al., 2021). In addition, the observed declines in the abundance of a number of parrotfish species, should serve as impetus for research and development into potential aquaculture of these species for stock rehabilitation programmes. In this context, the reported successful culture of the threatened Pacific bump head wrasse (https://www.reef2rainforest.com/2014/04/25/bumphead-breakthrough-tank-raised-parrotfish/) offers hope that other parrotfish species could also be cultured. Naturally, the business endgame in such benevolent aquaculture ventures is very different, in that no quantifiable financial profits are directly returned to the investors. Although it can rightly be said that real benefits in fact redound to everyone! Nevertheless, the potential sources of funding for such programs are limited. So far much of the lab-level research and development work has been funded piecemeal via research grants etc. to the handful of researchers involved but scaling up to large scale production is a totally different situation. However, the macroscale benefits from such benevolent aquaculture must not be overlooked.

Regardless of the scale or type of aquaculture or mariculture, it is incumbent on the government to systematically and transparently review all proposals for these ventures and, where necessary, offer guidance to proponents to ensure that if they are feasible then they are sustainably viable without compromising environmental protection and the well-being and livelihoods of Barbadians. To facilitate this process, it is recommended that a standing panel of stakeholders comprised of experts in their respective fields, be appointed not only to critically review, assess, and advise on aquaculture proposals but in addition to chart the way forward for the sector. It should be noted that since the 1980's the Fisheries Division has provided extension support and basic technical advice to people interested in aquaculture. However, it is at present not mandatory to for people to seek this assistance and a number of private ventures have been started and operated without any guidance from government.

All aquaculture and mariculture activities must be managed with the support of a comprehensive, equitable and transparent legislative framework by which unwholesome activities and untenable proposals are effectively disallowed while innocent, helpful and viable innovation is supported. To this end, the legislation should mandate *inter alia* that proposals for larger scale aquaculture ventures include such information and documentation needed to ascertain the legality of the proponents, provide all technical specifications of the operation both in the context of the physical plant, species to be cultured and culture techniques and provide for routine expert monitoring and inspection regimes. In addition, the legislation should mandate provision of a business plan and plans to manage waste and effluents, biosecurity, and escapements. While the business-related requirements will not be required for small-scale operations, even these operations must still be regulated primarily in the context of protecting the environment. The proposal review process and the granting of permission should however be transparent and as expeditious as possible, not being allowed to devolve into a mire of unnecessary "bureaucratic red tape" and delay. To this end the Sustainable Fisheries Management and Development Bill includes a section dedicated to Aquaculture and Mariculture and appurtenant draft Aquaculture and Mariculture Management Regulations have recently been submitted and approved by cabinet.

Nevertheless, especially given the limited space, both in the contexts of land area and coastal waters that can accommodate conventional aquaculture or mariculture in Barbados, it is even more critical that the commensurately limited number of such ventures, especially large-scale undertakings, be very carefully selected and monitored such that they meet all the highest standards of environmental safety and social acceptability, and provide real economic benefits for the island and its people. Simply put, failure in any of these criteria is not an option.

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