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# Sustainable Capture-Based Aquaculture of Rabbitfish in Pacific Island Lagoons

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## Introduction

As worldwide landings in capture-based fisheries increase, catch volumes and fish sizes are getting smaller. Both are clear indications of overfishing. Climate change and ocean acidification are also threatening fisheries. Over-fishing is depleting natural resources in Micronesia and other parts of the Pacific, creating a clear need to develop alternatives for the economy and food security for fishing communities. Sustainable capture-based aquaculture of high-value finfish species (Figure 1) has proven to be a viable option for many developing nations worldwide and makes up about 20% of global marine aquaculture production [1]. Capture-based aquaculture entails the use of "seed" fish, crustaceans, or molluscs that have been caught from the wild. Sustainable capture-based techniques for rabbitfishes have recently been developed at the Marine and Environmental Research Institute of Pohnpei (MERIP), opening up an exciting new farming opportunity for rural communities in the Pacific region. The purpose of this fact sheet is to inform resource managers, educators, and prospective farmers of the possibilities and benefits of sustainable rabbitfish cage culture in the U.S.-Affiliated Pacific Islands and broader Pacific.

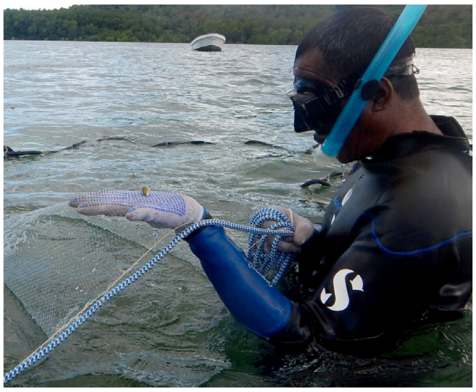

**Figure 1. Capture-based aquaculture can be a sustainable option for Pacific island economies.**

## Why Culture Rabbitfish?

Rabbitfishes comprise a family of tropical reef fishes of the family Siganidae that are abundant in the Indian and Western Pacific Oceans. In Micronesia, rabbitfish, which are locally known as "kioak," make up 18% of all subsistence fisheries and are one of the most preferred food fish locally [2]. Rabbitfish are herbivores (plant eaters), feeding mainly on macroalgae of the genus *Caulerpa* and *Sargassum*. Herbivores require less protein in their diet for good growth than many species of marine fishes. Their plant-based diet means that formulated diets for them can have less protein and more plant-based materials, which improves sustainability and lowers costs. Some species of rabbitfish have additional traits that make them good for aquaculture, namely schooling behavior, or grouping together, and mass spawning [3] in large numbers [4,5].

The potential for rabbitfish culture will be influenced by species selection and location. Understanding the natural life history of local rabbitfish species is one of the first steps in developing a successful capture-based aquaculture program in any region of the Pacific. The following list provides additional advantages for growing rabbitfish in comparison with other finfish in the Pacific region:

- Rabbitfish are one of the most abundant fish in Western Pacific lagoons.
- There is presently no long-term sustainable capture-based aquaculture of rabbitfish in the Pacific Islands.
- There is a demand for sustainably produced reef fish throughout the region.
- Rabbitfish are diverse in color pattern and appearance, making some species suitable for the marine aquarium trade.
- Rabbitfish will eat low-protein formulated fish feeds used to feed other commercially important finfish. They can also feed on algae, or a combination of algae and formulated diets.
- Rabbitfish grow fast in reef lagoon conditions.
- Most rabbitfish are non-aggressive and exhibit schooling behavior in cages.
- Rabbitfish are tolerant to changing conditions, such as temperature and salinity, in water.
- Rabbitfish farming can provide an alternative source of income for rural communities.
- Rabbitfish spawn at the same time, resulting in large quantities of young fish that are naturally available for collection at low cost.
- Sustainable capture of juvenile rabbitfish for farming is more suitable for developing areas than costly hatcheries.
- Growing rabbitfish in lagoon cages is inexpensive compared with growing them in tanks, where pumping water is required.
- Start-up costs are relatively low.

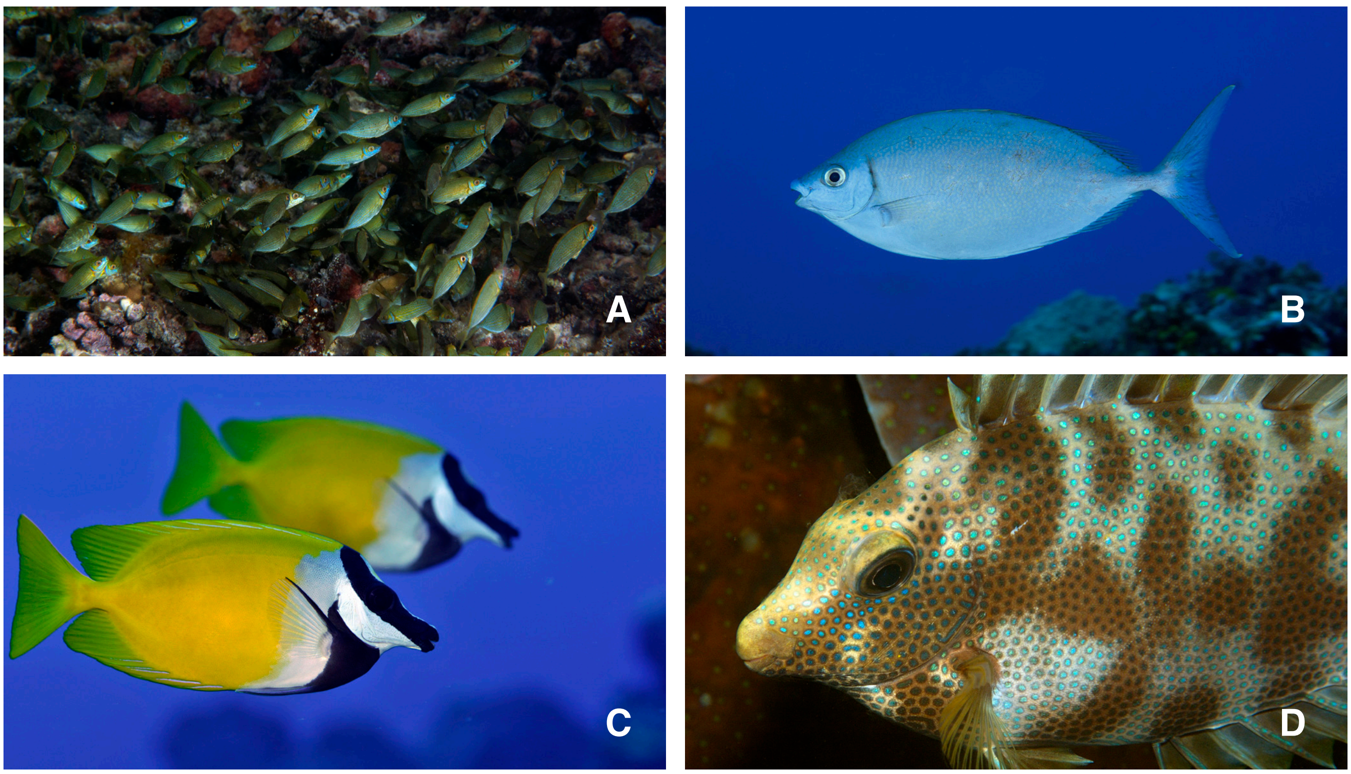


**Figure 2: A) Juvenile *S. argenteus* aggregate in large numbers to feed on algae, Faga‘alu Bay, Tutuila Island, American Samoa; B) Adult *S. argenteus* hovers over reef area, Pohnpei, F.S.M.; C) Pair of adult *S. vulpinus* near reef area, Pohnpei, F.S.M.; D) Adult siganid exhibiting mottled coloration at night, Palau. Images: A. Seale.**

## Biology

Rabbitfishes have an oval and compressed body with a narrow caudal peduncle. Their name is derived from the large dark eyes and small mouths, with the upper lip broader than the lower lip, resembling those of a rabbit. Rabbitfish have many spines: pelvic fins are formed from two spines, and there are 13 dorsal and 7 anal fin spines. Although their spines are venomous, and wounds from the spines are very painful, the damage inflicted is not as serious as injuries from scorpionfishes, and they are not considered dangerous to adult humans [7,8]. Most rabbitfish have complex and bright color patterns and range between 10 and 14 inches (25 and 35 cm) in size. Their intestines are long because they eat mainly plants. They are active during the day (diurnal) and are mainly herbivorous grazers, feeding on algae, seagrasses, and in some cases, small invertebrates such as tunicates and sponges. Their skin is smooth with small scales, and the caudal fin varies in shape from truncate to deeply forked. Rabbitfish are generally split into two groups based on their behavior: pair-bonding individuals and gregarious schoolers. Most species that forage in seagrass beds and algal flats are often seen in schools (Figures 2A and 2B show juvenile and adult *Siganus argenteus*, respectively), whereas pair-bonding species are typically seen together on coral reefs (Figure 2C). During rest and at night, rabbitfish have the ability to change color to a mottled pattern (Figure 2D). They may also exhibit this mottled coloration when stressed, such as during handling.

## Suitable Culture Species

The family Siganidae contains 28 species in the genus *Siganus*, all from the Indo-Pacific region. Five of the species have notably long snouts and were formerly placed in the genus *Lo*, which is now regarded as a subgenus of *Siganus* [7]. Generally, the reef-associated pair-bonding species are of limited aquaculture value, whereas gregarious schoolers, which are non-aggressive and can handle large changes in temperature and salinity, are considered to have the greatest commercial value and aquaculture potential. Several species of siganids have been reared in hatcheries with success, including *S. randalli*, *S. canaliculatus*, *S. lineatus*, *S. fuscescens*, *S. rivulatus*, and *S. guttatus*. Many studies on spawning, seedstock produc-

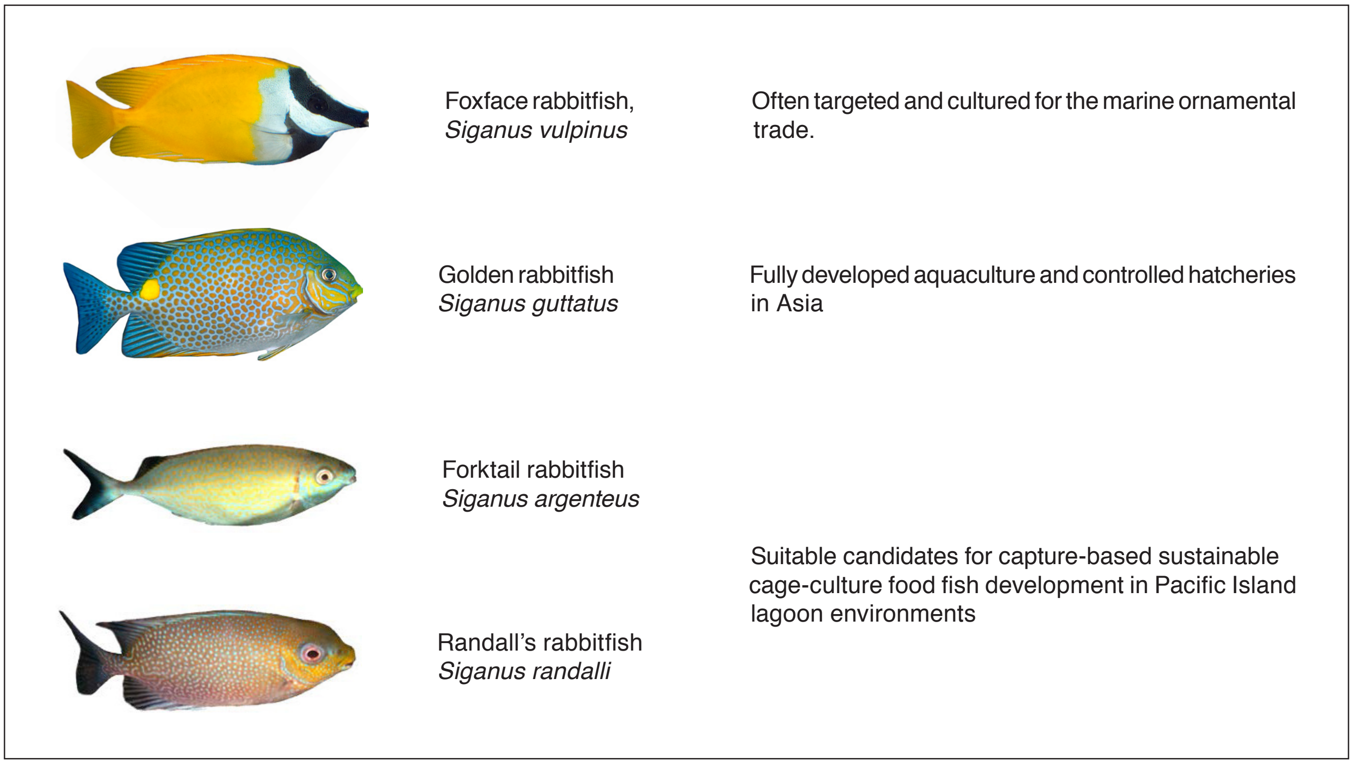


**Figure 3: Popular rabbitfishes for culture and marine ornamental trade, including suitable targets for capture-based sustainable aquaculture development. Images: A. Seale.**

tion, broodstock management, and advanced aquaculture practices are available for two species, *S. canaliculatus* and *S. guttatus*, which are currently bred in hatcheries and consistently aquacultured at production levels in Asia [9,10]. Four species have been used in grow-out trials in the Pacific: *S. argenteus* (Solomon Islands, Pohnpei, FSM, and the Cook Islands), *S. lineatus* (New Caledonia), *S. fuscescens* (Palau), and *S. randalli* (Guam and Pohnpei, FSM) [4]. These species are generally regarded as good food fishes in spite of their limited sizes. Other species, such as the foxface rabbitfish, *S. vulpinus*, are coveted for their appeal in the ornamental aquarium trade.

Growing interest in developing sustainable culture practices for aquaculture of rabbitfishes in Micronesia and the Pacific have prompted localized efforts to develop optimal pre- and post-settlement capture and grow-out methods (these terms are described in the next section). In Pohnpei, these efforts have been spearheaded by MERIP, where the two main species of rabbitfish targeted for capture-based aquaculture are the forktail rabbitfish, *Siganus argenteus*, and Randall's rabbitfish, *S. randalli*. These species, along with *S. guttatus* and *S. vulpinus*, are illustrated in Figure 3.

While not much is known about their biology and spawning patterns, *S. argenteus* and *S. randalli* are locally popular food fish and represent the best rabbitfish candidates for aquaculture so far in the mid-North Pacific region. Both species possess desirable traits for cage culture: fast growth; non-aggressive schooling behavior; tolerance to relatively poor water quality, high in particulate matter; tolerance to changes in temperature and salinity; good feed conversion; and herbivory. Grow-out cage trials with *S. argenteus* and *S. randalli* collected during recruitment events between 2016 and 2018 are underway at MERIP. Fish have been captured shortly after settlement, held in simple cages, and weaned onto formulated diets with excellent success to date. Results thus far indicate a potentially successful local aquaculture industry for these fishes in the Pacific region.

## Capture of Pre-Settlement Larvae and Cage Culture Workflow

### *Seedstock*

Capture-based aquaculture depends on collecting juvenile fish from the wild to grow out. Siganid life history favors this form of aquaculture. Large adults can lay up to 1 million 0.5 mm eggs at a time, and for many species, adults spawn together based on the phase of the moon. When larvae hatch, they are carried by tides and currents out of the lagoon into the open ocean, where they develop for between 30 and 60 days. Larvae undergo a transition, which is called metamorphosis, as they return to their home lagoons to settle. During metamorphosis the larval pre-settlement fish changes color, and sometimes shape, to resemble a smaller version of the adult fish, after which it is called a post-settlement juvenile. The time between these pre-settlement and post-settlement stages takes about 7–10 days, and during this period millions of fish can be found in seagrass beds and mangrove fringes.

In April 2018, surveys conducted in Pohnpei lagoon estimated that the pre-settlement population was 80–90 million rabbitfishes. However, nearly all fish die during the pre-settlement to post-settlement phase [4,5]. They are highly vulnerable to predation and starvation in this 7–10 day phase, and the amount of space for them to live, called the "carrying capacity," also appears to be a limiting factor. Based on their high natural mortality, most of the fish that are about to settle can be harvested sustainably, at minimal environmental cost, as long as the collection occurs during the critical 7- to 10-day recruitment window between pre- and post-settlement stages [11,12,13]. It is fish in this transition phase that are obtained from the wild to stock cages.

During these settlement events, newly settled fish are abundant and easy to catch in shallow environments with a seine net, with the added benefit that their capture has nearly no impact on the environment. Fish tend to settle around new-moon periods. To determine what species are settling and when, monthly surveys should be conducted in seagrass beds and mangrove fringes, along with net sets (see next paragraph), so fishing efforts can be concentrated during the correct time in subsequent years. At least one year of monthly surveys should be conducted. These can consist of 50–100 m swims and 4–5 net sets in target areas (seagrass beds and mangrove fringes). The natural abundance of seedstock combined with an understanding of the right timing to collect them comprise the necessary requirements for cost-effective juvenile capture for subsequent grow-out.

In preliminary trials in Pohnpei, *S. argenteus* has been collected in high numbers 4–5 days before the new moon in April of 2016, 2017, and 2018. For *S. randalli*, which has also been observed to feed and adapt well to cages, settlement-stage larvae have been seen

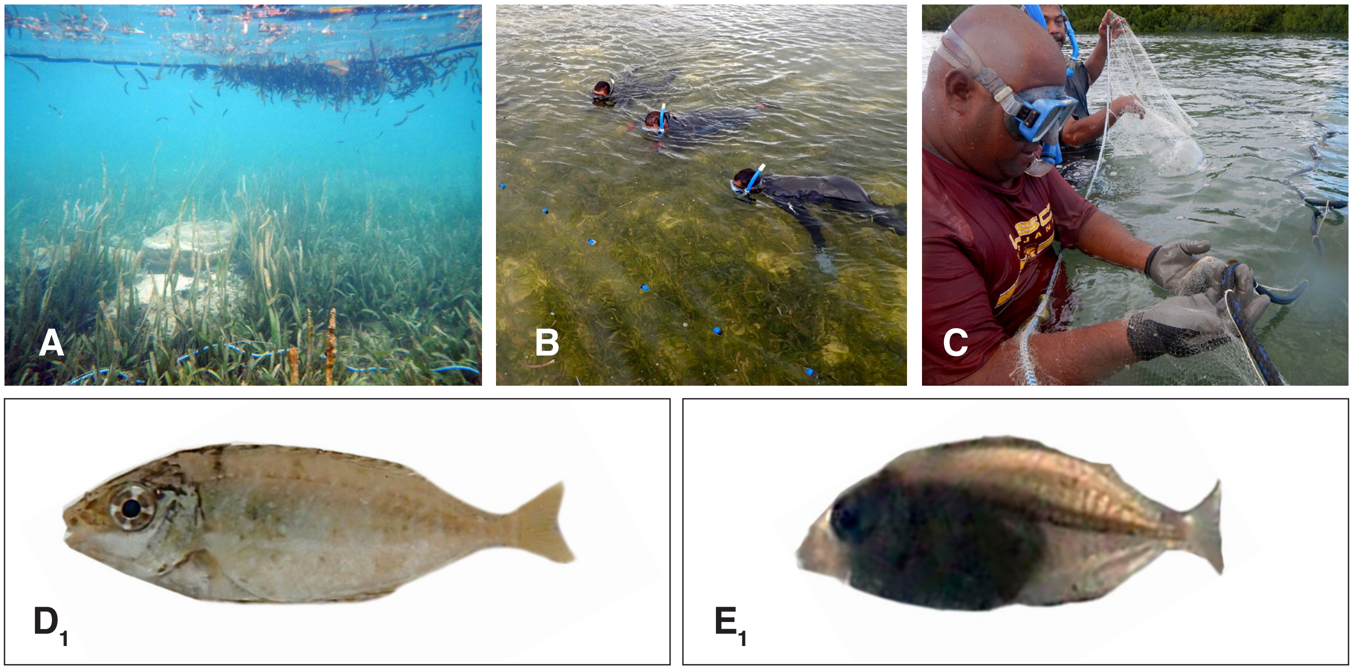

**Figure 4: Capture of settlement larvae: A) seine net set on sea grass bed; B) fish are chased into stationary net by swimmers; C) settlement fish are sorted by collectors; D) *S. argenteus* settlement and 1-month juvenile stages; E) *S. randalli* settlement and 1-month juvenile stages. Scale in centimeters. Images: S. Ellis.**

on mangrove fringes one week after the new moon in April at moderate to high densities. Successful seed collection during this period has been conducted using a near-bottom seine in shallow seagrass beds and shallow areas near mangroves. A near-bottom seine net is recommended because it does not drag at the bottom of the seafloor and therefore prevents damage to marine life. A 50’ ¼” mesh-size gill net has proven successful in the capture of siganids in the pre- to post-settlement stage. The net is set perpendicular to the current on the seagrass bed. Swimmers then circle around and chase the fish quickly into the stationary net (Figures 4A–C). Figures 4D and 4E show images of *S. argenteus* and *S. randalli* in the pre- and post-settlement phases respectively. Note the transparent rear of the *S. randalli* as they transition from pre-settlement to post-settlement fish.

### *Post-Capture Transport*

Ice chests filled with seawater are used for transporting captured fish at stable temperatures from the site of collection to the grow-out cages. Fish are collected as close to the grow-out site as possible to minimize stress during transport. Portable aeration is used, and dissolved oxygen can be monitored during transport. Stocking density of fish in the ice chest should not be more than 1 fish per liter. If portable aerators are not available, the water should be exchanged in the ice chest using a bucket every 2–3 minutes during transport. If oxygen gets low in the transport water, fish will lie on their sides and breathe very rapidly, a sign that water should be exchanged more frequently. The temperature of the transport water should be maintained as close as possible to that of the site of collection, usually between 26 and 30ºC.

### *Cage Grow-Out*

Rabbitfish can be grown in a variety of cages, so long as the fish cannot get out, predators cannot get in, and enough water can flow through to provide oxygen to the fish. In Pohnpei, fish are grown in rigid mesh floating cages designed to meet these specifications. Early use

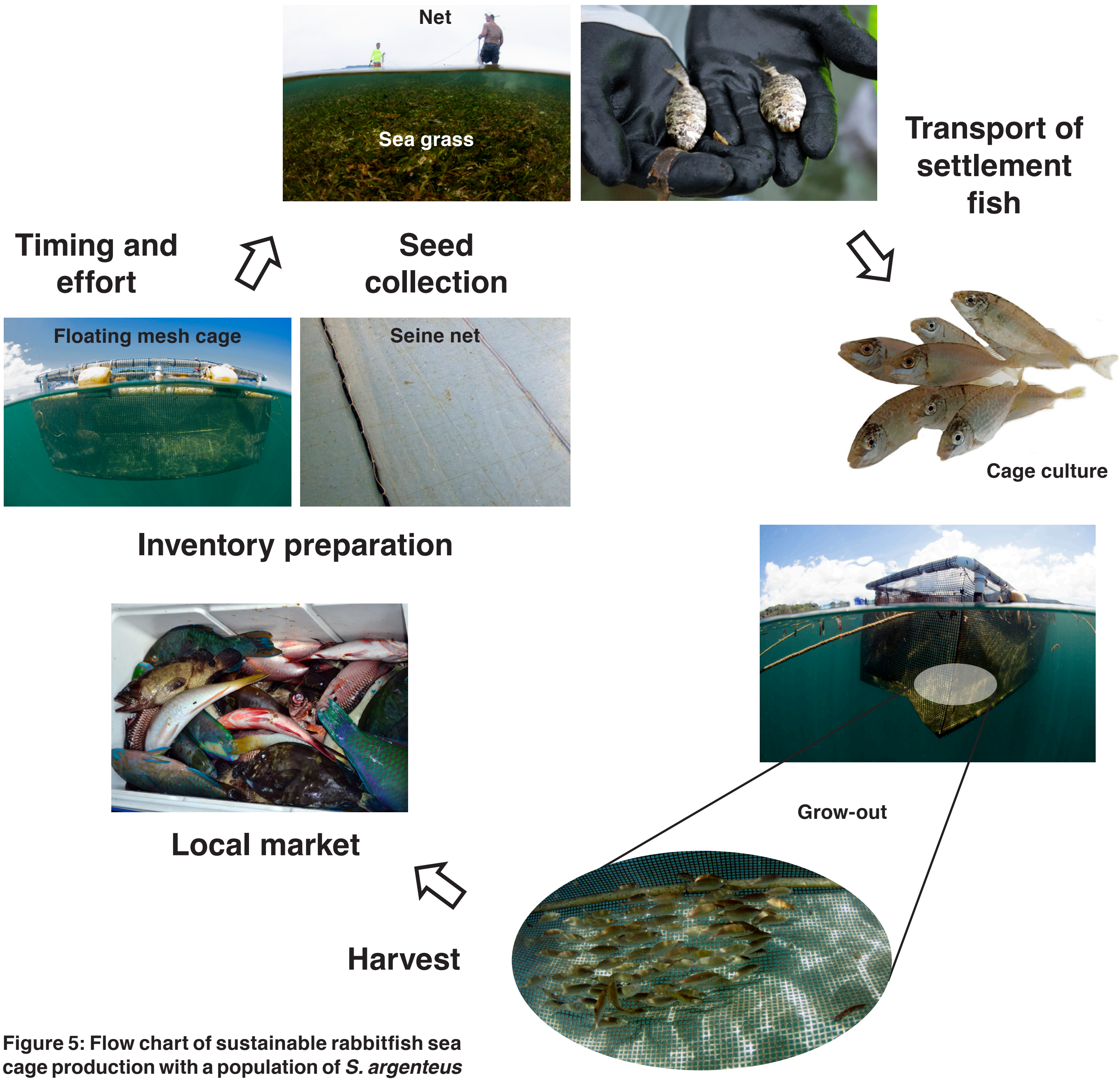


**Figure 5: Flow chart of sustainable rabbitfish sea cage production with a population of *S. argenteus* in Pohnpei, FSM. Images: A. Seale, S. Ellis.**

of soft mesh nets led to predation, so a rigid mesh cage was adopted. Cages at MERIP are 4’ wide x 8’ long x 4’ deep (1.2 m x 2.4 m x 1.2 m), and the rigid plastic mesh is hung on a 2” (5 cm) diameter schedule 40 PVC frame with added flotation (Figures 5, 7A, and 7B). Cages can be built for as little as $200, are easy to transport, and can last for at least 5 years in calm conditions. Periodic cleaning is required to prevent coral and algae growth on the mesh. Cages are typically stocked with 100–200 fish, with an expected yield of about 100 lbs. (45 kg) per year. Cages are moored to the bottom, or posts, with ropes. During grow-out, fish are fed twice a day with a commercially available formulated diet until they reach a desirable harvest size. An illustrated flow chart summarizing the main steps involved in the seed collection and grow-out of rabbitfish is presented in Figure 4.

## Site Selection for Cage Culture

Many areas of the U.S Affiliated Pacific Islands, and the broader Pacific, have large, sheltered, well-flushed lagoons near reef flats and seagrass beds that are ideal for rabbitfish cage culture. These lagoons are generally surrounded by fringing reefs that provide shelter from wave action and have abundant seagrass beds and mangroves. These habitats form key foraging grounds for newly settled rabbitfish, and for some species are their home for life.

Water-quality parameters, including salinity, turbidity, and dissolved oxygen, are essential to consider in any finfish aquaculture operation, including rabbitfish. Rabbitfish are resilient to low salinities and high turbidity only for short periods, such as during a heavy rainfall. Salinities lower than 12 ppt for extended periods are not recommended. A site location that has good water

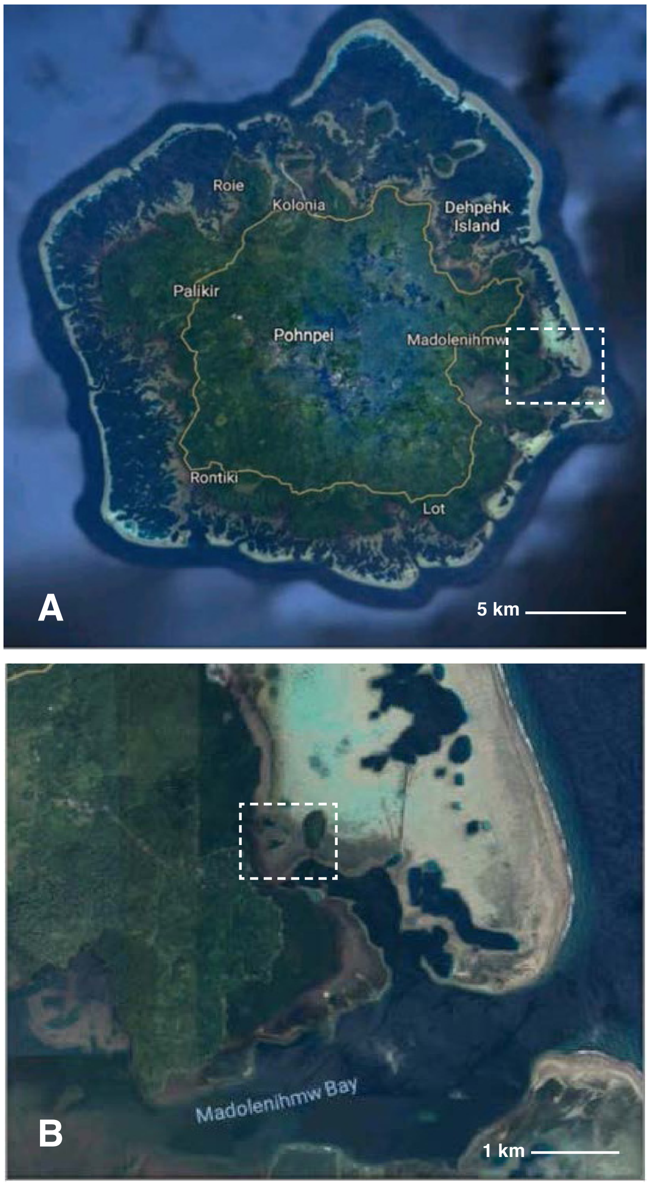



**Figure 6: Location of cages and personnel to maintain the cages is a key aspect of successful rabbitfish mariculture. Map of Pohnpei (A), the area surrounding Madolenihmw Bay (B), and a suitable location for the culture of rabbitfish (C). Images: Map data ©2018 Google.**

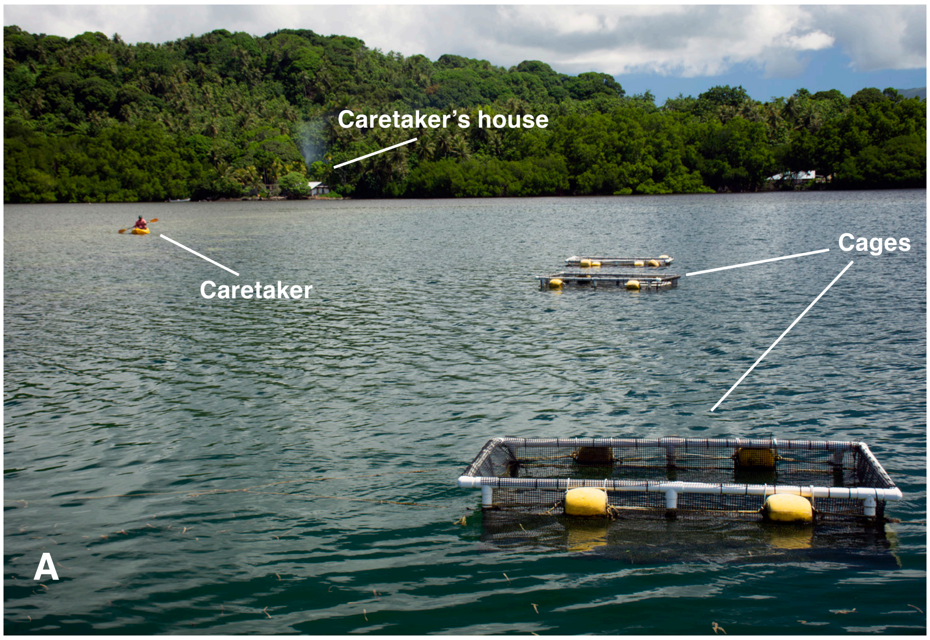


**Figure 7A) Site location of rabbitfish culture in Pohnpei depicting caretaker commuting from residence to cages.**


**Figure 7B) *S. argenteus* exhibit non-aggressive behavior and rapidly adapt to feeding on formulated pellet feed at the surface. Images: A. Seale.**

circulation, combined with the correct stocking density, should obviate problems with water quality.

Proximity to the farmer's house is a key factor for a successful operation. The longer the travel time to the farm site, the more difficult it will be to care for the fish. Security is also a concern. In many areas of the Pacific Islands, anything left unattended in the water is considered public property and can be taken. Sites should be chosen that are close to the primary caretaker of the cages. An example illustrating an optimal site, taking into account water quality and caretaker proximity, is shown in Figure 6. At this particular site, cages are located in sheltered waters next to seagrass beds and lagoon channels. The site is accessible to the caretaker, who lives on the main island and can reach the cages in less than three minutes' paddling on a kayak (Figure 7).

Suitable sites for rabbitfish grow-out cages will have these characteristics:

- Near to the farmer's house, making the cages readily accessible on a daily basis.
- Deeper areas or "blue holes" at least 30 feet (10 m) deep suitable for cage placement.
- Well flushed by oxygen-rich clean water.
- Sheltered from strong winds.
- Far enough from rivers to ensure salinity is not regularly lower than 12 ppt.
- Surrounded by their natural seagrass habitats.

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