Individual Summary Profiles
of Candidate Species

Environmental Defense Fund

What Will We Grow Here?

An Analysis of Candidate Species for Open Ocean Aquaculture in the United States

Authors: Poppy Brittingham and Rod Fujita

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Current Species

Species most likely to be farmed in U.S. open waters in the **near term** based on current market demand, commercial cultivation knowledge, and physical compatibility with open ocean conditions, among other considerations.

Blue Ocean Mariculture

COBIA

(Rachycentron canadum)

Native Range & Preferred Environment

Cobia *(Rachycentron canadum)* have a native range along the Eastern Coast of the United States and are especially concentrated along Florida and within the Gulf of Mexico. As a fish with no swim bladder, they have a higher tolerance for deeper waters. Their preferred water temperature ranges between 22-29 degrees Celsius.

Cultivation Traits

Cobia is a popular species for offshore cultivation. It is being farmed in commercial operations in Panama and Costa Rica and has been repeatedly identified as a strong candidate for proposed offshore farms in the Caribbean (Welch et al. 2019). Their fast growth rates allow harvest within a year (Benetti et al. 2010; Fraser and Davies, 2009). However, their growth rates are inconsistent as they can have unpredictable periods of fast growth followed by long periods of slow growth (Benetti et al. 2010). The FCR for cobia in nearshore farms was lowest when the fish were cultivated at 27-29 degrees Celsius, and would regularly range from 1.5-1.8, a highly efficient value (Fraser and Davies, 2009). The average FIFO for cobia is 3.5 (Seafood Watch, 2022). Their lack of swim bladder allows for cobia to comfortably be farmed in submerged conditions at length, which is optimal for farms looking to farm below the surface (Sievers et al. 2022). They are able to spawn in hatcheries, can consume commercial pellet feeds, and have high survival rates during stocking (Fraser and Davies, 2009).

Cobia are vulnerable to diseases and parasites in nearshore cultivation. Skin fluke parasites, bacterial diseases like vibriosis, mycobacteriosis, and furunculosis, and viral diseases like nervous necrosis virus are all risks to cultivated and wild cobia (Chu et al. 2013). Mortality with these diseases and parasites are all possible, although mass mortality events are rare (Chu et al. 2013). While the exact impact of submerged offshore farming on cobia diseases is unknown, it is expected that parasite concentrations and infection rates will decline when the fish are in conditions with higher flushing rates and colder temperatures.

COBIA

(Rachycentron canadum)

Environmental Defense Fund

Current U.S. Cultivation Status

There are currently no offshore or nearshore aquaculture farms of cobia in the United States. However, there are some in the Caribbean and Central America that are being farmed in similar conditions to U.S. waters. The longest operational offshore cobia farm, Open Blue, has been running since 2009 in Panama. It has 22 pens sited about 13 km from shore, and produces about 1,400 tonnes annually (Welch et al. 2019).

Environmental Impacts of Cultivation

An experimental offshore farm in Costa Rica has recently begun producing cobia at commercial scales (Sievers et al. 2022). The farm has submerged cages that have demonstrated low environmental impacts on surrounding marine ecosystems while maintaining high growth rates for the fish (Sievers et al. 2022). In fact, cobia cultivated in submerged pens outperformed surface-reared cobia in growth rates and have been observed naturally spawning at depth (Sievers et al. 2022). It is unknown whether spawning in pens could result in harm to local populations, especially when considering disease transmission.

Current & Future Markets

There is a strong market for cobia both in the United States and abroad. It is a fish with good flavor and high lipid content for human consumption (Fraser and Davies, 2009). It is often served as a filet, although in Japan the fatty belly is considered highly desirable (Fraser and Davies, 2009).

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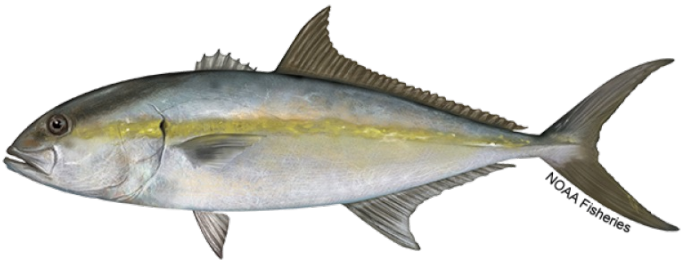
KANPACHI

(Seriola dumerili and Seriola rivoliana)



Native Range & Preferred Environment

Kanpachi *(Seriola dumerili and Seriola rivoliana)*, is a pair of two very similar species of jack also known as greater amberjack *(dumerili)* and almaco jack *(rivoliana)*, have been farmed nearshore in Japan *(dumerili)*, Mexico *(rivoliana)*, Europe *(rivoliana)*, and the United States *(rivoliana)*. They are both suitable for aquaculture in the United States, although *rivoliana* is better prepared. Their natural ranges are from the Gulf of Mexico to intertropical regions in the Pacific and Atlantic (Blanco et al. 2022). They can tolerate deeper waters and have an ideal temperature of 26 degrees Celsius.

Cultivation Traits

Kanpachi grow quickly, have a closed swim bladder, and thrive in submerged cultivation conditions when compared to their wild and surface-cultivated counterparts (Sievers et al. 2022). The average length is 90 cm (35 inches) and their weight is 4.5 kg (10 lbs) (Blanco et al. 2022). Fish are harvested young, at an average market weight of 1.8 to 2.5 kilograms after 10 to 12 months of cultivation (Blanco et al. 2022). Wild kanpachi adults exclusively eat fresh fish and other marine animals, although in cultivated environments they can be fed pellets without negative impacts to growth (Blanco et al. 2022). The feed conversion ratio for offshore kanpachi is still being understood, although in land-based farms the fish have FCRs between 0.9 - 2.6 and FIFOs of 1.09 (SeafoodSource, 2012; FortuneFish, 2024).

One of the bigger health threats to kanpachi is skin fluke infestations. These have particularly been a challenge with kanpachi cultivation in Japanese waters (Sievers et al. 2022). In nearshore waters, a common treatment and prevention method for skin flutes is to expose the fish to H202. While some offshore farms still complete this process (Blanco et al. 2022), skin flukes may be a lesser threat to submerged offshore kanpachi (Sievers et al. 2022). For example, decreasing infestation rates were observed when the fish were submerged even 2-4 meters below the surface, indicating that skin flukes are more successful in surface conditions (Sievers et al. 2022).

Current U.S. Cultivation Status

Kanpachi are considered a strong candidate for offshore aquaculture in warmer waters like those off of the coast of Florida and Hawai'i. The only kanpachi farm in the United States is called Blue Ocean Mariculture, which has been operating its commercial scale facilities in Hawai'i since 2005 (Blanco et al. 2022). Blue Ocean Mariculture has five SeaStation submersible net pens, with a volume of 8,000 m^3 (Blanco et al. 2022). The farm is in nearshore waters, but with conditions comparable to the open ocean environment.

KANPACHI

(Seriola dumerili and Seriola rivoliana)

Environmental Impacts of Cultivation

The exact environmental impacts of farming kanpachi are still being understood. However, risks like disease and parasite transmission to native stock or nutrient runoff from farm operations are possible.

Current & Future Markets

There is a well defined and high value market for kanpachi. Kampachi is largely considered a popular fish for human consumption because of its high quality flesh and fat content (30 percent) (Blanco et al. 2022). It is also a fish with a reputation for having good taste, versatile cooking methods, and many health benefits from the vitamins, oils, and protein in the flesh (Blanco et al. 2022). One hundred restaurants have signed up to purchase kanpachi from Forever Oceans and Blue Ocean Mariculture has sold their deep-water farmed kanpachi at sashimi grade for high market prices (Hogan, 2023a).

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ATLANTIC SALMON

(Salmo salar)

Native Range & Preferred Environment

Atlantic salmon's native range spans the Atlantic, from the East Coast of the United States to Iceland, Greenland, Europe, and Russia, resulting in a physical preference to colder (13-18 degree Celsius) water (NOAA 2024; Yingxin 2023; Hvas et al. 2020). Along the East Coast, Atlantic salmon are only native in the Northern half, above New York (MAIC, 2023). They are athletic fish and more resilient to fast currents by nature because of the migrations they have evolved to undertake in the wild (Hvas et al. 2020).

Cultivation Traits

In 2018, the average FCR for Atlantic salmon in nearshore farms was about 1.3, which is already very low compared to many other cultivated species (Fry et al. 2018). The fish in fish out ratio is on average a value of 1 (Kok et al. 2020). It is understood that salmon should not be stocked in conditions where the baseline currents surpass their swimming capacity, although they do have the ability to sustain quicker swimming for hours but not days (Hvas et al. 2020). Additionally, because Atlantic salmon have open swim bladders, it is critical that they have access to air they can use to refill their bladders either by being cultivated in floating pens or in submerged pens with an air pocket (Sievers et al. 2021).

Atlantic salmon are susceptible to parasites and disease in commercial, high density aquaculture settings. In Norway, there are significant investments into understanding how to reduce the prevalence of sea lice and amoebic gill disease (AGD) in nearshore cultivated salmon. Even with increased attention, these both remain serious problems for keeping the fish healthy (Sievers et al. 2021; Yu et al. 2022; Hvas et al. 2020). In nearshore waters, vaccinations are used to protect fish from contracting diseases, but there are certain risks and costs associated with the vaccines. In Chile, Piscirickettsiosis salmonis (SRS) is a disease that has resulted in high mortality for infected fish and cannot be prevented with vaccines, only antibiotics (Rozas-Serri, 2022). In offshore conditions, it is possible that instances of both parasites and infections decrease because of increased flow rates, cooler temperatures, increased distance from other farms, and lower stocking densities (Kragesteen et al. 2018).

Current U.S. Cultivation Status

The United States has a history of nearshore cultivation of Atlantic salmon. In Maine, where Atlantic salmon are within their native range, farms and hatcheries have run since the 1970s (MAIC, 2023). The hatcheries operate on land and the nearshore net pens are sited in protected bays and sometimes rotated depending on water quality and farm density (MAIC, 2023). While the Maine Atlantic farms are

considered commercial, the total production is not very large (~4 million fish annually) compared to U.S. consumer demand (MAIC, 2023). Many farms co-cultivate steelhead trout and Atlantic salmon together in Maine, due to their similar sizes, feeding behaviors, and preferred cultivation conditions (MAIC, 2023). The hatcheries cultivate Atlantic salmon on land in fresh water for 18 months where they are monitored and vaccinated (MAIC, 2023). They are then moved to ocean pens that are between 9.2-15.2 feet deep where the fish are pellet fed for the next two years until harvest (MAIC, 2023).

Environmental Impacts of Cultivation

One of the concerns for cultivating Atlantic salmon in the United States is the potential genetic risks of breeding between wild and escaped farmed salmon. The scale of this risk, however, is still a large knowledge gap. In Chile, escaped Atlantic salmon have been able to successfully establish themselves as free living individuals, although they have not yet been recorded breeding with wild populations (Marin-Nahuelpi et al. 2022; Sepulveda et al. 2013). In fact, previous attempts to repopulate Atlantic salmon populations in Chile through the release of raised fish have failed due to the salmons' inability to establish (Sepulveda et al. 2013). In the case of escapes, even without breeding, there is still a concern for disease and parasite transmission (Marin-Nahuelpi et al. 2022; Sepulveda et al. 2013).

Current & Future Markets

The market in the United States for Atlantic salmon is already well established. The United States is the largest consumer of salmon, at 600,000 tonnes consumed (whole fish equivalent) in 2022 (Salmon Business, 2022). Consumers purchase Atlantic salmon mainly for direct consumption, although it can come in many marketable forms: raw, frozen, and smoked, and in more processed forms like salmon oil supplements.

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STEELHEAD TROUT

(Oncorhynchus mykiss)

Native Range & Preferred Environment

Steelhead trout are native to the North Pacific Ocean and have a natural range from southern California up to Alaska (Chambers et al. 2024). Their life cycle is only partially marine, since they begin their lives in fully freshwater rivers as rainbow trout, but unlike adult rainbow trout, steelhead migrate to the ocean as adults and return to the rivers to spawn (Chambers et al. 2024). Compared to rainbow trout, steelhead have faster growth rates and can reach larger sizes, making them a good marketable species to cultivate. Additionally, their preferred environments are cold and oxygenated waters (9–15 degrees Celsius) with high flow rates, which results in high compatibility with expected offshore aquaculture conditions (Chambers et al. 2024).

Cultivation Traits

It takes about three years to get the steelhead trout to an ideal marketable weight of 7–10 kg. During cultivation, the trout have a very low FCR of between 1.0 and 1.2 (Chambers et al. 2024). In nearshore marine pens, the FIFO for steelhead trout is 1.2:1 (Strands Food, 2024). The trout can be grown from eggs to adults, and steelhead trout aquaculture farms source rainbow trout to grow out in tanks, raceways, and later brackish water containers to allow for the juveniles to build strength, adjust to salt water, and reach adulthood before being moved out into the marine pens (Chambers et al. 2024).

Current U.S. Cultivation Status

A company called Blue Water Fisheries has proposed an offshore aquaculture facility that would farm steelhead trout, salmon, and possibly lumpfish off of the coast of New Hampshire (Chase, 2023). Their plan is to operate 40 pens from Innovasea across 250 acres of ocean at depths of 15 meters. After a public hearing session and a long period of collaborating with the U.S. government to find an optimal site, a location was chosen (Chase, 2023). Another company, Manna Fish Farms also submitted a permit request in 2020 and is hoping to cultivate steelhead in 12 to 18 submersible net pens from StormSafe (Chase, 2023). In a small-scale New Hampshire IMTA steelhead trout, mussel, and kelp farm, fish were fed 3 and 6 mm Bio Oregon trout pellets with 45 percent protein and 22 percent lipids. There was a survival rate of 98 percent and an FCR of 1.24 (Chambers et al. 2024).

Environmental Impacts of Cultivation

Waters beneath and beside the IMTA steelhead farm in New Hampshire were monitored during a full cultivation cycle of the trout. Results showed that even with such high FCRs, steelhead aquaculture

facilities can still contribute nutrients to the surrounding environment. For example, of the 37.1 kg of nitrogen in the fish feed from the New Hampshire farm, 12 kg were taken up by the trout and 25.1 kg was washed into nearby waters (Chambers et al. 2024).

Current & Future Markets

Of the trout that is sold in the United States, steelhead has the largest market share (72%), which is equal to $97.2 million in sales (Sun et al. 2023). Steelhead sells for about $20 per kg. Rainbow trout has a higher price than steelhead at $9.9 per pound, but is a smaller part of the trout market (Sun et al. 2023). Supermarket sales of trout (rainbow and steelhead) increased from $100 to $135 million from 2016 to 2021, although pricing for steelhead did not change (Sun et al. 2023). The demand for steelhead trout exceeds the current national supply, with a large portion coming from Norway and Chile (Sun et al. 2023). Since steelhead and salmon are similar in size and flesh color, there is some market overlap and competition between the two. This trend could be expected to continue if offshore farms cultivated both species and added supply to the U.S. markets.

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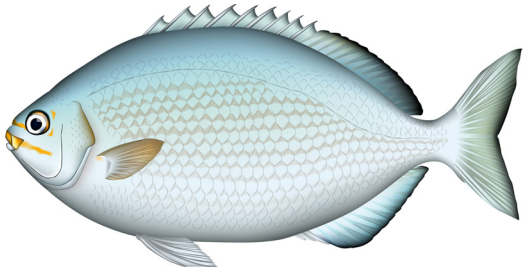
Nenue
Mutton Snapper
Florida Pompano
Atlantic Cod
California Yellowtail
Red Drum
Bluefin Tuna
Red Snapper
Common Sea Bream
Mahi-mahi

Future Species

Species most likely to be farmed in U.S. open waters in the **future** based on current market demand, commercial cultivation knowledge, and physical compatibility with open ocean conditions, among other considerations.

NENUE

(Kyphosus vaigiensis)



Native Range & Preferred Environment

Nenue is an herbivorous fish species native in Hawai'i. Due to their diet, they are often found in more shallow waters and can tolerate warm temperatures.

Cultivation Traits

Ocean Era, an offshore aquaculture company in Hawai'i, has demonstrated nenue rearing in a hatchery, thus eliminating any need to pull fish from the wild for broodstock (Ocean Era, 2021). In the hatchery, the nenue are fed five times a day. As they grow, feeding decreases to two or three times a day (Ocean Era, 2021). Feed is created from a combination of fresh limu seaweeds and pellets that are high in carbohydrates and low in proteins and lipids. In a feed trial in Kona, nenue exhibited high growth rates with an 80 percent duckweed diet (Ocean Era, 2021). While the FCR for nenue is not yet fully understood, the FIFO for the herbivorous fish is 0 as no fish are necessary in their feed.

Environmental Impacts of Cultivation

There are many potential environmental and economic benefits to the cultivation of herbivorous fish instead of higher trophic level fish like salmon or tuna. Fish feeds for carnivorous fish require a high protein and nutrient content often fulfilled with fishmeal and fish oils, which can put pressure on wild forage fish stocks. Feeds with expensive fishmeal and fish oils are also the highest operational cost for carnivorous finfish farms. Farming herbivorous fish would lower costs, eliminate the need to use fish-based feed, and would instead increase demand for carbohydrate-rich seaweed and other plant-based feeds (Ocean Era, 2021).

Current U.S. Cultivation Status

Ocean Era has been researching nenue as a potential herbivorous species for offshore cultivation. Having lower input costs and environmental demands, the dominant challenge for cultivating herbivores like nenue is generating enough profit from the final fish product to offset the costs of farm operation. There is an important balance between keeping prices low enough that the product is accessible to as many consumers as possible, while also keeping a high enough value that the farm can sustainably support its operation. With herbivorous fish, operational costs may be lower because plant-based feeds could be less expensive and there is no risk of cannibalism among the cultivated stock (Ocean Era, 2021; Benetti et al. 2003). With Ocean Era as the leading cultivator of nenue, the farming status is still in development.

NENUE

(Kyphosus vaigiensis)

Current & Future Markets

Nenue are a prized fish in Hawai'i and they are often called the "queen" nenue because of their cultural value to Hawaiians (Lilley, 2020). They have a desirable flavor and can be eaten raw in poke dishes or cooked as filets (Lilley, 2020). Since the fish has localized but strong popularity, it is possible that nenue could have a place in the broader U.S. market with enough marketing and education around the species.

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MUTTON SNAPPER

(Lutjanus analis)

Native Range & Preferred Environment

Mutton snapper *(Lutjanus analis)* is native to the East Coast of the United States and the Gulf of Mexico (Seafood Watch, 2016; Watanabe, 2001). Juveniles stay in nearshore shallow waters and move to deeper waters of up to 28 meters when they mature (Watanabe, 2001). As warm water fish, their ideal temperature is between around 25 and 32 degrees Celsius (McGuigan et al. 2023). Mutton snapper wild stocks in the Gulf of Mexico and South Atlantic fisheries are healthy, although declining, and not considered overfished (Seafood Watch, 2016; SCRFA, 2019; Bradshaw, 2023).

Cultivation Traits

Mutton snapper are mainly carnivorous fish that require aquaculture feeds with concentrations of 44 percent crude protein and six to nine percent lipids (Nunes et al. 2010). The FCR for mutton snapper is relatively low, with averages ranging between 1.1 and 1.6 (McGuigan et al. 2023).

Although they are carnivorous fish, cannibalism is not a concern for mutton snapper (Benetti et al. 2003). This allows for the species to be stocked more densely than other fish like tuna, red snapper, or red drum that experience high rates of cannibalism, especially at the juvenile stage (Benetti et al. 2003). In the wild, mutton snapper have been observed with low instances of parasites and disease, although it is unknown if this trait will carry over to aquaculture environments (Hermida et al. 2014).

Current U.S. Cultivation Status

While some is known about farming mutton snapper in nearshore waters, knowledge of offshore marine aquaculture cultivation for mutton snapper is still in development (Nunes et al. 2010). However, they have long been identified as a prime candidate for commercial cultivation in the United States although there are not yet any domestic commercial farms (Watanabe, 2001; Benetti et al. 2003).

The first well documented experimental offshore aquaculture farm, Snapperfarm, that cultivated mutton snapper was located in Puerto Rico (Alston et al. 2005; Benetti et al. 2003). Using two pens that were secured at a depth of 27 meters, 10,000 mutton snappers and 10,000 cobia were co-stocked and cultivated (Alston et al. 2005). The site was located off the shore of Culebra island in an area with currents ranging between 0.25 and 1.0 knots (Benetti et al. 2003). Cultivation was successful, with mutton snapper demonstrating higher than expected growth rates (Alston et al. 2005; Benetti et al. 2003). However, operations closed after Snapperfarm struggled to expand operations.

MUTTON SNAPPER

(Lutjanus analis)

Environmental Impacts of Cultivation

As a high trophic level fish, there is an environmental impact of the feed used in mutton snapper cultivation. They require aquaculture feeds with concentrations of 44 percent crude protein and six to nine percent lipids (Nunes et al. 2010). A majority of the feeds used to cultivated mutton snapper are composed of at least 30 percent fish meal (Nunes et al. 2010). As a result, there is a strong interest in finding alternative protein sources for mutton snapper feeds. Nunes et al. (2010) experimented with feeding farmed mutton snapper varying concentrations of soy protein concentrate instead of fish meal, although the results were not promising. Challenges with plant-based protein feeds have continued since this study, and developing alternative protein sources to reduce reliance on fishmeal while maintaining growth rates remains a barrier to decreasing the cost and environmental impact of farming high trophic level species like mutton snapper.

Current & Future Markets

Since the early 2000s, demand for mutton snapper as a food fish has been increasing in the United States (Watanabe, 2001). Local fishing of mutton snapper has helped meet some of the demand, but imports into the United States have been necessary for decades (Watanabe, 2001). Mutton snapper is popular with commercial and recreational fishers because of their size and mild, sweet flavor (MA, 2024). Additionally, they have increased in popularity with fishers recently because they are considered a suitable replacement in the market for red snapper, which has been more seriously regulated by NOAA (MA, 2024). Ensuring fishers and farmers are mutually benefiting in the mutton snapper market will be important should this species be cultivated commercially in the U.S.

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FLORIDA POMPANO

(Trachinotus carolinus)

Native Range & Preferred Environment

Florida pompano (Trachinotus carolinus), or Atlantic pompano, can be found along the eastern Atlantic Ocean, from Massachusetts to Brazil, and in the Gulf of Mexico (Weirich et al. 2021). Within the United States, they are most concentrated along North Carolina down to Florida, with Floridian coasts having the highest concentrations (Weirich et al. 2021). As a warm water fish, Florida pompano are very sensitive to cold temperatures, with mortality events recorded below 10 to 12 degrees Celsius (Weirich et al. 2021).

Cultivation Traits

Florida pompano reach maturity after one to three years and can grow to weights between 0.7 and 2.3 kg (Weirich et al. 2021). Florida pompano are carnivorous and have high food demands, resulting in feed efficiency challenges for farmers. It is still unknown why exactly Florida pompano have high FCRs, but hypotheses include high metabolisms from activity, inefficient digestion, and poor feeding technology (Weirich et al. 2021).

There are a few diseases that Florida pompano are vulnerable to in aquaculture farms. Red-Spotted Grouper Nervous Necrosis Virus, red pest (V. anguillarum), fish tuberculosis (M. marinum), and parasite-induced diseases like white spot disease and velvet disease are all concerns while farming Florida pompano either in submerged pens or onshore facilities (Weirich et al. 2021). In order to keep the fish healthy, early detection measures, vaccines, and antibiotics are all used (Weirich et al. 2021). However, antibiotics are only used when other prevention measures have not been successful, as there is the risk of antibiotic resistant strains evolving from their overuse (Weirich et al. 2021).

Current U.S. Cultivation Status

Florida pompano has been identified as an optimal species for commercial aquaculture cultivation in the United States (Weirich et al. 2021; FAU, 2023). Marine cultivation of Florida pompano is still at a very early stage, with concerns over the viability of commercial offshore cultivation due to research needs and high operational costs (Weirich et al. 2021).

While Florida pompano has been identified as fish with high market potential, there are currently only ten aquaculture farms in the United States that have been able to rear and harvest the fish successfully in terrestrial facilities at commercial scales (FAU, 2023). Abroad, marine net pen farms have been operating commercially in the Bahamas, Dominican Republic, and Panama, with varying degrees of

economic success (Weirich et al. 2021). Inefficient feeding challenges remain one of the largest barriers to economically feasible offshore production.

Current & Future Markets

The market for Florida pompano is largely constrained to where it can be fished, with high popularity and a high market price along the East Coast and the Gulf of Mexico (Weirich et al. 2021). It is also currently considered a seasonal fish, with consumer preference towards fresh filets rather than frozen products (Weirich et al. 2021). As a result, should Florida pompano become a species farmed in offshore waters, it would be necessary to educate consumers in the Central and Western United States.

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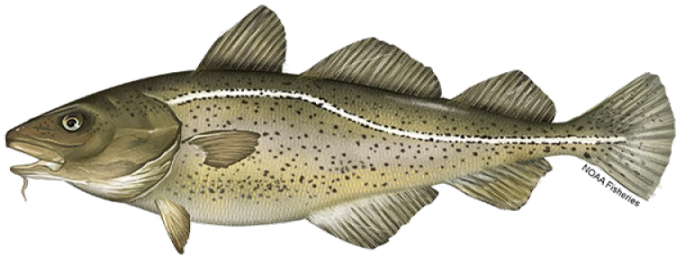
ATLANTIC COD

(Gadus morhua)



Native Range & Preferred Environment

Atlantic cod can be found in Northern Europe and the Northwest Atlantic, from Greenland to Cape Hatteras, North Carolina (NOAA, 2024). They are often found in New England and are common in the Gulf of Maine and Georges Bank, although recent declines in population have resulted in their recognition as an over-fished species (NOAA, 2024). Atlantic cod prefer deep waters below 20 meters and can often be found near the sea floor. Their ideal temperature ranges between 7 and 9 degrees Celsius.

Cultivation Traits

Cod grow well in both surface and submerged pens, due to their closed swim bladder and their natural preference for deeper waters (NOAA, 2024). In one farm, Atlantic cod cultivated in submerged pens for over a year saw a 99 percent survival rate and higher growth rates than projected (Sievers et al. 2021). To prevent damage and stress to the fish when transporting from high-pressure deep waters to the surface, it is recommended that farms cultivating cod in deep waters raise the fish in multiple 10 hour intervals to allow time for fish to adjust (Sievers et al. 2022). In offshore trials, farmers found that submerged cultivated cod fared as well as those that were surface reared (Sievers et al. 2022).

In nearshore marine farms, Atlantic cod are often fed pellet feed either every day or alternating days (Bjørnevik et al. 2021). Research shows that feeding frequency influences the FCR in cod, with alternating daily FCR values averaging around 1.07 and daily feedings resulting in an average FCR of 1.45 (Bjørnevik et al. 2021). Diseases and parasites are a challenge for Atlantic cod cultivation (Nardi et al. 2021). A widely accessible and affordable vaccine is now available for Vibriosis (V. anguillarum), a disease that threatens juvenile farmed cod in Europe and Maine during warmer months (Samuelson et al. 2006). Sea lice have also presented a seasonal risk in Maine, but this could be alleviated with submerged pen infrastructure.

Current U.S. Cultivation Status

Atlantic cod has long been considered a species with strong cultivation potential in the United States and abroad. In 2001, the first offshore aquaculture facility for Atlantic cod was run experimentally at a site 1.6 km offshore of New Hampshire using submersible SeaStation pens (Nardi et al. 2021). Ten years later, NOAA funded a 13 week curriculum and training program, called the Cod Academy, for fishers in Maine interested in farming Atlantic cod (Nardi et al. 2021). However, there are no commercial size Atlantic cod aquaculture farms operating in U.S. offshore waters.

ATLANTIC COD

(Gadus morhua)

Environmental Impacts of Cultivation

Atlantic cod can spawn in captivity, which could bolster wild stocks if the farm is in their natural range and near overfished waters (NOAA, 2024; Nardi et al. 2021). As a result, offshore aquaculture of this species has the potential to positively contribute to natural stock numbers. However, captive spawning could threaten local cod species if Atlantic cod are farmed outside their native range. Another concern is disease or parasite transmission from farmed fish to native stocks, which can be best addressed through high quality infrastructure and monitoring. In Norway, a bacterial disease Francisellosis cannot be treated with antibiotics and unfortunately it has been observed that escaped individuals from Atlantic cod pens can carry the disease to wild populations (Nardi et al. 2021). Like Vibriosis, this pathogen thrives in warmer waters.

Current & Future Markets

There is a strong market for Atlantic cod in the United States, primarily as a fish for direct human consumption. Because it has a high value and was previously overfished, one challenge with selling and stocking Atlantic cod is that Pacific cod (Gadus macrocephalus) from Alaska has widely replaced Atlantic cod in U.S. markets, including on the East Coast (Nardi et al. 2021). As a less expensive alternative with a similar flavor, Pacific cod has driven prices down to a point where Atlantic cod farm operations may not be economically sustainable (Nardi et al. 2021). Additionally, during normal harvest seasons, wild-caught cod prices are below the production costs of farmed cod, making it challenging for farmers to sell their fish at a high enough price.

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CALIFORNIA YELLOWTAIL

(Seriola dorsalis)

Native Range & Preferred Environment

California yellowtail *(Seriola dorsalis)* is a species that would be optimal for offshore cultivation on the Western coast of the United States because they are endemic to the region and are well suited for the environmental conditions (NOAA, 2020). Their natural range is from southern Washington to Mazatlán, Mexico (NOAA, 2020).

Cultivation Traits

California yellowtail reach sexual maturity after two or three years, and can reach 130 cm in length and 36 kg in weight (NOAA, 2020). FCRs are still being studied for California yellowtail, although some researchers were able to rear the fish to market sizes in under two years with FCR values between 1.6-1.8 (Rotman et al. 2021). However, since most of the studies have been conducted in terrestrial aquaculture systems, FCR values are unknown for marine aquaculture in nearshore and offshore waters.

Current U.S. Cultivation Status

Pacific Ocean Aquafarms, a U.S. offshore aquaculture farm company, is getting permits to farm California yellowtail on the West Coast but has no finalized site (White, 2020). The proposed farm would be 323 acres large and would host 28 submersible pens for the yellowtail (Sapin, 2023). NOAA is currently working on an environmental impact statement of the farm and is deciding between two sites, one four miles off of the coast of San Diego and the other off of Long Beach (Sapin, 2023).

One of the larger challenges to commercial cultivation is the lack of developed hatcheries for California yellowtail (NOAA, 2020). Survival and growth rates have not yet reached stable and sustainable levels in hatcheries due to a lack of knowledge around raising larval and juvenile yellowtail (NOAA, 2020; Rotman et al. 2021). In 2020, there were a series of research projects focused on California yellowtail. Their current status of these projects is unknown but they are likely operational. The first is focused on gathering data on the health and fitness of yellowtail to develop baselines on “growth, feed conversion, metabolism, and swimming capacity” (NOAA, 2020). Another project aimed to understand if exercise resulted in increased muscle mass and tissue development (NOAA, 2020). The third project specialized in quantifying and monitoring the swimming speeds and respiration rates of California yellowtail (NOAA, 2020).

CALIFORNIA YELLOWTAIL

(Seriola dorsalis)

Environmental Defense Fund

Environmental Impacts of Cultivation

When the Pacific Ocean Aquafarm sites were announced, there were concerns from local fishers about potential negative impacts on the surrounding ecosystem, including concerns around water pollution and entanglement risks (Sapin, 2023). However, the environmental impact report from NOAA on the sites will provide valuable insights into predicted ecological risks from California yellowtail offshore aquaculture.

Diseases and parasites are a known risk factor when considering aquaculture cultivation of California yellowtail. The fish are vulnerable to ectoparasites like Capsalid Monogeneans and sea lice and bacterial infections that have resulted in mortalities while being cultivated in nearshore net pens (Rotman et al. 2021). However, disease and parasite transmission from farmed California yellowtail to native populations, especially in offshore conditions, is not well studied.

Current & Future Markets

There is a well-established, although not large, U.S. market for California yellowtail, with most of the supply coming from imports (Rotman et al. 2021). With high growth rates and valuable meat, California yellowtail has been identified by NOAA as a "strong candidate for the development of offshore commercial aquaculture in southern California and neighboring Baja California" (NOAA, 2020).

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RED DRUM

(Sciaenops ocellatus)

Native Range & Preferred Environment

Native to the Atlantic and Gulf coasts of North America, red drum is a species that has already been considered as a potential fish for offshore aquaculture in the Gulf of Mexico and specifically off the coast of Florida (Lutz, 2022; Luening 2014; Guthrie et al. 2023). They are resilient to warmer temperatures, but very vulnerable to cold shocks, which have been known to cause large mortality events at temperatures below 8 to 10 degrees Celsius (Lutz, 2022; FAO 2024). Their life cycle involves spawning nearshore, growing out in coastal waters, and migrating to offshore waters in their maturity (Lutz, 2022).

Cultivation Traits

Red drum have fast growth rates, high tolerance to variable salinities, and a strong survival rate in cultivation. Although early cultivation attempts face challenges like temperature sensitivity, parasite infestations, and cannibalism (FAO, 2024; Lutz, 2022), farming of red drum has become increasingly feasible as technology and knowledge continues to develop. However, because of the fast growth rates and high resilience of red drum, it is not recommended as a cultivar outside of its natural range (Benetti et al. 2003).

Red drum are susceptible to various diseases and parasites. Viral nervous necrosis (virus), enteromyxosis (parasite), and lymphocystis (virus) are all currently untreatable, leading farms to quarantine and often cull the sick fish to prevent further transmission (FAO, 2024). Other diseases like Vibriosis and systemic bacterial infection can be treated with antibiotics given to fish through their feed (FAO, 2024).

Current U.S. Cultivation Status

While there have been many attempts at commercial aquaculture farming of red drum, few have been successful. As of 2018, there were twelve Red drum aquaculture farms all operating in nearshore waters (AGMRC, 2022). Eight of those farms were in Texas, followed by two in North Carolina and Delaware respectively (AGMRC, 2022). However, a severe cold shock in Texas in 2021 resulted in mass mortality events and business closure for many of the Texan farms (AGMRC, 2022). As a result of their temperature sensitivities, red drum are often cultivated in other countries in terrestrial aquaculture ponds or nearshore cages in warm waters.

RED DRUM

(Sciaenops ocellatus)

Current & Future Markets

Red drum has had a strong market presence in the United States since the 1980s (Lutz, 2022). Overfishing in the Gulf of Mexico led to a moratorium of commercial fishing of the species to allow for recovery, which catalyzed an interest in aquaculture cultivation of red drum to meet the market demand (Lutz, 2022).

China is now the leading producer of red drum, with net annual production 20 times more than what is harvested in the United States (Lutz, 2022). As a result, the United States has begun importing red drum cultivated in Chinese aquaculture farms in the form of individually quick frozen (IQF) filets (Lutz, 2022). Other nations that

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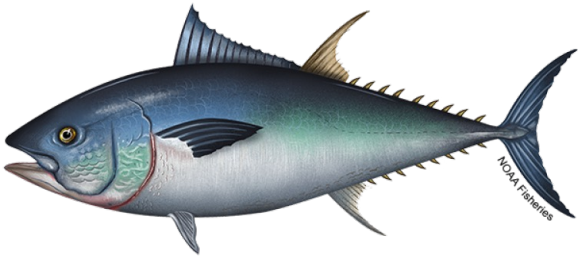
BLUEFIN TUNA

(Thunnus thynnus & Thunnus orientalis)



Native Range & Preferred Environment

There are two species of bluefin that have native ranges in the United States: the Atlantic *(Thunnus thynnus)* and Pacific bluefin tuna *(Thunnus orientalis)*. Each species has a range that spans their respective ocean. As a highly migratory species, their preferred environment is also variable, although they are commonly found in deeper, colder waters.

Status of Wild Stock

Fishing of bluefin has reached unsustainable levels, with many being caught before they are of reproductive age (Ma, 2021). Measures are being taken by the International Commission for the Conservation of Atlantic Tunas (ICCAT) to reduce overfishing, like introducing quotas, minimum landing sizes, and seasonal fishing moratoriums (Gasparac, 2023). Cultivating bluefin from the larval stage and thus eliminating the need to catch juveniles for ranches could alleviate some of the pressure on wild populations or at least meet some of the demand currently being met largely by wild stock.

Cultivation Traits

Bluefin tuna has been a challenging species to cultivate for multiple reasons. Knowledge of cultivation in general and especially full life cycle cultivation is low, with Japan, Croatia, and the United States being some of the first countries to successfully rear tuna from eggs (Gasparac, 2023; Jelić Mrčelić et al. 2023). It takes three to five years for bluefin to mature to reproductive age, and their average lifespan is 25 years (Ma, 2021). They have a high oxygen demand and the large, quick moving, and highly migratory fish are not optimal to keep contained in pens as they require a low stocking density and can cause damage to themselves and the infrastructure in the case of collisions (Loew, 2022). The predatory fish also consume a lot of feed and the current FCR and FIFO for bluefin are very high. However, there are some developments in feed technology that are reducing these values (Leschin-Hoar, 2020)

Current U.S. Cultivation Status

Bluefin tuna are currently commercially “cultivated” in sea ranches, where they are wild caught while young and then reared in large enclosed marine spaces (Jelić Mrčelić et al. 2023). The cages in the sea ranches look similar to floating aquaculture pens, only with a much larger volume to fish ratio. Once the fish are stocked into the pens, they are raised for an additional 2.5 years until they reach the desired

size (Gasparac, 2023). As a result, sea ranching does not remove stress to wild populations like full life cycle cultivation can. There are no bluefin sea ranches in the United States. The San Diego-based bluefin farming company, Ichthus Unlimited, specializes in rearing tuna in a hatchery and making feed (Leschin-Hoar, 2020). The hatchery operates on land, with the intention of selling the cultivated fish to sea ranches in Mexico (Leschin-Hoar, 2020).

Environmental Impacts of Cultivation

There is increased risk of escape from infrastructure damage done by the fish themselves, which could result in escapes. As the native ranges for bluefin are so large, the main concern with escapes would be disease outbreaks. In Japan, praziquantel and oxytetracycline are medicines administered to ranched tuna to address blood fluke parasites and bacterial infections. While praziquantel, which is used to treat parasites, is nontoxic to the surrounding marine ecosystem, oxytetracycline has been known to encourage antibiotic resistant bacteria that could be harmful if transmitted to wild tuna (Ma, 2021). However, there has been no recorded evidence of disease transmission between wild and cultivated/ranched bluefin tuna (Jelić Mrčelić et al. 2023).

Current & Future Markets

Currently, the bluefin is predominantly imported from Japan, Croatia, and Mexico. In 2019, the cost of establishing a bluefin farm in the Mediterranean was about 3.6 million USD including all infrastructure. Due to the knowledge gaps in full lifecycle cultivation of bluefin, getting the species ready to be farmed offshore instead of ranched will take significant investment into research and experimental farms. However, when the technology and information is available, bluefin could be an attractive species for many U.S. offshore farmers.

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RED SNAPPER

(Lutjanus campechanus)

Native Range & Preferred Environment

Red snapper is a reef fish found in offshore waters of the Gulf of Mexico that is highly resilient to changes in temperature (from 15.0 to 29.0 degrees Celsius) and salinity (from 2 to 36 ppt) (McGuigan et al. 2023). Aside from the Gulf of Mexico, their native range includes the Caribbean (McGuigan et al. 2023). Between the 1970s and the 1990s, the wild red snapper stock in the Gulf of Mexico dropped by about 90 percent because of fishing pressure and bycatch in the shrimp fishery (Saillant et al. 2012). In 2000, NOAA categorized red snapper as an overfished species (Ogle and Lotz, 2000).

Cultivation Traits

Due to the red snapper's overfished status, the fish went under a stock enhancement program that involved hatchery rearing of juveniles before stocking them back into the Gulf of Mexico (Ogle and Lotz, 2000; Saillant et al. 2012). They were fed a pelleted mahi mahi diet regularly to reduce the instances of cannibalism that were common in the rearing tanks (Ogle and Lotz, 2000). In a 2023 study conducted by McGuigan et al., red snapper were reared from larvae to full sexual maturity in terrestrial tanks. The fish were fed a pellet feed first and then fresh feed of chopped squid, sardines, and shrimp once they were fully grown (McGuigan et al. 2023). The FCRs for cultivation varied between 0.93 and 1.47 (McGuigan et al. 2023). The farmed red snapper were consistently observed to have faster growth rates in terms of length and weight than the wild red snapper (McGuigan et al. 2023).

Current U.S. Cultivation Status

While red snapper has not been farmed for commercial aquaculture since 2000, there is a solid knowledge base around juvenile cultivation because of the U.S. wild stock recovery attempts and interest in future cultivation (McGuigan et al. 2023; Gonzalez, 2020). There are no offshore red snapper farms in the United States to date, but there is a new offshore farm in Aruba that plans to cultivate red snapper to sell in the United States (FishFocus, 2023; Hogan, 2023). The farm will use Innovasea's SeaStation pens submerged more than ten meters in water with depths of 80 to 100 meters (Hogan, 2023). The site is located five miles off of the southwest coast of Aruba and the farm will have a 3,000 tonne capacity, with 16 pens monitored by advanced technological systems and artificial intelligence (Hogan, 2023; FishFocus, 2023).

RED SNAPPER

(Lutjanus campechanus)

Environmental Defense Fund

Current & Future Markets

There has long been a strong market for red snapper in the United States. For example, fisheries in Florida, on the Gulf of Mexico, have been catching snapper for human consumption since the 1870s (Ogle and Lotz, 2000). With a good sized filet and mild flavor, red snapper has a high demand in restaurants and markets across the country. However, the current supply comes from fisheries and is restricted to specific fishing seasons (FishFocus, 2023).

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COMMON SEA BREAM

(Pagrus pagrus)

Native Range & Preferred Environment

Common sea bream is suitable for offshore commercial cultivation based on past farming history in the United States and current techniques in China (Morris et al. 2008). The native range of common sea bream includes the Mediterranean, the eastern Atlantic, the western Atlantic from North Carolina to Mexico and from Venezuela to Argentina (Morris et al. 2008). The fish's ideal conditions are temperatures of 22 degrees Celsius, depths of 10-80 meters, and salinity concentrations of 34 g per liter (Fishbase, 2024; Morris et al. 2008). Common sea bream can reach weights of up to 9 to 17 kgs, average a weight of about 35 cm, and can live up to 26 years (Fishbase, 2024). There are two parasites, Anoplodiscus longivaginatus and Anoplodiscus richiardii that are a threat to sea bream and target their fins and the sides of their bodies (Fishbase, 2024).

Wild Stock Status

In the United States, common sea bream fisheries have been identified as overfished, resulting in a moratorium followed by stricter regulations and decreases in allowable catches (Smart et al. 2020; Morris et al. 2008). Common sea bream or "red porgy" remains on NOAA's overfished and overfishing lists as of December 2022 (NOAA, 2022). It is possible that farming sea bream offshore in U.S. federal waters would allow for domestically sourced sea bream markets to strengthen while the fisheries are recovering.

Current U.S. Cultivation Status

The first attempt at aquaculture cultivation of common sea bream in the United States was in 2005 on a collaborative project between NOAA's National Marine Fisheries Service and the University of North Carolina Wilmington. The focus of this project was to understand how to breed and grow sea bream from egg to juvenile stage. Since that initial cultivation experiment, there has been limited progress in the red porgy industry in the United States. However, offshore cultivation of sea bream in China has been successful. Additionally, Chinese offshore farms observed that common sea bream were healthier when they were submerged than when they were cultivated on the surface (Sievers et al. 2022).

Current & Future Markets

The market for sea bream is mostly filets for human consumption, which are sold both fresh and frozen (Fishbase, 2024). A different species of sea bream, red sea bream, that is cultivated in China in submerged pens, sells in Japan for 1.2 to 1.5 times higher than other red sea bream products due to its bright red color. It is marketed to consumers as "deep-sea red sea bream" (Towers, 2016).

COMMON SEA BREAM

(Pagrus pagrus)

Environmental Defense Fund

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MAHI-MAHI

(Coryphaena hippurus)

Native Range & Preferred Environment

Mahi-mahi are carnivorous fish that have a wide natural range in global tropical and subtropical waters (Santhosh et al. 2014). They can be found in the Atlantic, Indian and Pacific oceans (Santhosh et al. 2014).

Cultivation Traits

Mahi-mahi cultivation is another species with low current likelihood due to lack of knowledge and challenges with specific species traits but high market demand. They are strong, fast moving, and active. It takes about 180 days for mahi-mahi to grow to harvest size (~1.7 kg). They can be fed dry pellet feeds and had a FCR of about 1.6 in 2014 (Santhosh et al. 2014). There is a risk of farmed mahi mahi contracting vibriosis (Santhosh et al. 2014). Vibrosis is a disease that is caused by Vibrio alginolyticus and can cause symptoms like anorexia, caudal fin erosion, and epidermal lesions (Santhosh et al. 2014). Another illness, called red tail disease, is caused by stress to the fish and is common in mahi-mahi during the cultivation period of days 40 through 90 (Santhosh et al. 2014). Finally, parasites like worms and protozoa are a risk for mahi-mahi. Outbreaks may be controlled through lower stocking densities and periods of submergence to bring the fish outside of the optimal conditions of the parasites.

Current U.S. Cultivation Status

Mahi-mahi aquaculture broodstock was first raised in the Waikiki Aquarium and Oceanic Institute in Hawai'i, with individuals raised from eggs and kept in indoor tanks. This process demonstrated that stocking densities play a significant role in the survival rates of juvenile mahi-mahi (Santhosh et al. 2014). This challenge persists as the fish get older and more individuals mature, as male mahi-mahi can be territorial and aggressive to other males. The University of Miami, in partnership with New York's Aqquua LLC, has an aquaculture and hatchery program that has successfully cultivated and reared mahi-mahi (Mayer, 2018). However, there are still challenges with getting the fish to full adult sizes (2.7-3.6 pounds) as the mortality rates increase with the size and age. It is not necessary for the mahi-mahi fish to be cultivated to maturity for there to be a market, because there is demand for canned and "plate" size mahi-mahi (Mayer, 2018).

MAHI-MAHI

(Coryphaena hippurus)

Environmental Impacts of Cultivation

The leading treatment for vibriosis is mahi-mahi is to administer a feed medicated with 75 mg Terramycin for ten days (Santhosh et al. 2014). It is unclear how excess feed containing this medicine would affect local ecosystems.

Current & Future Markets

Like bluefin tuna, Mahi-mahi may have low current cultivation likelihood due to lack of knowledge and challenges with specific species traits but high market demand. However, it is not necessary for the mahi-mahi fish to be cultivated to maturity for there to be a market, because there is demand for canned and "plate" size mahi-mahi (Mayer, 2018). Mahi-mahi is generally sold either fresh or frozen and there is an international market demand, especially for imports into Japan, China, and Taiwan (Santhosh et al. 2014). With more advanced cultivation technology and understanding, mahi-mahi could be a popular species to farm because of its large size and high demand and price in food markets.

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For questions, please contact:

Poppy Brittingham
poppyb@stanford.edu

Maddie Voorhees
mvoorhees@edf.org

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