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FEASIBILITY STUDY ON IMPLEMENTING A SMALL-SCALE PRODUCTION SYSTEM FOR YELLOWTAIL SNAPPER (*OCYURUS CHRYSURUS*) AND BROWN SEA CUCUMBER (*ISOSTICHOPUS BADIONOTUS*) USING AN INTEGRATED MULTITROPHIC AQUACULTURE (IMTA) APPROACH IN CORN ISLAND, NICARAGUA

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ABSTRACT

Fisheries and aquaculture play key roles in Nicaragua's economy. The development of aquaculture projects that focus on species of high economic value, especially those from the Caribbean Sea, can contribute to the diversification of production of coastal communities, having an impact on the local and national economy, which is in line with the policies of the Government of Nicaragua to fight poverty and guarantee food security. Based on published and unpublished literature, this study aimed to determine the feasibility of implementing a small-scale production system of yellowtail snapper (*O. chrysurus*) and brown sea cucumber (*I. badionotus*) on Corn Island, located on the South Caribbean Coast of Nicaragua, using inland facilities and cage culture for different growth stages. In addition, because of the ecological impacts usually related to marine aquaculture activities, this study evaluated the possible implementation of rearing systems using an Integrated Multitrophic Aquaculture (IMTA) approach. After an evaluation of the ecological characteristics of the site, the biological characteristics of the species, and challenges and opportunities related to the establishment of the project, the results demonstrated that the rearing of juveniles of both species that focuses on the evaluation of their acclimation, feeding, and growth performance is feasible in inland conditions, and the use of the IMTA approach is highly recommended. However, reproduction trials of both species are not feasible until further evaluation of their reproductive behaviour in the wild is performed to allow for better broodstock collection and reproduction strategies under controlled conditions. Because of the repercussions of feeding mismanagement on the growth of the species and ecology of the marine environment, the use of cages as a rearing method for yellowtail snappers is not feasible until optimal feeding strategies are achieved in inland facilities. However, because of their detritivore habits, rearing brown sea cucumbers in coastal areas is feasible. As part of the results and based on the knowledge gaps found during the formulation of this study, an action plan is included as a tool for the future execution of the project.

Keywords: aquaculture, IMTA, yellowtail snapper, sea cucumber, Caribbean Sea, Nicaragua.

Table of Contents

LIST OF FIGURES:

LIST OF TABLES:

1 INTRODUCTION

1.1 Background

Fisheries and aquaculture have played a key role in Nicaragua's economic diversification; in 2022, the production reached 86 million kg, which corresponded to 32 million kg of farmed shrimp (36,96%); and 33 million kg from fisheries in marine waters (38.55%) shared between 19.3 million kg from the Caribbean Sea (95,6%) and 13.5 million kg from the Pacific Ocean (29.6%) (INPESCA, 2024). In terms of economic value, the total production from fisheries and aquaculture in the country reached USD 335 million, of which farmed shrimp had most of the value of USD 166.2 million (49,6%), followed by the Caribbean Sea fisheries with USD 103 million (30,7%).

The Nicaraguan Institute of Fisheries and Aquaculture (INPESCA) is the main authority responsible for managing the use of Nicaragua fishing and aquaculture resources. Moreover, as a government institution, fishery communities receive support through economic bonuses, fuel exemptions, capacity building through technical advisory, the opening of marketing channels for fishing and aquaculture products, and private investors by facilitating operation licences and market opening through international export agreements. In terms of aquaculture in the country, INPESCA is currently working on the promotion of a National Strategy for Small-Scale Aquaculture (Estrategia Nacional de Acuicultura a Pequeña Escala-ENAPE), offering technical support to those interested in freshwater and marine aquaculture.

The experience of INPESCA includes Nile tilapia (*Oreochromis niloticus*) aquaculture, which has shown satisfactory results around the country, with the establishment of 1,477 inland ponds in 2023. During the first quarter of 2024, an additional 109 ponds started operating, with a total of 5,782 tilapia fingerlings that were distributed to new small-scale farmers. These fingerlings were produced at the Freshwater Species Laboratory, Panchito Batata, which is managed by INPESCA.

The only marine finfish species that has been produced in a steady manner is the spotted snapper (*Lutjanus guttatus*) on the Pacific Coast. With initial support from the LIDER Foundation and Friends of the Earth, Spain, and technical support from INPESCA and local authorities, organised cooperatives have been involved in cage farming of this species, collecting fingerlings from the wild, and formulating diets with alternative raw materials. Moreover, scientific research conducted by academics of the National Autonomous University of Nicaragua (UNAN-León) achieved reproduction of this species under controlled conditions for the first time in the country in 2022.

In terms of marine finfish, in the Caribbean Coast at a research level, the common snook (*Centropomus undecimalis*) has been used by INPESCA to explore its reproduction at the Caribbean Pearl Technological and Experimental Fishing Centre, and the feasibility of cage culture in Pearl Lagoon (Figure *1*). However, because of biological requirements, reproduction of the species has not yet been achieved, but other experiences regarding acclimation and artificial feed formulation for juveniles have been acquired.

Figure 1. Site of implementation of marine aquaculture projects supported by INPESCA in the Pacific and South Caribbean Coasts of Nicaragua.

Nonetheless, there are other marine species that can be considered for the implementation of marine aquaculture projects in the country because of their endemic distribution in the Caribbean Sea and high commercial value, both locally and internationally. These species include yellowtail snapper (*Ocyurus chysurus*) and brown sea cucumber (*Isostichopus badionotus*).

In 2016, INPESCA, in collaboration with the Food and Agriculture Organization of the United Nations (FAO) under the Caribbean Coast Food Security Project (PAIPSAN) project, built a coastal aquaculture cage for yellowtail snappers in the community of Monkey Point, South Caribbean Coast of Nicaragua (GAFSP, 2017). The coastal community anglers received theoretical and practical workshops to enhance their knowledge about marine fish farming; however, due to natural and social constraints, further aquaculture activities in that area ceased, preventing the project from moving forward with acclimating and feeding trials.

Regarding sea cucumbers in Nicaragua, no aquaculture-related research or production has been conducted with any of the identified species in the country, indicating that their supply depends exclusively on capture fisheries. For this reason, since 2019, a global Capture Quota System of 556 tonnes has been established based on fisheries research information and remains active to this day. Specifically, the brown sea cucumber is not included in the quota system because its fishing is now prohibited as a measure of overfishing because of its high price in the market, which, despite its banned fisheries, continues to be best paid in the Nicaraguan market. Moreover, in January 2024, its price reached USD 190 per dried kg in the People's Republic of China (MCAS, 2024).

Wild sea cucumber populations have been shown to be susceptible to environmental constraints and human intervention, which can be seen in the catch tendencies for some years reported by INPESCA (2022). Given their tremendous importance, other non-banned species continue to be caught; in 2022 a total of 5,471,686 kg of fresh product, equivalent to 440,621 kg of dried product, with an economic value of USD 18.5 million was exported to the international market (INPESCA, 2024).

1.2 Justification

According to FAO (2022), fisheries and aquaculture are key contributors to food security and nutrition worldwide. In Nicaragua, the development of marine aquaculture can be considered a necessary step for improving the quality of life of coastal communities because of their historical links to the sea, which can increase the acceptability of marine-oriented aquaculture strategies. Moreover, its development is an opportunity to increase seafood production in the face of a growing demand for proteins (Gentry et al., 2017).

Among finfish species, yellowtail snapper is well accepted by household consumers on the South Caribbean Coast, but its importance is most visible in the tourist sector which relies on daily catches to supply restaurants located in the municipalities of Bluefields, Great Corn Island, and Little Corn Island (Figure *2*). Furthermore, exports by private companies to the international market have demonstrated their importance to the national economy.

Figure 2 Municipalities of Bluefields, Great and Little Corn Island, South Caribbean Coast, Nicaragua.

The market for sea cucumbers is entirely international, putting pressure on the resource given its growing demand. According to local anglers, low catches have been evident in some areas close to the shore, forcing them to travel larger distances. The implementation of sea cucumber aquaculture, specifically the highly valuable brown sea cucumber, is of interest to local

communities on the South Caribbean Coast (personal communication, McCoy (2023)), and it could help alleviate both economic and ecological challenges in this region.
Moreover, because of their natural distribution in the marine ecosystem, they can be considered part of an Integrated Multitrophic Aquaculture (IMTA) system. Yellowtail snapper is a pelagic carnivorous species that lives around reefs in coastal areas (Buitrago & Barahona, 2019) and fishing banks within the South Caribbean Coast have been identified (Ibarra-Arana, 2016); and given the benthic and detritivore feeding habits, the brown sea cucumber is an essential species for substrate remediation and chemical processes (Ibarra-Arana, 2019), and their co-culture with finfish species have been evaluated in different parts of the world (Appendix 1). Because of their dynamism, integrated production systems are of great interest for small-scale aquaculture, given the need for the effective use of available resources and lower operational costs (FAO, 2022).

2 OBJECTIVES

In Nicaragua, marine aquaculture is an alternative economic activity to fisheries, aiming to improve livelihoods in coastal communities. However, technical aspects such as site selection, species viability, challenges of implementation, and socioeconomic relevance require evaluation to correctly establish aquaculture projects. For these reasons, this project aimed to evaluate the possibility of executing a small-scale aquaculture production system using yellowtail snapper and brown sea cucumber, and their potential for co-culture through an IMTA approach in the South Caribbean Sea of Nicaragua. The possibility of research on these two species represents not only a benefit for the scientific output from the country to the region, but also a knowledge-transfer opportunity for the future implementation of small farming units in coastal communities, which is the final aim of INPESCA’s ENAPE strategy.

The analysis focuses on the ecological characteristics of the proposed site for two rearing stages in land-based facilities and coastal cage culture, the ecosystem services provided by IMTA systems, a description of the biology and rearing requirements of the proposed species, the identification of challenges related to the implementation of the project, and an action plan for its execution.

2.1 General

- To evaluate the feasibility of implementing a small-scale production system for yellowtail snapper (*O. chrysurus*) and brown sea cucumber (*I. badionotus*) under the IMTA approach on Corn Island, South Caribbean Coast, Nicaragua.

2.2 Specific

- To characterise the ecological conditions of Corn Island as an implementation site for a small-scale marine aquaculture production system.
- To describe the biological characteristics of yellowtail snapper and brown sea cucumber to be considered for use in marine aquaculture.

- To identify the challenges and opportunities associated with the implementation of small-scale aquaculture production using the IMTA system.
- To formulate an action plan for the implementation of a small-scale aquaculture production facility operating under land-based and cage aquaculture IMTA system approaches.

3 LITERATURE REVIEW

3.1 General definitions

3.1.1 Integrated multitrophic aquaculture (IMTA)

Described by Chopin, Cooper, Reid, Cross, & Moore (2012), integrated multitrophic aquaculture (IMTA) refers to a type of aquaculture farming where two species from different trophic levels, are brought together without compromising each other´s growth. To obtain the benefits of this approach, the selected species must show complementary ecosystem functions (Boyd et al., 2020). This is usually achieved by having one of the species feeding from detritus and other organic matter present in the water column and sediment (Carras, 2017), which usually comes from another species' by-product, such as faeces (Figure *3*).

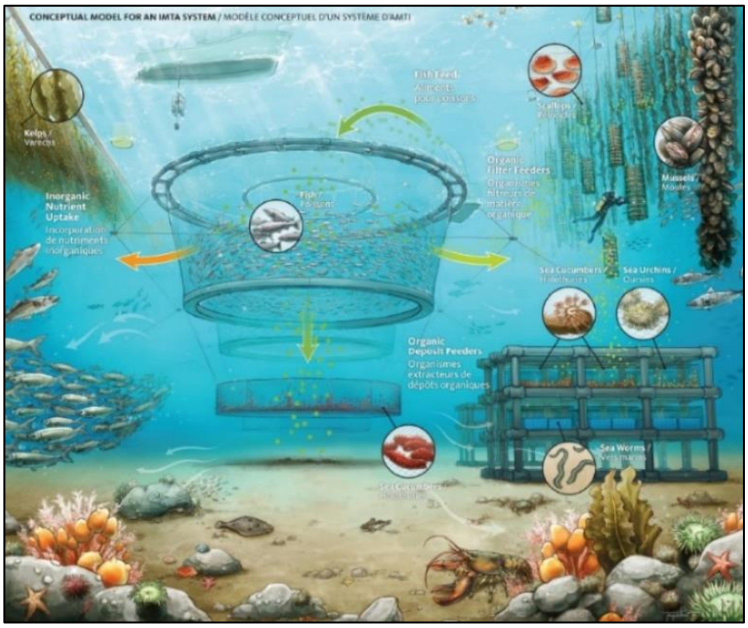

Figure 3. Conceptual model of an IMTA system (Government of Canada, 2022)

Like any other aquaculture system, IMTA seeks to enhance production through four regulating factors: growth, reproduction, recruitment, and natural mortality rates (Beveridge, 2004). It targets three main problems in aquaculture, namely: pollution, feed input, and space (Nissar et al. 2023). For this reason, it is considered a more sustainable mode of aquaculture than monocultures (Custódio, Villasante, Calado, & Lillebø, 2020) (Chopin et al., 2001).

As explained by Boyd et al. (2020), the execution of IMTA systems includes operations in open-water and land-based systems; depending on their trophic integration, the systems can be arranged at different levels; however, more than one level of integration can be recognised in most IMTA systems.

In this sense, the different levels that fit the execution of this project are related to the culture of the two species occupying different spaces in the same production facilities, which can be seen during the early juvenile rearing stages, and the utilisation of by-products from one of the species that serve as input for the other, which is related to the biological characteristics of sea cucumbers, as described in Section 3.3.

3.1.2 Land-based IMTA

The development of modern land-based IMTA using extractive organisms began in 1970 (Shpigel, 2013); since then, it has been explored as an alternative to the main challenge of traditional aquaculture (Ministry of Food, Agriculture and Fisheries of Iceland, 2023). According to Tal *et al*. (2009), land-based facilities are under strictly controlled environmental conditions, facilitating the rearing of marine species that tend to be more sensitive to changes in salinity, temperature, pH, and ammonia levels in the water column than are freshwater species.

However, the benefits of a controlled environment go beyond water quality management. In Nordic countries, the use of land-based facilities is necessary during the initial rearing stages of certain species, such as Atlantic salmon (*Salmo salar*). The rearing period on land has been demonstrated to be particularly useful to increase survival rates and lower economic losses due to sea lice infections, which have severely affected the salmon industry (Bjørndal & Tusvik, 2020). In this sense, smolts (fish that are ready to move from fresh to marine water) are kept for longer periods on land, before moving into sea cages until commercial sizes are achieved. This concept of optimisation of production can be applied to any levels of production, especially if at any given point, it is necessary to move from in-land to marine cage culture (Section 3.1.3).

According to Shpigel (2013), the optimisation of IMTA in land-based systems typically focuses on the most profitable “nuclear” product at any given time, and it may be shifted according to climatic conditions and economic considerations. For example, if an IMTA system is to be established using yellowtail snapper and sea cucumber, the latter is the most valuable species; therefore, efforts within the production system will respond to sea cucumbers’ needs and, if necessary, yellowtail snapper could be replaced with other suitable finfish species that supply better co-culture conditions around the sea cucumbers.

The main issue in the effective implementation of these systems is their optimal functioning, which requires an in-depth understanding of the physiology and nutrition of selected species (Chopin et al., 2001). However, when knowledge is acquired, good operations are provided and harvest is successfully achieved (Ministry of Food, Agriculture and Fisheries of Iceland, 2023).

3.1.3 Marine floating cage IMTA

Marine commercial cage aquaculture was pioneered in Norway and Scotland in the 1960s and 1970s with the rise and development of salmon farming (Sievers et al., 2021) (Halwart, Soto, & Arthur, 2007) (Beveridge, 2004).

Currently, with all technological developments, and as a response to the growing production of farmed aquatic organisms, cage aquaculture, as previously shown in Figure 3, presents itself as an alternative to traditional inland ponds because it can also be used at various stages of the life cycle, such as breeding, fry and fingerling rearing, or production (Beveridge, 2004). Moreover, this type of farming system can be found in family-owned farms, making them an excellent option for different purposes, such as food security (Sievers et al., 2021).

In Nicaragua, specifically on the South Caribbean Coast, efforts have been made to promote the construction of cages utilising low-cost materials. One experience goes back to 2016 in the Community of Monkey Point, where a PVC squared cage of 4 × 4 × 6 m was constructed with the support of FAO, to start research on yellowtail snapper culture. Later, in 2019, with the establishment of the Laboratory Caribbean Pearl, communities around the Pearl Lagoon basin demonstrated interest in establishing small cages (3 × 3 × 4 m) to validate the growth of the common snook.

Although the deployment of cages was successful and offered valuable knowledge about the use of accessible and low-cost materials for their construction, no further results were obtained regarding yellowtail snapper culture because of social constraints. However, ongoing work is being conducted to identify suitable farming conditions for common snooks. At the same time, on the Pacific Coast, the current production of spotted snapper is performed under a cage culture of 6 × 6 × 4 m.

3.1.4 Ecosystem services of IMTA

Given that aquaculture has gained importance in food production worldwide, concerns regarding its environmental impacts, especially those arising from intensive monoculture activities, have brought attention to co-culture as a more environmentally friendly aquaculture operation method.

Marine aquaculture, especially if developed under the IMTA approach, provides both tangible and intangible goods (Alleway et al., 2019), the first of which is related to food security and access to marine protein; the second is related to ecological regulation of the site of implementation and cultural services related to social elements (Custódio, Villasante, Calado, & Lillebø, 2020).

This categorisation allows the planning of new projects under the Ecosystem Approach to Aquaculture (EAA), defined as *a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems* (FAO, 2010).

In this sense, the following are some of the ecosystem services that have been previously reported and that are foreseen to be obtained if the project proposed in this document is carried out under the IMTA approach (Table *1*).

Table 1. Ecosystem services obtained from implementation of Integrated Multitrophic Aquaculture systems.

Reported ecosystem services	Source
Bioremediation given the use of a filter-feeder species.	(Felaco, Olvera-Novoa, & Robledo, 2020); (Carras, 2017)
Diversification of aquaculture production and potential implementation of eco-labelled products.	(Knowler, et al., 2020)
Water optimization due to pre and post use treatment.	(Buck, et al., 2018)
Social participation through dissemination of knowledge among coastal communities and collaboration for scientific research.	(FAO, 2010)

3.2 Ecological characteristics of Corn Island

The specific site proposed for the implementation of this project is the Municipality of Corn Island (12.166667, -83.033333) (Figure *4*), which is a group of two islands located in the Caribbean Sea of Nicaragua with an extension of 1,754 km^2, with a distance of approximately 15 km between each island and approximately 83 km from Bluefields, the capital town of the Autonomous Region of the South Caribbean Coast (Municipality of Corn Island, 2000).

Both Great and Little Corn Island are accessible by air and maritime transportation. The islands are a tourist attraction for both national and international visitors. In terms of fishing activities, it holds significant importance for the local economy given the high demand from the tourist sector and household consumption (Mendoza, 2018). Private fishing vessels can conduct industrial fishing activities only beyond twenty-five nautical miles from the coastal area and take their products to processing companies located on Big Corn Island.

The islands' average altitude is 5 m above sea level, and their climate is categorised as a Very Humid Tropical Forest with an atmospheric temperature of approximately 37°C and from 2,800 mm of rain between March and April to 4,000 mm of rain between July and August.

Among the most important parameters to evaluate in aquaculture, especially for the deployment of cages (Prema, 2009), are depth, waves, and currents. In this sense, wind speed during 2023 in the South Caribbean Coast is mostly from East to West, with a minimum of 6 kph in October and a maximum of 10 kph in February. This element is especially important for waves, which have been reported by the Nicaraguan Institute of Territorial Studies (INETER) to be 1 meter under normal conditions.

Figure 4. Big and Little Corn Island, South Caribbean Coast, Nicaragua. Courtesy of Jairo Antonio Fuertes

Regarding seawater temperature, INPESCA, during on-field activities, and INETER recorded similar values in temperature and salinity, from 26°C to 29°C and 33 ppm, respectively. These values are optimal for all-year-round aquaculture activities, providing a more stable environment.

In a study by Buitrago and Barahona (2019), the marine ecosystems on both islands were described (Table 2). The following are the elements for Great Corn Island which is the main island of interest for this project:

Table 2 Ecological marine characteristics of Great Corn Island

Areas	Characteristics
North	Sandy beaches, seagrass beds, small rocky patches
South	Deeper water zone, small reef systems
East	Longest accessible sandy coastal area
West	Second largest accessible beaches, used mostly for local infrastructure

Moreover, the authors identified reef systems around the island under the terminology of *conglomerates*, with different marine species living among them (**Error! Reference source not found.**), including the yellowtail snapper.

Table 3. Ecological conglomerates and marine species of Great Corn Island.

Conglomerate	Marine species
Blowing Rock	Corals (*Millepora spp.*, *Diploria spp.*, *Montastrea spp.*), Finfishes (*O. chrysurus, Lutjanidae spp.*, *Pterois spp.*, and other smaller reef species), Sharks (*Carcharhinus spp.*), Rays (*Ateobatus nairnari*).
Slaly-Cana	
Half-way Bank	
Pusa Bank	
Old Nasa Bank	

Ecological sensitivity against the state of conservation was also evaluated in this study. In this sense, from five conglomerates, Slaly-Cana and Pusa Bank were classified as very highly and highly sensitive, respectively, with a medium state of conservation. Other conglomerates were considered to have low ecological sensitivity with a mid and very high state of conservation.

The research conducted by Buitrago and Barahona (2019) also described the depths around the site of the study, which increased from Bluefields in the West to Corn Island in the East, with the deepest point reaching 42 m. In addition, between Great and Little Corn Island, the maximum depth is approximately 33 m, with some sandy patches irregularly dispersed, specifically to the west of both islands.

Although aquaculture has never been carried out on any of the islands, the conditions in terms of water parameters, depths, and wild stock distribution of the species of interest for this research (Ibarra-Arana, 2016) make the Corn Islands a place to be considered for the development of small-scale marine aquaculture. Moreover, because of the rich biodiversity, a more sustainable approach, such as the IMTA system, could be more environmentally and socially accepted than monoculture for commercial production of any of the suggested species.

3.3 Biological characteristics of the species

Species selection is a major step prior to the establishment of aquaculture projects. In this regard, their local distribution is crucial to avoid the introduction of species (Wiltshire, Tanner, Gurgel, & Deveney, 2015) because of the ecological repercussions this will have on marine ecosystems, and it is also a key factor for the success or failure at any level of production.

A deep understanding of the biological needs of the selected species (Chopin et al., 2001) (Zajovits, 2021) will provide guidelines for the establishment of a correct rearing system, better formulation of feed and improved feeding methods, and suitable water quality management, which will translate into efficient mid- and long-term management and production (Nissar et al., 2023) (See Appendix 2).

In this section, the biological aspects of the two potential species for a small-scale aquaculture production system using the IMTA approach are described to provide a better understanding of their rearing requirements.

3.3.1 Yellowtail snapper (Ocyurus chrysurus)

3.3.1.1 Geographical distribution

Yellowtail snapper (Figure *5*) is frequently found in aggregations in tropical and subtropical regions in different oceans of the world (Riley, Holt, & Arnold, 1995) and is a major component of reef ecosystems, with higher abundance in Southern Florida and the Caribbean Sea (Zajovits, 2021).

Figure 5. Yellowtail snapper (Ocyurus chrysurus) (Hareskov, n.d.)

In an exploratory trip near the coastal community of Monkey Point (11°36′N, 83°40′W) in the South Caribbean Coast, the Department of Aquaculture of INPESCA (Ibarra-Arana, 2016) was able to identify four different banks of yellowtail snapper which can be seen in Figure *6*, providing evidence of their natural distribution even several miles from Corn Island, the site of interest for this project.

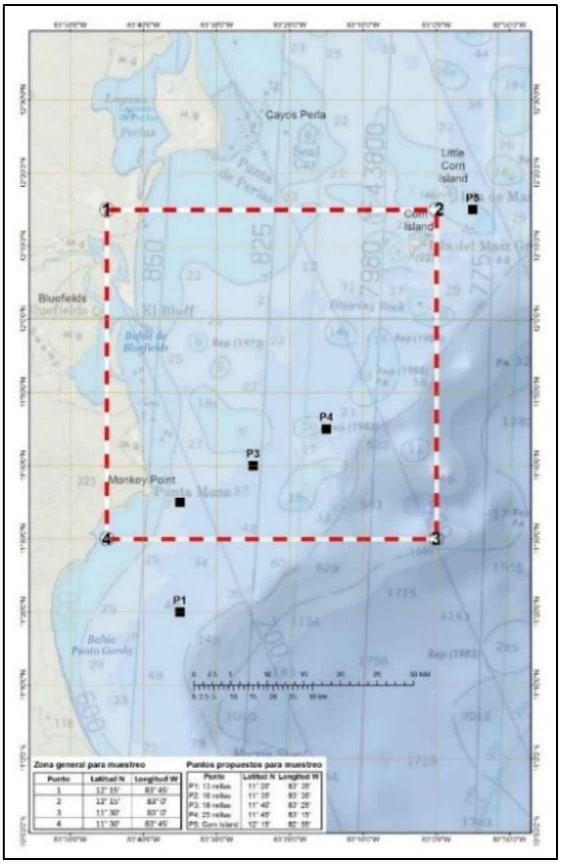

Figure 6. Yellowtail snapper fishing banks in the South Caribbean Coast, Nicaragua

In the same report, a fifth location in Corn Island was identified to have populations of the species, which correlates with reported data from Buitrago & Barahona (2019), in which a characterisation of the coastal-marine biophysical status of the two islands found yellowtail snapper in at least four coastal marine conglomerates.

One essential element observed was that the sizes of the fish in these banks differed between reports, with the largest individuals being approximately 45 cm in length and juveniles from 8 cm to 25 cm. This difference in size and distribution was also described by Zajovits (2021), with juveniles in waters closer to the shore and older juveniles and adults in more open waters.

In terms of depth variation, reports from Buitrago and Barahona (2019), Zajovits (2021), and Ibarra-Arana (2016) agree that the species can usually be found within 15 m to 40 m depth which can facilitate the selection of fishing methods for capturing.

3.3.1.2 Morphology and Reproduction

According to (Zajovits, 2021), the yellowtail snapper main physical characteristics are its streamlined body and deeply forked tail.

In terms of reproduction, it has separated sex; the spawning seasonality has been described by Garcia et al. (2003) in Jamaican waters, where spawning occurs during February and later in September and October. In another study by Trejo-Martinez et al. (2011), spawning was reported in the southern Gulf of Mexico from January to September, with peaks in April and

May. Age and growth observed in the Caribbean calculated an age range (years) between 6 to 17 years, and fork lengths between 173–681 mm (Garcia, Potts, Rulifson, & Manooch, 2003).

In Nicaragua, observations made *in situ* in different locations of the South Caribbean Coast have demonstrated the presence of juveniles and adults of yellowtail throughout the year; however, more detailed research on the reproductive cycle of the species in the wild should be considered, as it will provide key elements for trials under controlled conditions. This step has also been considered by several researchers because of the importance of defining the reproduction strategy that should be used (Table *3*).

Table 3. Reproduction strategies applied to Lutjanidae species in Latin America and the Caribbean.

REPRODUCTION STRATEGIES FOR LUTJANIDAE SPECIES IN LATIN AMERICA AND THE CARIBBEAN					
Country	**Species**	**Methodology**	**Results**	**Difficulties**	**Reference**
México	Yellowtail snapper (*Ocyurus chrysurus*)	Natural and hormonal induced spawning	Reproduction achieved	Larval rearing methodologies under research Dependent on wild-stock populations due to low availability of seed (juveniles) coming from aquaculture production	(Mexican Research Institute of Fisheries and Sustainable Aquaculture, 2021)
	Spotted snapper (*Lutjanus guttatus*)	Natural and hormonal induced spawning	Reproduction achieved with larval rearing protocols established	Increase of larval survival for commercial scale production	(Abdo-de la Parra, Rodríguez-Ibarra, Rodríguez-Montes de Oca, Velasco-Blanco, & Ibarra-Castro, 2015) (Ibarra–Castro, Muñoz-Meza, & Álvarez-Lajonchere, 2012)
Cuba	Mutton snapper (*Lutjanus analis)*	Natural spawning	Reproduction achieved	Larval rearing methodologies under research	(Fisheries Research Center (CIP); Japan International Cooperation Agency (JICA), 2022)
Nicaragua	Spotted snapper (*Lutjanus guttatus*)	Natural spawning	Reproduction achieved and survival up to 46 days	Larval rearing methodologies under research Acclimation period of broodstock >12 months	(Aguilar, Palacios , Osorio, & Hsieh, 2022)

Other existing studies can also be used to develop pre-experimental strategies. A description of histological criteria developed by Brown-Peterson et al. (2011) and that was used to determine reproductive phases of yellowtail snapper in a study performed by (Trejo-Martinez, Brule, Mena-Loria, Colas-Marrufo, & Sanchez-Crespo, 2011), can be seen in Appendix 3. In addition, breeding of yellowtail snappers has been achieved and described by Riley, Holt, & Arnold (1995). A graphic reference of larval growth and morphology is provided in Appendix 4.

Furthermore, since the yellowtail snapper is part of the Lutjanidae family, there have been research focusing on the reproduction of other species of this family, such as spotted snapper *Lutjanus guttatus*; a detailed description of the characteristics of egg stages and maturation stage of the ovary and testicle can be found in Appendix 5 (Lucano-Ramirez, et al., 2023)

3.3.1.3 Feeding habits

A profitable IMTA might include predatory finfish as a fed species (Nissar et al., 2023). Stated by Riley, Holt, & Arnold (1995), yellowtail snapper is included in the genus of Lutjanus, that includes fishes with carnivorous feeding habits, hence it is an important predator in some reef zones (Vasconcellos, Vianna, Paiva, Schama, & Sole-Cava, 2008).

In this sense, it has been reported that yellowtail snappers usually consume small fishes and invertebrates, such as shrimps, crabs, worms, and cephalopods (Lucano-Ramirez, et al., 2023) (Zajovits, 2021) (Valle-Lopez, et al., 2021) (Garcia, Potts, Rulifson, & Manooch, 2003). Their feeding is not restricted to night periods and their feeding habits are seasonal-related; therefore, they consume more feed outside the spawning season (Zajovits, 2021).

Regarding artificial diets for carnivorous species, protein requirements have been reported to be between 40% and 50% during the initial stages (Kiran, 2023). Moreover, certain feed trials with Lutjanidae species (*L. guttatus)* have included up 48% of crude protein (Silva-Carrillo, Hernández, Hardy, González-Rodríguez, & Castillo-Vargasmachuca, 2012). In addition, there is great interest in finding alternatives to replace fish meal in fish feeds. Some studies have shown that *Ulva lactuca* can be used for up to 25% inclusion without negative effects on the production of this species (Lasco, 2023).

In feed formulation trials executed by the Department of Aquaculture INPESCA, the utilisation of a mixture of fresh seafood reached 43% protein content for juveniles of the carnivorous species, common snook. However, feeding trials to evaluate their efficiency in growth performance could not be conducted.

Moreover, some researchers have found that Lutjanus species tend to differ in prey selectivity according to their sex (Valle-Lopez, et al., 2021), and division between females and males, especially when reproductive sizes are achieved, could be considered for better feed formulation. Taking this into consideration for the technical handling of this project, it could lead to better feed formulation strategies and avoid economic losses due to the possible low preference of the fish for the feed.

For larval feeding strategies, it has been demonstrated that a mixture of microalgae with copepods, and later the use of enriched Artemia prior to the inclusion of artificial diets, can cope with the nutritional requirements of carnivorous species such as spotted snapper (Abdo-de la Parra, Rodríguez-Ibarra, Rodríguez-Montes de Oca, Velasco-Blanco, & Ibarra-Castro, 2015). According to Bennett-Wilson (2018), the enrichment of Artemia over a period of 12h significantly improved the content of essential fatty acids in common snook larvae.

3.3.1.4 IMTA experiences

Only one pilot-scale co-culture study using yellowtail snapper (*O. chrysurus*) has been performed by Lasco (2023), where fish were stocked at densities below 26 kg per m^{-3} together with macroalgae (*Agardhiella subulata, Caulerpa racemosa, Gracilaria caudata and Ulva lactuca*) on land facilities. Water quality parameters (dissolved oxygen (DO), pH, phosphorus, total ammonia nitrogen (TAN), and CO_2) were measured, and the results showed that the different species did not have negative performance when co-cultured. On the contrary, algae have positive effects on water quality, given their bio-extractive properties.

Other research, under monoculture systems, focused on rearing performance of yellowtail snapper under different stocking densities in seawater RAS, demonstrating that the lower stocking density of 10 fish/tank gave higher growth after 238 days of trial compared to 20 fish/tank (Beltrán, Vela, Dumas, & Peñalosa, 2022), which correlates with results from García, Cervantes, & Ancona (2006), who found better growth performance of the species in floating cages under 10 ind/1.5 m^3, compared to 15 ind/1.5 m^3.

3.3.2 Brown sea cucumber (Isostichopus badionotus)

3.3.2.1 Geographical distribution

At the regional level, brown sea cucumbers (Figure *7*) can be found in the Atlantic Ocean, Gulf of Mexico, and the Caribbean Sea, from North Carolina in the United States to the south of Brazil (Martinez-Milian & Olvera-Novoa, 2016).

Figure 7. Brown sea cucumber (Isostichopus badionotus) Courtesy of Eliezer Suazo, INPESCA 2023

In Nicaragua, the species is locally distributed, with a higher presence on the North Caribbean Coast than on the South Caribbean Coast; however, both locations are active fishing grounds. The species has been reported to be found in shallow waters between 5 m and 15 m in depth, in sandy areas around reefs (Alfonso, 2006) with cyclical feeding habits, feeding during the day and night, but with higher activity before midnight.

Specifically, the brown sea cucumber is not present in the coastal area of the Corn Islands (Buitrago & Barahona, 2019), and its distribution expands to the west (Figure *8*), in a triangular area between Corn Island, Set Net Point, and Bluefields. Capturing and transporting individuals is possible following environmental considerations such as seasonality (capturing in the open season), quantity, growth stage, and capture zones.

Figure 8. Reported area of distribution of brown sea cucumber (*I. badionotus*) populations, West of Corn Island, Nicaragua.

3.3.2.2 Morphology and Reproduction

Sea cucumbers are omnivorous invertebrates (Liu, Tian, Wang, & Gao, 2009). The body wall of sea cucumbers is the main edible organ processed for commercialisation (Gao & Yang, 2015). Sea cucumbers have separated sex without external differences; therefore, gonad examination is required to identify the sex (Pasquini et al., 2022). During the reproductive stage, the single gonad becomes enlarged prior to spawning.

In Nicaragua, there is a gap in knowledge regarding the seasonality of reproduction of sea cucumber species reported in the Caribbean Sea. However, from capture fisheries research missions, minimum allowable catch length has been established for each species under “pre-cooked” method, which for brown sea cucumber is 4.72 inches, equivalent to 20 individuals per half kilogram (INPESCA, 2017).

Guzman et al. (2003) reported that the minimum reproductive body length is 13-20 cm and 150 g of weight. In another study, the maximum length observed at the adult stage was 45 cm (Alfonso 2006).

For tropical species, such as *I. badionotus*, reports have shown that gonads are present year-round with different developmental stages according to the reproductive season (Slater & Chen, 2015). For this reason, other species with similar biological characteristics, such as *Holothuria scabra*, can be used as a reference (Appendix 6). In general, the life stages of most species are gastrula, auricularia, doliolaria, pentactula, early juveniles, late juveniles, and adults (Altamirano & Rodriguez, 2022). Regarding reproduction strategies, Table *4* shows the different methodologies that have been used in countries with vast knowledge on sea cucumber rearing. Although all reproductive methodologies require sufficient knowledge of pre-spawning behaviour and gonadal maturation, because of the success in its application and lower cost of implementation, the most suitable method to be implemented in this project could be thermal stimulation.

Table 4. Spawning induction strategies for sea cucumber.

SPAWNING INDUCTION STRATEGIES FOR SEA CUCUMBER					
Country	**Species**	**Methodology**	**Results**	**Difficulties**	**Reference**
Philippines	Sandfish *(Holothuria scabra)*	Thermal stimulation	Successful spawning trials with mature broodstock	Sex ratio is unknown until first trial is performed Strategy for cooling/heating water is required	(Altamirano & Rodriguez, 2022)
		Spirulina "baths"	Alternative or complementary method to thermal induction	Requires initial evaluation of concentration	
Australia	Sandfish *(Holothuria scabra)*	Gonad extraction	Successful spawning trials can be executed from using "gonad bank"	Storage period of gonads needs to be evaluated for different species	(Agudo, 2007)
		Algamac "baths"	Alternative or complementary method to thermal induction	Requires initial evaluation of concentration	
		Thermal stimulation	Successful spawning trial with mature broodstock	Sex ratio is unknown until first trial is performed	(Giraspi & Ivy, 2005)
Kiribati	Sandfish *(Holothuria scabra)*	Thermal stimulation + Algamac "baths"	Successful spawning trials if collected broodstock has mature gonads	Sex ratio is unknown until first trial is performed	Secretariat of the Pacific Community (SPC) 2015

3.3.2.3 Feeding habits

The brown sea cucumber is a deposit feeder (Martinez-Milian & Olvera-Novoa, 2016), meaning that it feeds on organic matter, bacteria, and microphytobenthic content in soft sediments (Slater & Chen, 2015). Sea cucumbers, especially bottom feeders such as brown sea cucumbers, have selectivity based on the organic content of the sediment and grain size. Therefore, their daily movement is mostly driven by feed availability (Dar & Ahmad, 2006).

In general, sea cucumbers have less demand for formulated feeds when compared to other species in the trophic chain; therefore, water quality benefits can be obtained from this species when culture systems are sited appropriately (Boyd et al., 2020). Furthermore, given its detritivorous feeding habits, there has been scientific interest in the species for their contribution to marine ecosystems, including their capacity to increase oxidation-reduction, potential to break down detritus from plants and animals, organic matter for bacteria, protozoa, diatoms, and recycling nutrients (Ibarra-Arana, 2019).

In the Caribbean Sea of Nicaragua, species of macroalgae can be explored as feed for the sea cucumber rearing period in tanks. During research field trips made by the Fisheries Research Office of INPESCA, the presence of *Ulva lactuca* and *Sargassum sp*. was recorded floating in the open ocean.

In this context, Martinez-Milian & Olvera-Novoa (2016) showed that the inclusion of certain algae powder in artificial diets has positive effects on the growth performance of *I. badionotus* under culture conditions. Other results from Ibarra-Arana (2019) showed that *Ulva sp*. powder has high palatability attraction, and given its thin cellular wall and low cellulose content, it is easier to digest. For *Sargassum* species, fresh and powder inclusions have been tested, showing a significant difference in the growth performance of sea cucumbers compared with other macroalgal species (Xiao Li, 2022).

Moreover, the use of dried faeces from other aquaculture species as a complementary ingredient with dried macro-algae has been proven to enhance the growth of the Japanese species *Apostichopus japonicus* (Yuan, Yang, Zhou, & Mao, 2006). Other feed ingredients, such as natural marine sand, have been tested in tank rearing, demonstrating that their inclusion has positive effects on growth performance given active feeding (Ibarra-Arana, 2019) which simulates conditions in the natural environment.

3.3.2.4 IMTA experiences

Sea cucumbers and macroalgae are the two most common species used in integrated multitrophic aquaculture systems (Zamora et al., 2016).

In China, IMTA has been performed with shrimp and sea cucumbers, and the results indicated that the body weight and survival rate of sea cucumbers were not significantly affected by shrimp or sea cucumber stocking density (Dong, Fang, Jansen, & Verreth, 2013).

In Malta, the survival of *Holothuria poli* at different depths under fish cages was evaluated (Cujatar, et al., 2022), which were cultured directly below a fish cage at 0, 10, and 25 m distances from the fish farm cages, demonstrating that sea cucumbers grew better in locations near a commercial fish farm, possibly due to the utilisation of nutrients from the waste released by the fish.

In Greece, Chatzivasileiou et al. (2022) also investigated *H. poli* under co-culture with sea bream (*Sparus aurata*), European sea bass (*Dicentrarchus labrax*). The authors concluded that the use of adults instead of juveniles may have been the main cause of the negative growth observed in this study. Furthermore, the authors recommend locating sea cucumbers suspended from the sea bottom to avoid anoxia and underfeeding.

In Canada, the economic value of IMTA using deposit feeders, such as *Curcumaria frondosa* and *Parastichopus californicus*, was evaluated (Carras, 2017), showing that higher profitability is obtained compared to salmon (*Salmo salar*) monoculture.

Furthermore, in Mexico, the REMAPE Project has been executed since 2021 in Mérida, Yucatán, and is so far the only project carried out by private and government institutions regarding sea cucumber aquaculture with *Holothuria floridana* (Reporteros Hoy, 2023). The REMAPE project, like the one proposed in this document, is working with coastal communities for the initial obtention of adults for reproduction trials.

3.4 Socio-economic importance of the species

The Caribbean Coast of Nicaragua is of great importance for fishery grounds. On the South Caribbean Coast, according to the Artisanal Fisheries Department of INPESCA, the three main communities that have the majority of registered fishermen owning fast boats for fishing activities are Corn Island, Bluefields, and Pearl Lagoon.

Approximately 2,500 people are dedicated to sea cucumber fisheries; therefore, considerable efforts have been made to protect the life of fishermen, who dive using a compressor and hose to capture sea cucumbers at different depths (15–40 m). For yellowtail snappers, authorised fishing methods are handlines, gillnets, and longlines, which represent a lower risk of decompression accidents (NTON, 2009).

From daily captures during open season in 2022 (INPESCA) recorded an annual capture of 5.5 million kg of fresh sea cucumber from different species, except brown sea cucumber which is currently under restriction; and 1.5 million kg of yellowtail snapper in the Caribbean Sea.

Brown sea cucumber is the most valuable species exported to the international market. When sold to companies, depending on the species, fishermen can be paid USD 45 to USD 75 per dried pound and USD 10 per fresh pound.

Some yellowtail snapper captures are sold in local markets on Corn Island, Bluefields, Pearl Lagoon. Specifically, the Municipality of Corn Island was reported as occupying the eighth position on the list of top tourist attractions for national and international visitors in 2021 (INTUR, 2021). Therefore, great pressure for finfish supply from the tourist sector has made the yellowtail fisheries industry a key element to maintain economic development on the islands. Prices of yellowtail snapper vary from USD 1.60 to USD 2.46 for uncooked fillet. However, the price of cooked (plated) fillets in restaurants can reach USD 7.67.

Given that there is an already established market for both species, with a promising future for its expansion in local and international markets, the possibility of enhancing the prices of both yellowtail snapper and brown sea cucumber under the co-culture approach could be obtained through environmental sustainability labels, which have been demonstrated to potentially increase market prices (Knowler et al., 2020); (Carras, 2017) (Whitmarsh, Cook, & Black, 2005).

3.5 Legal framework

Because the project is intended to be implemented in Nicaragua, the following national laws and regulations must be considered for its execution:

- Fisheries and Aquaculture Law, N°. 489.
    - Chapter VII. Scientific Fisheries Articles: 87-90, related to special permits for capturing species from the global quota system established for finfish and sea cucumbers.
    - Chapter VIII: Collection and breeding of larvae from the wild. Articles: 91-92, related to the initial stages of any aquaculture project when it is not possible to obtain larvae of the species of interest at the initial stages.
    - Title VI, Chapter I: Aquaculture. Articles: 97-103: Related to the establishment of new projects, a Project Profile needs to be submitted.
- NTON 03 045-09: Nicaraguan Technical Obligatory Norms of Arts and Fishing Methods: Related to the capture of wild larvae, different species have different authorised fishing methods, not only based on capture efficiency but also to prevent by-catch. All the fishing methods used should be addressed in the Project Profile.
- Environmental Evaluation System of Permits and Authorizations for the Sustainable Use of Natural Resources N°. 20-2017: Related to the number of individuals intended to be captured for the project.
- Regulation for the Discharge of Wastewater N°. 21-2017: Related to the treatment of water effluents from aquaculture-rearing facilities. Monitoring of water effluents should be performed and presented to the authorities.

4 IMPLEMENTATION CHALLENGES AND OPPORTUNITIES

The difficulties in developing coastal aquaculture should be addressed in four categories: production, ecological, economic, and social (Gibbs, 2009).

In this section, possible challenges and opportunities related to implementing small-scale aquaculture production systems are described.

4.1 Ecological

- *Climatological events:* The Atlantic Ocean and the Caribbean Sea are characterised by high climatological activity in the presence of tropical depressions, tropical storms, and/or hurricanes that have caused different scales of damage to the coastal communities in that area. In Nicaragua, historical data show that the region most affected by the latest hurricanes is the Caribbean Coast. According to the Meteorological Directorate of INETER, the hurricane season in the Caribbean begins 1 June and lasts until 30 November and it is estimated that more than 80% of these occur between August and September, with September and November being the months of greatest activity.

- *Assimilative capacity (mid- and long-term):* When performing aquaculture activities, initial results regarding the carrying capacity of the ecosystem are of great importance. However, with time, other factors, such as tropical storms or hurricanes, can change the assimilative capacity of the environment, and new analysis on this matter should not be left behind. This is particularly important for cage culture. However, regarding possible water effluents from inland operations, the analysis of total suspended solids and other chemical parameters should be studied.

- *Macro-algae presence*: It is well-known that the yearly appearance of *Sargassum spp.* (Figure *9*) in the coastal areas of the Caribbean Sea has had an enormous impact on tourism as well as on the ecological components of these areas.

  When it reaches areas with less water current, the floating algae can compete for oxygen and decrease light in the water column, causing massive killing of fish species and threatening seagrasses, which, in relation to this project, will serve as a rearing area for sea cucumbers when placed in open water.

Figure 9. Sargassum sp.

The main opportunity for aquaculture and the presence of *Sargassum spp.* comes from the possibility of utilising this macroalgae as an alternative feed for one of the species in the production system, sea cucumbers.

- *Increased sedimentation:* Stocking density is one of the most important considerations when developing aquaculture in floating cages because of its relationship with the periodicity of feeding and percentage of residual feed input into the ecosystem. It is necessary for these densities to be in accordance with the initial research objectives (validation of small-scale production) to avoid changes in the benthic community derived from bad feeding practices.

4.2 Biological

- *Transport of species:* Initial rearing activities rely on wild juveniles. Given the distance between the natural banks and the facilities, a protocol for transporting them via fast boats must be considered, since it represents a high risk of mortality due to stress, possible economic loss, and negative ecological impacts.

- *Reproduction trials:* The main constraint comes from the knowledge gap regarding reproduction cycles in the wild population for both species. As explained earlier, for yellowtail snapper and sea cucumber, initial trials were conducted in other countries using mature individuals that were ready to spawn, but data from wild populations were previously researched. In the specific case of sea cucumbers, their observation is significantly easier than that of yellowtail because of their benthic habits and movement patterns.

  In general, the possibility of capturing adults of both species could provide valuable information about their acclimation, sex ratio, and gonadal maturation. However, the cost of maintenance could increase general expenses, especially with the uncertainty regarding spawning success under controlled operations.

- *Feed formulation:* Daily feeding strategies should be developed not only in quantity, but also in quality. Knowing that the finfish species this project aims to work with is carnivorous, a high percentage of crude protein and other micro-and macronutrients must be included in the feed formulation for juveniles and adults. Correct evaluation of the proximate composition of the feed represents a high cost, at least at the initial stages of formulation validation.

  Special attention should be given to feeding fish larvae, including the production of Artemia, copepods and rotifers, in this matter INPESCA has already gained experience by working with common snook at the Caribbean Pearl Laboratory. However, detailed analysis of fatty acid composition and other key nutrients for larval development should be studied specifically for the yellowtail snapper, given its carnivorous habits.

- *Disease management:* When aquaculture activity occurs, the risk of diseases introduced into the system is an imminent threat. This risk increases when working with two different species from different trophic levels, particularly in inland facilities. Therefore, it is important to develop contingency plans. An evaluation of possible diseases should be performed based not only on the identification of natural pathogens existing at the site prior to the project, but also focusing on those with higher risk of proliferation given stocking density, feed input, and waste.

4.3 Socio-economic

- *Land use and consultation:* The Caribbean Coast of Nicaragua has historically been inhabited by indigenous and Afro-descendant communities, who have protected their cultural and social heritage over the years. Within these social traditions, land use is one of them and is based on communal use. In this sense, the establishment of public and private investment projects must go through a consultation process before the Regional Government of the Southern Caribbean Coast, which is the highest authority in the region in which this project intends to be established.

- *Investment:* Although initial investment and other maintenance costs for inland facilities and cage construction can be funded by the Government of Nicaragua, other alternatives must be considered for funding. As in previous cases, the Food and Agriculture Organisation of the United Nations (FAO) and the Japanese International Cooperation Agency (JICA) have collaborated on projects regarding fisheries and aquaculture. Also, the Central American Bank for Economic Integration (CABEI), has supported the aquaculture promotion plan of the government through INPESCA.

  Furthermore, the Republic of Nicaragua currently has a Free Trade Agreement (FTA) with the People's Republic of China signed on 31 August 2020 and has been officially running since January 2024 (MHCP, 2023). Under this FTA, 71% of the country's export products have immediate access to the Chinese market, with the possibility of increasing significantly.

  Another benefit is related to cooperation funds for research linked to the fishing and aquaculture sector in Nicaragua, for which INPESCA is currently working on project proposals regarding key aquaculture topics to be presented soon. In addition, private Chinese investors are expected to establish businesses around aquaculture species, especially sea cucumbers in the Caribbean.

  - *Equipment acquisition (technology):* Local markets can offer equipment to be used for the construction of aquaculture systems. However, specific RAS systems and durable cage materials must be imported. The main constraint is economical in terms of the cost of materials and shipping, but special consideration is given to import prices for government projects and private investments.

- *Research collaboration:* As part of the Development Plan for the Caribbean Coast and High Wangki and Bocay 2019-2029 executed by the Government of Reconciliation and Unity of Nicaragua (GRUN, 2019), all activities that take place in these areas must bring not only economic revenues to the communities involved but also positive social impacts on innovation and knowledge transfer.

In this sense, the establishment of a research project such as the one proposed here must include the participation of academic entities that will act as facilitators for research development with students involved in Marine Biology, Aquaculture programs, and other national research centres. These entities are Bluefields Indian and Caribbean University (BICU), University of the Autonomous Regions of the Nicaraguan Caribbean Coast (URACCAN), National Agrarian University (UNA), National Technological Center (INATEC), and Center for Research in Aquatic Resources of Nicaragua (CIRA-UNAN Managua).

5 ACTION PLAN

Based on the information collected through the literature review, the following content aims to provide a step-by-step recommendation guide for the execution of a small-scale aquaculture production system considering the administrative, ecological, biological, and social components for a better decision-making process.

5.1 Component I: Administrative procedures

5.1.1 Submission of the project to national authorities

Approval for any project will be given only after all the institutions (Figure *10*) involved have revised and agreed on the documentation. If necessary, meetings to address enquiries would be carried out. The process might take 1 to 2 months.

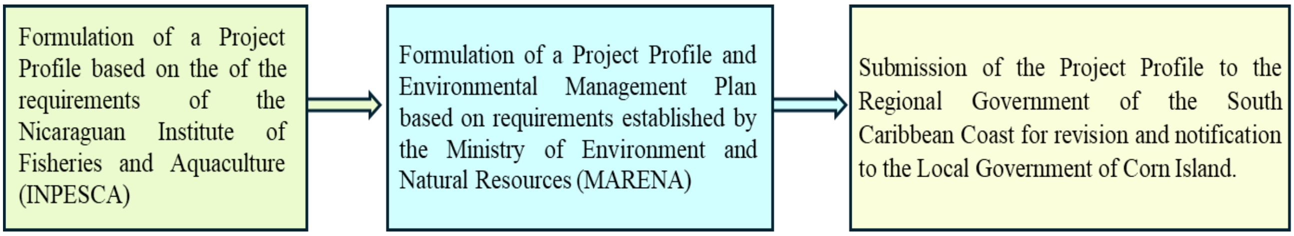

Figure 10. Application procedures for new aquaculture projects in Nicaragua.

5.1.2 Social consultation

Social consultation can take place only after the approval of the project profile by administrative institutions. In this sense, the organisational scheme that should be considered is presented in Figure *11*.

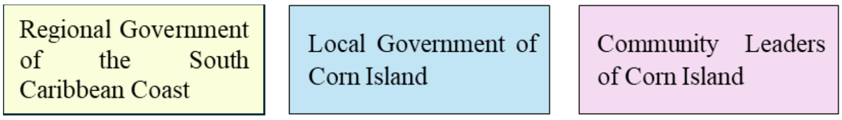

Figure 11. Stages of social consultation for new projects in the Caribbean Coast of Nicaragua

Since communities from different coastal areas in the South Caribbean Region will be aware of the execution of this project, other community leaders from Pearl Lagoon and Pearl Cays should take part in informative meetings.

Most importantly, the goal of the consultation should be not only to obtain a general perception of the execution of the project, but also to discuss the selection process for the participation of local fishermen. In this sense, leaders can inform the participants of the knowledge-transfer stage for future implementation of the project in their communities.

5.2 Component II: Ecological

5.2.1 Suggested sites of implementation in Great Corn Island

Based on the existing knowledge about the ecological and environmental characteristics that were described earlier in this document, infrastructure accessibility, the recommended sites for the possible establishment of small-scale aquaculture inland facilities and floating cages for an IMTA system in Great Corn Island are presented in Figure *12*.

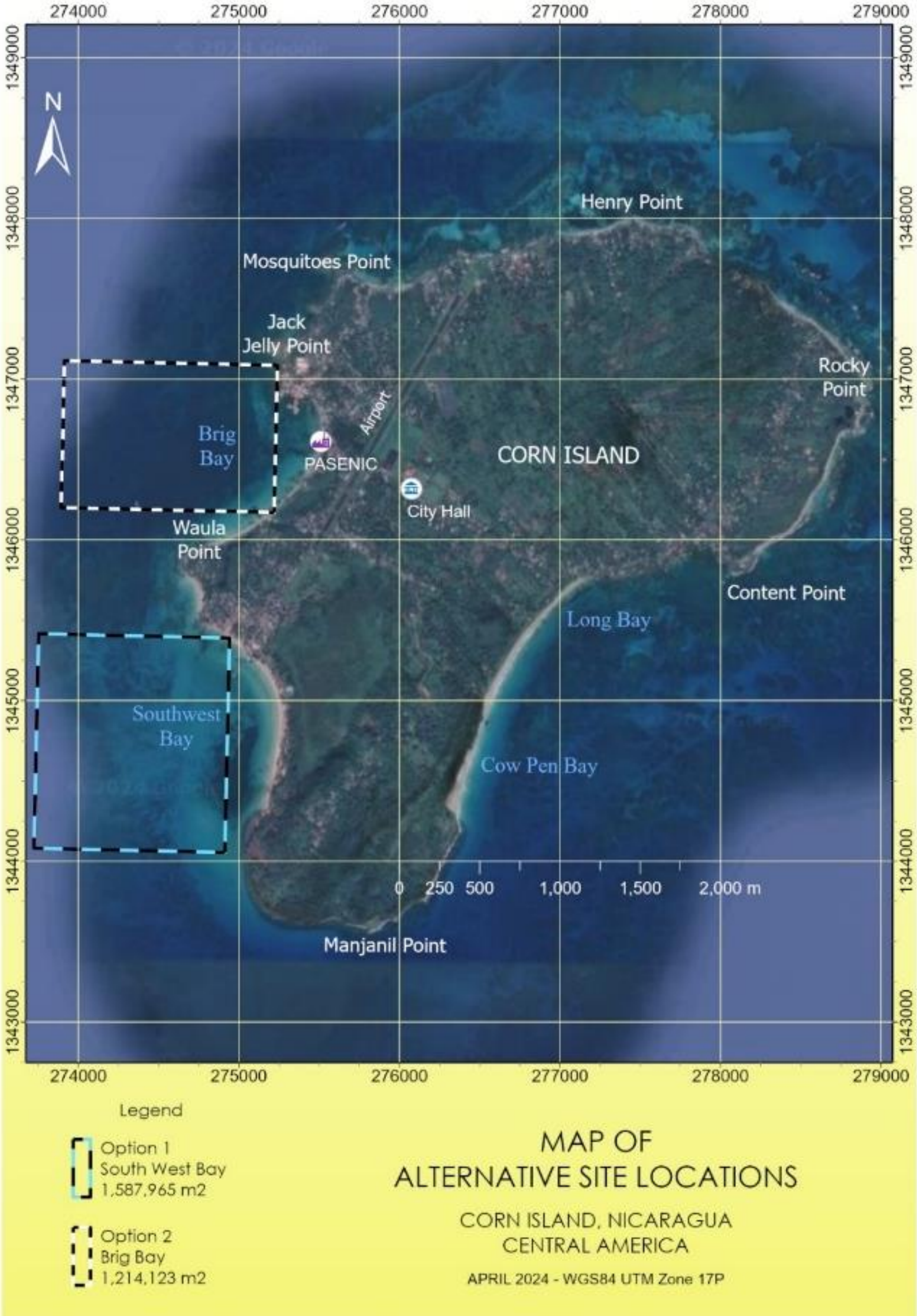

Figure 12. Site proposal for the implementation of a small-scale aquaculture production system under IMTA approach in Corn Island, Nicaragua.

Site 1: Locally known as Southwest Bay, which presents the deepest waters near the shore of all the islands, with mostly sandy bottoms and unevenly distributed seagrass patches. The total area that could be utilised is approximately 1.5 km^2, with easy access by boat and a low risk of accidents caused by maritime traffic.

Site 2: Locally known as Brig Bay, this area has a higher coverage of seagrass and sandy bottoms. The total area that could be utilised is approximately 1.2 km^2, and the location has an advantage over others because of accessibility, since the inland infrastructure could be established for the laboratory in front of the bay. However, it presents a higher risk of accidents because of maritime traffic as the communal dock is located slightly north of the bay.

The sites described here have one common and important ecological characteristic: the absence of nearby coral reef systems. This aspect facilitates the sampling of water quality parameters, sediment, and benthic populations, and the possibility of cage deployment without harming coral populations.

Furthermore, regarding the establishment of inland facilities, a suitable alternative could be collaboration with the well-established company PASENIC, which has historically been involved in economic activities related to fisheries in the Caribbean Coast. The second possibility is the construction of new facilities; however, this process requires further calculations of investment and construction time.

5.2.2 Ecological evaluation pre and during operations.

Previous research on the ecological status of Corn Island, described in the literature review, provides valuable information. However, a list of specific ecological aspects relevant to aquaculture operations should be evaluated at the two suggested implementation sites (Table *5*) to help decide which area is ecologically more suitable for the implementation of this project.

Table 5. Ecological parameters suggested for evaluation pre and during the execution of the project.

<table>
<tr><th>Evaluation parameter</th><th>Indicators</th><th>Type of duration</th><th>Expected outome</th><th>Responsible</th><th>Collaborators</th></tr>
<tr><td>1. Water quality</td><td>Variations of physical and chemical parameters</td><td rowspan="4">Permanent - Once per month for at least 12 months</td><td>Record of water quality parameters to be used for impact projections on the environment due to aquaculture activities</td><td rowspan="4">INPESCA</td><td>CIRA UNAN-Managua</td></tr>
<tr><td>2. Oceanographic</td><td>Velocity of currents, wave height, and tides during normal and extreme conditions</td><td>Determination of current speed and oxygen availability for stocking density management</td><td>BICU</td></tr>
<tr><td>3. Benthic community and sedimentation</td><td>Biodiversity index analysis of substrates at 0, 15, 25, 50, 100, 150 m</td><td>Record of benthic fauna used for ecological projection of the site under aquaculture activities</td><td rowspan="2">CIRA UNAN-Managua</td></tr>
<tr><td>4. Effluent discharge</td><td>Maximum allowable values by Law 21-2017 of effluent discharge from the aquaculture system into oceanic water</td><td>Record of permissible water parameters dispossal from aquaculture activities in the aquatic environment</td></tr>
</table>

Parameters one, two and three refer especially to on-site conditions, and parameter four refers to expected water effluent discharge from aquaculture facilities. It is recommended that calculations of this last parameter be taken as if it operates under a flow-through system because it represents a major input of water into the sea. All parameters should be evaluated for at least one year to gain a better understanding of the changes in different weather patterns.

5.3 Component III: Biological

The necessary information required for a complete understanding of the biology of the species to be used in this project is described in *Table 6* and *Table 7*.

5.3.1 Information from wild populations

Table 6. Suggested evaluation aspects of wild populations for aquaculture purposes.

Task	Objective	Species	Type of duration	Expected outcome	Responsible	Other participants
Obtention of detailed information on the wild population	Status of populations on the pre-identified fishing grounds in the South Caribbean Coast	Yellowtail snapper	Punctual – Only for initial collection. Extendable for other fisheries management purposes	Selecting fishing banks with abundance of the species be used as source of seed for aquaculture purposes	Fisheries Research Department and Aquaculture Department (INPESCA)	Fishermen / Community
	Status of populations on the fishing grounds near Corn Island	Brown sea cucumber		Identifying fishing banks with greater abundance of the species to be used as source of seed for aquaculture purposes		

5.3.2 Biological information for aquaculture

Table 7. Suggested evaluation aspects for aquaculture rearing strategies.

Task	Objective	Expected outcome	Type of duration	Responsible	Other participants
Obtention of detailed information on the biological requirements of yellowtail snapper and brown sea cucumber	Transport of individuals	Establishing the transport protocols with lower risks of mortality from the fishing grounds to the aquaculture facilities	Punctual – Only when new individuals are collected	Department of Aquaculture (INPESCA)	Department of Fisheries Research (INPESCA)
	Acclimation	Understanding the survival rate of the species from wild to controlled environments			N/A
	Feed formulation	Establishing the feeding protocols starting from the transitional requirements of the species from the wild and the different grow up stages	Permanent		BICU and URACCAN
	Reproduction	Understanding the reproduction cycles under controlled conditions and seasonality efficiency of the trials	Long-term - Executed based on optimal conditions of broodstock		

5.4 Component IV: Aquaculture production system

5.4.1 Rearing

The present project can be executed in two different types of systems, as described in Table 8.

Table 8. Aquaculture rearing system proposal for yellowtail snapper and brown sea cucumber.

AQUACULTURE REARING SYSTEM PROPOSAL							
Type of system	**Species/ Stage**	**Weight (g)**	**Density**	**Feeding**	**Estimated growth time (months)**	**Harvest weight (g)**	**Harvest length (cm)**
In-land	Yellowtail snapper						
	Juveniles	5-10 g	6 ind/m^3	Fresh / Dry (experimental)	~8	100 g	
	Broodstock	>900 g	1-2 ind/m^3	Fresh			
	Brown sea cucumber						
	Juveniles	2-4 g	5 ind/m^2	Dry (experimental)	~3	80 g	
	Broodstock	>150 g	3 ind/m^2				
Cage culture	Yellowtail snapper						
	Grow-out	>100 g	4 ind/m^3	Fresh	~10	680-907.2 g	>35 cm
	Brown sea cucumber						
	Grow-out	>80 g	5 ind/m^2		~6	>200 g	>20 cm

5.4.1.1.1 In-land facilities

- For yellowtail snappers, it is recommended to use circular HDPE tanks of at least 4 m diameter and 1 m height, with a water capacity of 12 m2 for juveniles. For broodstocks, tanks with a diameter of at least 6 m are necessary.
- The initial weight stocking for yellowtail snapper is 5-10 g, with 6 individuals per cubic meter of water. The suggested weight to harvest and relocate to floating cages is 100 g.
- It is suggested that broodstock remain in land facilities for better control.
- The initial weight stocking for sea cucumber is 2-4 g, with 5 individuals per meter squared in the tank surface. The recommended weight to harvest and relocate to the cages is 80 g.
- Sea cucumbers can be placed with yellowtail snappers for IMTA evaluation at any given size, but special attention should be given to stocking densities.
- Under monoculture conditions, sea cucumbers can be allocated to circular fibreglass tanks of 1 m diameter and 1 m height. For smaller individuals (< 10 g), larger sizes can be allocated to the same tanks, but special attention should be given to the stocking density. Broodstock individuals should be placed in rectangular tanks of 3 m length x 2m width x 1.5 m height for 9 m^2 of rearing area.
- If the rearing activities of finfish are to be performed under monoculture settings, daily water exchange through syphoning to remove faeces and other feed particles is necessary, removing no more than 20% of water per tank. This material can be reused, as explained in Section *5.4.2*.

- Permanent aeration in tanks is necessary, and daily measurements of temperature, salinity, dissolved oxygen (DO), and other relevant water-quality parameters should be performed.

5.4.1.1.2 Cage culture

- For management purposes, circular floating cages no greater than 4 m in diameter should be considered in this project.
- Daily measurements of temperature, salinity, dissolved oxygen (DO), and other relevant water quality parameters should be performed.
- Monitoring external pathogens and monthly analysis of microbiological content in marine water should be performed as disease control management strategies.

5.4.2 Feeding

Because artisanal anglers perform fishing activities almost every day, a significant number of finfish, crustaceans, and macroalgae can be captured as bycatch species that can be reutilised for feed formulation, as shown in Table 9, to evaluate the effectiveness of their use on the growth performance of the species of interest in this project.

Table 9. Proposal of diet formulation for yellowtail snapper and brown sea cucumber.

DIET FORMULATION PROPOSAL*			
Yellowtail snapper		**Brown sea cucumber**	
Ingredients	*% of inclusion*	*Ingredients*	*% of inclusion*
Fresh shrimp meat	35	Macroalgae powder	54
Fresh fish meat	20	Soybean meal	42
Fishmeal	20	Cellulose	2
Shrimp meal	20	Vitamin and mineral pre-mix	2
Vitamin and mineral pre-mix	4		
Fish oil	1		
Total	100	Total	100

Yellowtail snapper: It is recommended to feed on approximately 15–10% of biomass daily for early juvenile phases. The suggested percentage of feed given should be adjusted according to weight gain (Table *10*), which should be measured every 2-3 weeks. For adult stages, feeding 3-4 times a week until satiation should allow weight maintenance.

Table 10. Suggested feeding regime according to biomass.

Weight of fish (g)	*% Biomass*
5	15
10	10
50	5
100	3
500	1

Diets should be prepared and delivered fresh and stored, as decomposition of the ingredients can cause water quality and mortality issues. Moreover, all diets should be tested for proximate composition following the analytical methods adopted by the AOAC to guarantee optimum protein and lipid contents.

Brown sea cucumber: The macroalgae *Ulva lactuca* and *Sargassum sp.* can be used for feed formulation; however, it is necessary to perform an attractivity trial with any of the macroalgae to evaluate palatability. The diets can be prepared and stored for no longer than 7 days at 4°C. The use of natural marine sand and small amounts of sea grass can be included as fresh feed at the bottom of tanks during grow-out stages in land facilities. Regarding the reuse of faeces from fish and other particles removed from the tanks, the material can be dried and mixed. It is important that when sediment is used at the bottom of the tank, inspection of the colour and smell of the sand is performed weekly.

It is recommended to feed approximately 3% of body weight daily for juvenile sea cucumbers. Adult individuals can be placed in open water under a fish cage using the sea ranching method, where natural feeding habits are acquired. Weight measurements are suggested once every 3 weeks.

5.4.3 Reproduction

Knowledge of the reproduction of species in nature is critical for new aquaculture projects because of the high dependency on broodstock collection from the wild.

Because of their benthic habits and slower movements, sea cucumbers are relatively easier to study than yellowtail snappers. Therefore, it is suggested that initial efforts are put into this species. However, the following are a group of recommendations regarding future reproduction trials for both species.

5.4.3.1 Brown sea cucumber

- If collection takes place in more than one fishing bank, individuals should be allocated according to their origin, avoiding mixing in the tanks.
- If only one fishing ground is used, a maximum of 45 individuals are suggested. If different fishing grounds are used, the total number of collected animals should not exceed 20 per location.
- Modifications in the total number of individuals collected should be made only after evaluating the sex ratio obtained from initial reproduction trials, and the installed capacity of the facilities should be considered.
- Because of nocturnal habits and lower temperatures, collection should be done in the evening/nighttime.
- Collection of broodstock should not occur during the spawning season in the wild; instead, it should be at least one month before or after.
- The minimum weight for collection should be >180 g.
- Individuals collected one month prior can be used for natural spawning trials.
- Individuals collected one month later could be used for induced spawning trials.
- Induction trials should be performed only once per month, and only 5–15 individuals from each collection site be used. Identification of sex ratio should be done at this stage.
- Identified females and males should be kept separated after spawning trials.

- The individuals used for the trials should not be reused for at least two months to avoid stress and over-manipulation of the broodstock.
- The initially recommended method for spawning induction is thermal stimulation.
- If successful, a maximum of 2 thousand larvae per litre of water is suggested as the stocking density.
- Special attention should be paid to the weight loss of broodstock, and diets for weight maintenance should be developed accordingly.

5.4.3.2 Yellowtail snapper

- Broodstock should be captured using passive fishing gear as the preferred method; if a mesh to hold them is required, no knots are required.
- The selected location(s) for broodstock capture should be based on ecological evaluations of the stock to avoid capturing juveniles of yellowtail or other species of no interest in the project.
- Only individuals weighing > 900 g (> 1 kg) should be considered.
- The total number of broodstock should be based on the installed capacity in the facilities; however, initial research using five males and ten females is sufficient.
- To reduce stress, no more than two individuals should be allocated to 1 m^2 tanks for their transport, and clove oil should be added to the tanks.
- Constant aeration and dissolved oxygen measurements should be taken during the transport.
- Gonadal index measurements could be performed on some individuals captured only for this purpose, as a general evaluation of the broodstock in that location.
- After arrival, the broodstock should be separated by sex under the same density, as suggested earlier.
- Antibiotic treatment is suggested to be implemented under low concentrations.
- No feed should be given for at least two days to allow total recovery from transportation, and the percentage of feed should not exceed 1% of the biomass.
- Gonadal revision can be performed after total acclimation has been achieved, and only half of the fish should be manipulated per trial.
- Special attention should be paid to the weight loss of broodstock, and diets for weight maintenance should be developed accordingly.

5.5 Component V: Social participation and knowledge-transfer

After social approval is achieved, it is suggested to develop a series of workshops regarding aquaculture and its technical principles with the aim of promoting active social participation and knowledge transfer with local communities and fishermen (Table *11*).

Table 11. Proposal of theoretical and practical workshops to anglers in coastal communities in the South Caribbean Coast of Nicaragua

Workshop topic	Sub-topic	Objective	Responsible	Other participants	Beneficiaries (communities)	Expected outcome
1. Aquaculture: an overview Part I	1.1 Definition of aquaculture 1.2 Marine species currently used in aquaculture (focusing on snapper and sea cucumber) 1.3 Discussion on the potential species for marine aquaculture in the Caribbean Coast of Nicaragua (focusing on yellowtail snapper and brown sea cucumber)	To introduce the definition of aquaculture, its development and importance for socio-economic development	INPESCA	BICU - URACCAN	Corn Island, Pearl Lagoon, Pearl Cays	Understanding of aquaculture as an economic activity and community participation as an important element for its development in the South Caribbean Coast of Nicaragua
2. Aquaculture: an overview Part II	2.1 Ecological criteria for site selection for aquaculture development	To explain water quality parameters and other ecological aspects regarding the site selection parameters to be considered to develop marine-coastal aquaculture		MARENA/ SERENA		Understanding of ecological and environmental factors that should be considered when establishing a marine-coastal aquaculture project
3. Design, construction and maintenance of floating cages for aquaculture	3.1 Types of cages 3.2 Design considerations according to site characteristics 3.3 Types of materials 3.4 Demonstrative small-scale model	To provide theoretical and practical tools for the construction of floating cages with appropriate design and materials		BICU - URACCAN - INATEC Bluefields		Understanding the general principles for the design and construction of floating cages for aquaculture with accessible materials and hands-on small-scale model

	construction (practical)					
4. Biological aspects of yellowtail snapper and sea cucumber	4.1 Distribution (participatory) 4.2 Feeding habits 4.3 Reproduction	To introduce the general biological characteristics of yellowtail and sits implication for aquaculture	INPESCA	BICU-URACCAN		Familiarize the participants with general knowledge of the species of interest for potential marine aquaculture
6. IMTA systems as an alternative to monoculture and the role of aquaculture in marine ecosystems	6.1 Wrap-up of previous workshops and introduction to ecosystem cucumbers, and services provided by marine coastal aquaculture	To explain the ecological and socio-economic aspects of using IMTA systems in marine coastal aquaculture				Understanding of benefits of aquaculture for socio-economic development and ecological restoration of ecosystems in the South Caribbean Coast of Nicaragua

Furthermore, the project should develop a training process within the facilities and research process once it starts to be carried out. This training should include fishermen and academics.

The training provide practical knowledge regarding the following:

- Juvenile acclimation process
- Artificial feed formulation and feeding strategies for yellowtail snapper and sea cucumber
- Water quality management in marine aquaculture systems

The following steps (Table *12*) should be considered before establishing small-scale aquaculture units (floating cages) within the communities.

Table 12. Suggested topics of evaluation prior to the establishment of farming units in coastal communities in the South Caribbean Coast of Nicaragua.

<table>
<tr><th>Task</th><th>Expected outcome</th><th>Responsible</th><th>Other participants</th></tr>
<tr><td>1. Site evaluation for marine coastal aquaculture</td><td>Identification of potential sites within the coastal communities of the South Caribbean Coast for the establishment of small-scale production units under monoculture or IMTA systems depending on conditions for yellowtail snapper and brown sea cucumber.</td><td>INPESCA</td><td>Community</td></tr>
<tr><td>2. Cage construction and deployment</td><td>Build-up small-scale cage production system for individual and/or community-based management (knowledge initially acquired during community workshops).</td><td rowspan="2">Community</td><td rowspan="2">INPESCA</td></tr>
<tr><td>3. Feed formulation using low-cost raw materials</td><td>Evaluation of available low-cost raw materials for the formulation of feed to be used with yellowtail snapper and brown sea cucumber.</td></tr>
<tr><td>4. Value addition of aquaculture species and quality</td><td>Knowledge about product diversification methods and quality management for future commercialization of yellowtail snapper and brown sea cucumber.</td><td>INPESCA</td><td>Community, MEFCCA</td></tr>
</table>

6 CONCLUSIONS

Considering the ecological characteristics of the proposed site, endemic distribution of the species, and possibility of knowledge transfer from other experiences in the region, the implementation of a small-scale aquaculture system that evaluates acclimation, nutritional requirements, and growth rates of yellowtail snapper and brown sea cucumber on Corn Island is feasible. However, due to gaps in knowledge of the reproductive behaviour of wild populations in Nicaraguan waters, which is a pivotal aspect for successful production and economic stability of the project, reproduction trials are not feasible at the initial stages of the project until further information is obtained.

The execution of the project in inland facilities for early juvenile stages is feasible compared to cage culture, as it will allow for faster achievement of the rearing requirements of both species. The use of cages as a culture method for juveniles and adults of yellowtail snapper should be considered only after optimal feed formulation is found to decrease the risks of negative growth and ecological repercussions to the marine environment. However, because of their detritivorous feeding habits, the growth of juveniles and adults of brown sea cucumbers can be evaluated in coastal cages without major environmental concerns.

The benefits of the IMTA approach as a rearing system have been proven to enhance the overall rearing conditions of these two species in previous studies; therefore, its application and evaluation of efficiency in inland facilities can be considered feasible for this project, but its implementation in cage cultures requires further consideration.

This project proposal demonstrates the necessity of implementing research on wild populations as a tool for better execution of strategies for marine aquaculture projects.

If properly executed, the project will allow the acquisition of knowledge on aquaculture methods of two economically important species in the Caribbean Coast of Nicaragua and promote knowledge transfer strategies to coastal communities, which aligns with the policies of the Government of Nicaragua regarding the use of scientific research in service of social inclusion and development.

7 RECOMMENDATIONS

- Research on the reproductive behaviour of brown sea cucumber natural populations is recommended first because their benthic habits and slower movements make them more accessible to work with compared to yellowtail snappers. The collaboration of local anglers is key to this step, as they access distribution areas very often.

- Broodstock collection and reproduction trials can take place only until further studies on the status and reproduction behaviour of populations in different fishing grounds are conducted.

- Technical aspects that have not been described in this document, such as microalgae production, light regime, and possible use of probiotics, are subjects of evaluation to be considered in this aquaculture project, and the collaboration of academia for this matter is recommended.

- Owing to the climatological characteristics of the site suggested for this project, it is necessary to invest in a floating cage with durable and high-quality materials. All aspects of engineering, design, and construction should be consulted by experienced companies in this matter.

- To offer better technical advice to the local communities interested in developing small aquaculture farming units with any of the two species, the dissemination of knowledge and access to the project for academic purposes and informative workshops should be considered an integral part of the success of this project.

- It is recommended that the research methodology of previous INPESCA fellows' projects, "*The fatty acid composition of enriched artemia and larvae rearing: An overview of common snook (Centropomus undecimalis) culture"* by Mr. Keith Bennett, and "*Effective and low-cost feed for Nile tilapia (Oreochromis niloticus), using alternative ingredients found in Nicaragua"* by Mrs. Tatiana González, are taken into consideration for future live feed production and use of alternative raw materials for feed formulation, and should be adapted in accordance with the species considered in this project.

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ANNEX

Annex 1: Proposal of Field Guide: Sampling for the analysis of physical-chemical and microbiological parameters in oceanic waters.

NICARAGUAN INSTITUTE OF FISHERIES AND AQUACULTURE

Aquaculture Department

Objective: To describe the collection of oceanic water samples for monitoring physical and chemical parameters, phytoplankton, and zooplankton, and as a means of *in situ* consultation during monitoring and technical assistance of marine coastal aquaculture projects.

I. Methodology

The physical and chemical parameters will be taken with the available and previously calibrated field multiparameter equipment. Currently, the Aquaculture Department has a HANNA 9828, which allows the measurement of pH, temperature, electrical conductivity (EC), salinity, Redox Potential, dissolved oxygen (O_2), and total dissolved solids (STD). It is necessary to verify the units of measurement used by the multiparameter and reflect them correctly in the field notes.

Because ocean water samples are carried out at depths greater than 30 m, three depths are the main ones to measure: the first with the Secchi Disk, the second with a probe, and the third the calculation of the photic zone (depth obtained with the Secchi Disk in meters, multiplied by 3). Once these data are obtained, the field technician must establish the distances and replicas per sample to collect not only the required amount of water for the requested analyses, but also an additional one for the phytoplankton and chlorophyll a samples, which is explained further forward.

It is recommended that field parameters be recorded continuously from 0.5, 1, 3, 4, and 10 m, and subsequently every 5 m until the total depth of the sampling point is completed. All decisions regarding the establishment of distances will be at the discretion of the field technician after evaluating the site conditions.

Another factor to consider is the significant or abnormal variations in the field parameters recorded during sampling. If there are changes that the field technician considers important, the distance from sample collection can be modified, which must also coincide with the samples from other requested analyses.

Multiparameter HANNA 9828

Once the depths at which the water samples will be taken have been determined, each one must be extracted with the Van Dorn Bottle. The capacities varied from 1 l to 4.5 l. Therefore, it is recommended to carry a plastic container that allows water samples to accumulate.

Van Dorn Bottle (3.5 l)

Integrative sample container

The first sample to be collected will be destined for microbiological analysis. It is placed in a sterile bottle, using latex gloves to avoid contamination. The sample must be immediately stored on ice and remain at least 4°C, and not exceed 7 hours from collection until delivery to the laboratory.

Subsequently, what is called a comprehensive photic zone sample will be carried out, which consists of taking a certain amount of water with the Van Dorn bottle at each sampling point within the photic zone, in such a way that it allows filling all the containers for the analyses of interest, and leave a surplus of water for the analyses explained below:

- Integral qualitative phytoplankton: leftover water from the integral sample will be used, and it will be filtered through a 20-micron mesh, which will be washed and deposited in a bottle without the need for a preservative, storing it on ice with the rest of the containers. In the case of qualitative phytoplankton, it is not necessary to determine the liters of water since “the greater the amount of filtered water, the greater the diversity.” The sample size will be up to the decision of the field technician.

- Chlorophyll a: this is also collected from the excess water of the integral photic zone sample. It is not necessary to filter it; however, it is necessary to store it on ice with the rest of the containers.

For both the analysis of phytoplankton and chlorophyll a, the containers must be amber/dark in colour to avoid photo-oxidation of the samples, which will be provided by the laboratory responsible for the analysis. In the case of chlorophyll a, the analysis should not exceed 24 hours after taking the sample, and throughout its storage it should remain in ice at a temperature no higher than 4°C.

For some water samples, reagents must be added as specified below.

• Nitric acid to preserve total Iron (Fe): 2 ml x every 1,000 ml
• Sulfuric acid to preserve total Phosphorus (P) and Ammonium (NH_4): 2 ml x every 1,000 ml
• Lugol to preserve quantitative phytoplankton: 3 ml x every 1,000 ml

Annex 2: Proposal of Rearing Control Format

Aquaculture Department - Oceanic Water Sampling Format			
Project:			
Technician		Date	
Sample ID		Start time	
Geoposition		Finish time	
Community		Sample distances	
Municipality		Total depth	
Department		Secchi disk	
Elevation	(m)	Photic zone	

Depth (m)	Depth (m)	pH	Temp (°C)	Oxygen saturation	Salinity	TDS: ________	EC: ________
0							
0.5							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Equipment description	
Other information	
Technician (Full name)	
Date	

NICARAGUAN INSTITUTE OF FISHERIES AND AQUACULTURE

Aquaculture Department

I. General information

Technician name: ____

Name of person responsible: _____________________________________

Date: ______________Time: _____________ Location: ______________

Geoposition: ____

Species: ____

II. Aquaculture system information

Tank/cage identification: _____________________

Total tank/cage area/capacity: _______ m^2 _______m^3

Initial tank/cage stocking date: ___(month)___(day)______(year)

Initial tank/cage stocking density: _______ m^2 _______m^3

Initial average weight/length of tank/cage organisms: _______g ________cm

Total number of individuals stocked in the tank/cage: _________

Total tank/cage biomass: ________________

III. Monitoring details (by unit)

No. of individuals sampled (15%): ________

Average tank/cage sample weight: ____________g

Average tank/cage sample length ____________cm

Survival (tank/cage total): __________________

- Controlled feeding (in-land facilities)

Amount of food per tank/cage: _________________g

Feeding frequency: ________________

Type of feed: ____

Weight gain in relation to the previous sampling (%): ______

IV. Water quality during sampling (by unit)

Temperature (°C) _______ pH_______ Salinity (‰) ______

O_2_____ STD (mg. l-1____ g.l-1____) ____

CE (µ3.om-1 __ m2.om-1 __) ____

Depth: _______ m (cages)

Secchi disk: _______ m (cages)

Total water capacity: _______ m^3

Water change frequency (tanks): ______________________

Water exchange percentage (tanks): ______________________

Water treatment (inlet): ___________________________

Water treatment (outlet): ____________________________

V. Other procedures

If applicable:

Tank/cage cleaning: ________________ Date: __________

V. Spawning trials

Date: __________________________

Induction pond water capacity: ________________ m^3

Pre-induction water treatment: __________________ (if applicable)

Number of organisms induced: ______males _____ females.

Induction method used: ______________________________

Start time: ________________ Duration: ___________________

Number of organisms that spawned: _________________________

Number of females: ______________ Number of males: ____________

Fertilization rate: ______________________

Physical condition of eggs: ____________________________________

Density: ______________________eggs/ml

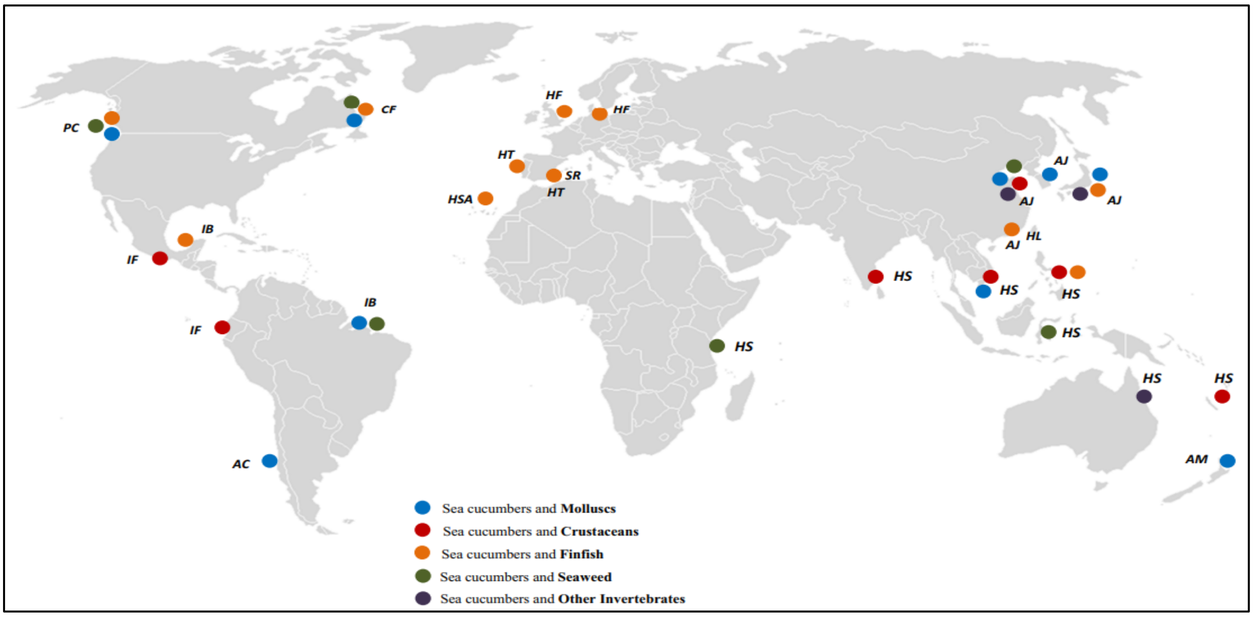
Other information: ____

Observations:

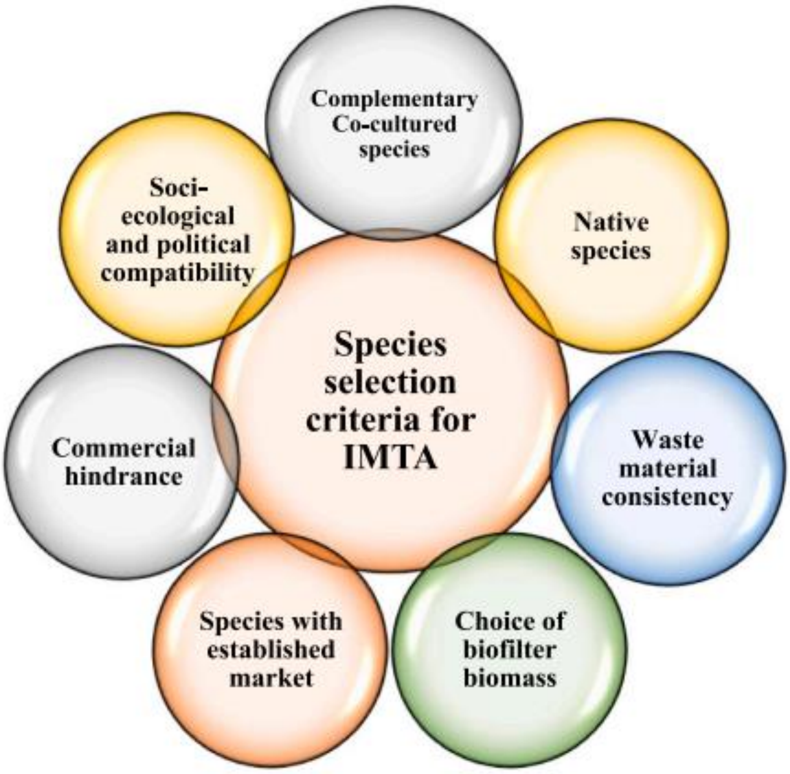
- Once the acclimation period has passed after fishing and prior to stocking in the inland facility tanks, initial weight data must be taken from 100% of all organisms.
- Monthly sampling must be carried out for all the rearing units.
- The equivalent of 15% of the total number of individuals in the pond/cage must be randomly sampled monthly.
- Sampled individuals must stop being fed 24 hours before weighing.
- The raw material used as food (fish meal, shrimp meal, macroalgae, seagrass, commercial product, etc.) and presentation of the food (fresh, dry, pelletised, granulated, or other) per pond must be specified. If the combination of two or more ingredients is carried out for the diets, the percentage of inclusion of each ingredient and the preparation methodology must be presented in the report.
- Mortalities will be reflected in the total of individuals per tank/cage (monthly).

APPENDICES

Appendix 1. Global distribution of sea cucumber IMTA efforts (Mostly experimental coastal- and land-based system (Zamora, Yuan, Carton, & Slater, 2016)



Appendix 2. Species selection criteria for Integrated Multitrophic Aquaculture species (Nissar, et al., 2023).

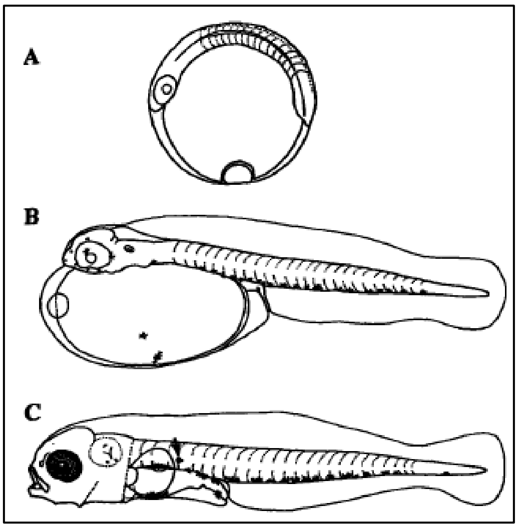


Appendix 3. Histological criteria used to determine reproductive phases in *Ocyurus chrysurus* from the Campeche Bank, southern Gulf of Mexico (Lucano-Ramirez, et al., 2023) (Brown-Peterson, Wyanskib, Saborido-Reyc, Macewiczd, & Lowerre-Barbierie, 2011)

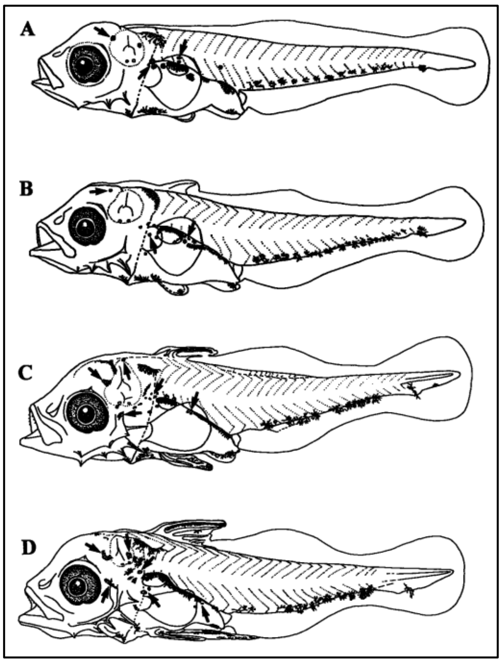
Reproductive phase	Histological features: Female	Histological features: Male
I Immature	Only oogonia (OG) and primary growth (PG) oocytes present.	Inactive spermatogenesis. Only spermatogonia (Sg) present.
II Developing	OG, PG and cortical alveolar (CA), primary and secondary vitellogenic (Vtg1, Vtg 2) oocytes present.	Initial spermatogenesis. Interior lobule totally covered by a continuous germinal epithelium. Sg and spermatocytes (Sc) present.
III Spawning capable	OG, PG, CA, Vtg1, Vtg2 and tertiary vitellogenic (Vtg3) oocytes present. Postovulatory follicles (POF) and early oocyte maturation (OM): early stages of germinal vesicle migration (GVM), may be present.	Active spermatogenesis. Discontinuous germinal epithelium occurs at the proximal part of lobule and continuous germinal epithelium occurs at the distal part of lobule. Sc, spermatids (St) and spermatozoa (Sz) present in lumen of lobules or sperm ducts.
Sub-phase: Actively spawning	OG, PG, CA, Vtg1, Vtg2, Vtg3 and late OM: late stage of GVM, germinal vesicle breakdown (GVBD) and hydration. POFs may be present.	Active spermatogenesis. Discontinuous germinal epithelium occurs even in distal parts of lobule. Sz present in lobule lumen and sperm ducts. Few scattered Sg present.
IV Regressing	OG, PG and some residual CA, Vtg1, Vtg2 and Vtg3 oocytes present, most of them in atresia.	Inactive spermatogenesis. Spermatogonial proliferation along basement membrane and at the distal termini of the lobules. Residual Sz present in lumen of lobules and sperm ducts.
V Regenerating	Only OG and PG present with muscle bundles, connective tissue and blood vessels present at centre of ovarian lamellae.	Inactive spermatogenesis. Interior lobule totally covered by a continuous germinal epithelium. Spermatogonial proliferation; few residual Sz sometimes present in lumen lobules or sperm ducts.

Appendix 4. Growth and morphology of larval and juvenile captive bred yellowtail snapper, *Ocyurus chrysurus.*

Early developmental stages of yellowtail snapper, Ocyurus chrysurus, illustrated from live specimens. (A) late embryo egg, 0.96 mm diameter; (B) 2.23 mm SL newly hatched larva; (C) 3.36 mm, 3 days posthatch (Riley , Holt , & Arnold , 1995).



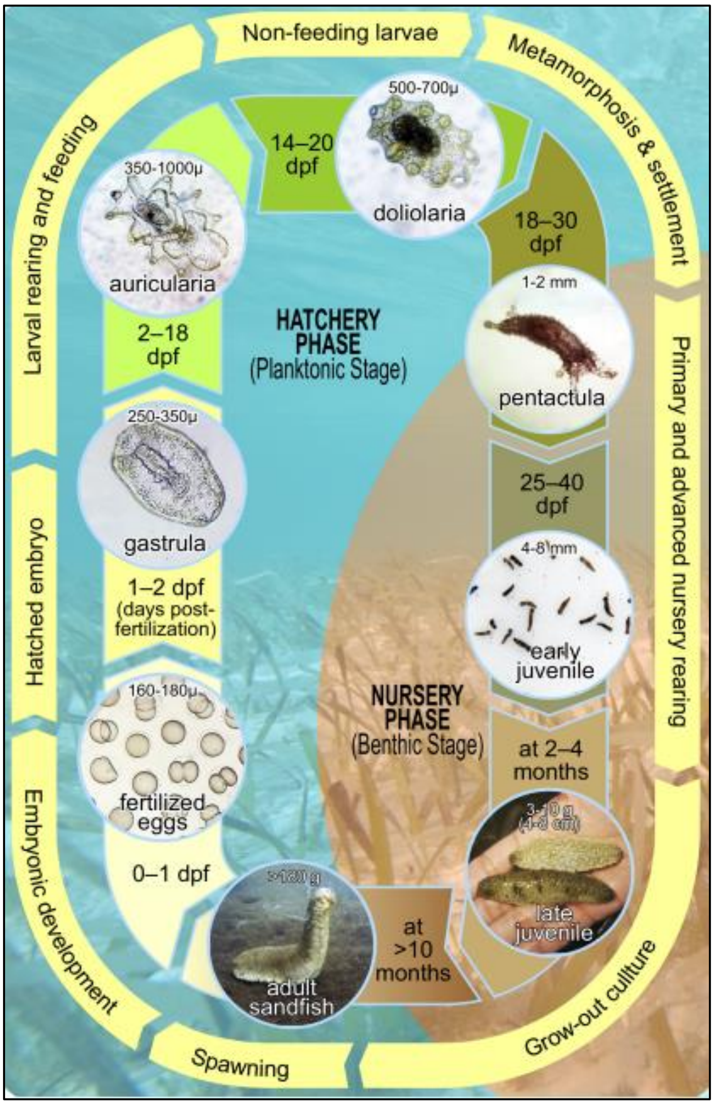
Developmental stages and mean live lengths of yellowtail snapper. Dark arrows indicate the location of yellow chromatophores. CA) 3.67-3.82 mm SL, days 7-9 posthatch; (Bl 4.10-4.53 mm SL, days 10-11 posthatch; (el 4.51 mm SL, day 12 posthatch; CD) 4.11 mm SL, day 13 posthatch. (Riley , Holt , & Arnold , 1995).



Appendix 5. Characteristics for each maturation phase of the ovary and testicle of *Lutjanus guttatus* (Lucano-Ramirez, et al., Reproduction of Lutjanus guttatus (Perciformes: Lutjanidae) captured in the Mexican Central Pacific, 2023).

Ovary in the immature phase	Testicle in an immature phase
The ovaries are small, thin, thread-like, translucent, pale, or dirty white with inconspicuous vascularisation. The ovaries occupy only a small part of the body cavity, and ova are not visible to the naked eye. Histologically, the ovary shows ovigerous lamellae, having nests of oogonia and primary growth oocytes (PG). No atresia or muscle bundles. Thin ovarian wall and little space between oocytes; there is scarce connective tissue between the follicles. The lumen is wide. Virgin	Testes are small, thin, flattened, and ribbon-like, more or less translucent (or opaque) with a smooth appearance. Only spermatogonia (Sg) present and cysts. No lumen in lobules. There are no spermatozoa (Sz) in any testicular área
Ovary in the developing phase	**Testicle in the developing phase**
Ovaries become slightly larger, thicker, opaque, and light yellowish. There is an increase in the weight of the ovary, and they cover a greater space in the body cavity. Blood vessels are becoming more distinct. Histologically, PG, cortical alveolar (CA), primary vitellogenesis (Vtg1), and secondary vitellogenesis (Vtg2) oocytes are present. No evidence of postovulatory follicle (POFs), tertiary vitellogenesis (Vtg3) oocytes, or atresia. Increases the thickness of the ovary wall	Testes are increasing in size and triangular in cross-section, whitish color. The sperm does not flow with pressure. Larger than immature gonads. Spermatocysts are evident along lobules. Sg, spermatocyte (Sc), spermatid (St), and Sz can be present in spermatocytes. Sz is absent in the lumen of lobules or sperm ducts or just a little.
Ovary in a mature phase	**Testicle in a mature phase**
The ovaries are further enlarged, occupying a large part of the body cavity. They are turgid and yellow, and many spherical ova, both translucent and opaque, are present and visible to the naked eye through the thin ovarian wall. The blood supply increases considerably, and the ovary attains its maximum weight. In this phase, ova are sometimes extruded by applying gentle pressure on the abdomen. Histologically, immature oocytes are reduced in number, while a large number of Vtg2 and Vtg3 in stage VII, and germinal vesicle breakdown (GVBD), germinal vesicle migration (GVM), and oocyte maturation (OM).	Large and firm testes well developed, with conspicuous superficial blood vessels; whitish-pinkish color: abundant spermatids and some spermatozoa within seminiferous tubules. The sperm duct is relatively full of sperm. All stages of spermatogenesis (Sg, Sc, St, and Sz) can be present. Spermatocysts throughout testis, active spermatogenesis. Accumulation of sperm in the spermatic ducts, sperm flows with low pressure
Ovary in spawned phase	**Testicle in spawned phase**
The ovaries are flaccid, shrunk, and sac-like, reduced in volume, and have a dull color. The vascular supply is present but is reduced. The weight of the ovary decreases. Some unspawned large ova and a large number of small ova are present. Histologically, the ovary shows some CA or Vtg1, Vtg2, atresia (any stage), and POFs, but not GVBD, GVM, and OM. Muscle bundles and thick ovary wall	Testes are flaccid and bloodshot, pinkish. Sperm may still flow (only a small quantity). Residual Sz is present in the lumen of lobules and sperm ducts. Widely scattered spermatocytes near the periphery containing Sc, St, and Sz. Little to no active spermatogenesis

Appendix 6. Reproductive cycle and larval stages of sandfish *Holothuria scabra*. (Altamirano & Rodriguez, 2022)



Appendix 7: Experience of feed formulation for carnivorous common snook (*C. undecimalis*) utilising by-catch species. INPESCA, 2022.