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Characterization of supply of marine finfish species with potential for commercial growth in the United States

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Abstract

Global production of marine finfish has grown in total volume of production and the number of species farmed commercially, but there has been little production in the United States of marine finfish other than salmon and red drum. For most species considered to be ready for commercialization, there are few or no farms from which to evaluate the size of the market or to estimate revenues and costs necessary to assess economic feasibility. This present study takes a first step to fill this gap with an analysis of the existing supply of 20 marine finfish species identified as candidates for commercialization in the United States, as a proxy for effective demand (the volume of a product sold at the market equilibrium price). Secondary data from 1950 (where available) through 2019 were compiled on each species, including (1) global aquaculture production, (2) US aquaculture production, (3) US commercial landings, (4) US recreational landings, and (5) imports. Current effective market demand (measured as the sum of commercial landings, farmed production, and imports) was low, totaling 36.6 million kg across the 20 species, which is equivalent to less than 23% of the annual volume sold of US farmed catfish. Commercial landings for 17 of the 20 species exhibited declines, potentially offering opportunities for farmed product to capture market share by filling the increasing gaps in supply. The variability in commercial landings provides opportunities for farms to capitalize on their advantage in supplying product with a high degree of consistency of volume, size, delivery frequency, and quality. Several unknown factors suggest the need for follow-up studies on consumer preferences, degree of substitutability among finfish species, and effects of recreational landings on demand. An important limitation to prospective producers is the lack of species-specific import data for the generic categories of "flounder," "bass," and "snapper." This supply analysis provides a foundational analysis for prospective producers, investors, and researchers interested in commercialization of these marine species.

KEYWORDS
commercializable species, economic feasibility, marine finfish, market supply, supply

1 | INTRODUCTION

Growth of aquaculture worldwide has included increased production of marine finfish, which accounted for 13.4% of global farmed finfish production in 2018 (FAO, 2020). While much of this growth has been from salmon farming, the "other marine finfish" category contributed 1.4% of the 2018 share of all finfish produced in aquaculture, an increase of 64% from 2010 to 2018. In the United States, while foodfish composed nearly half (47%) of all aquaculture sales, the majority (84%) of foodfish production was of freshwater fish (Engle, van Senten, Schwarz, & Watkins, 2021).

Research over the last several decades has resulted in critical breakthroughs for marine finfish production, particularly in larval feeds and hatchery methods, which constitute major bottlenecks for farmed production. As a result, it is now biologically feasible to grow a number of marine finfish species, but little research has been conducted on the economic feasibility of commercial production. Understanding the economic requirements for emerging species requires comprehensive information on market conditions (i.e., demand and supply) and of production costs. This analysis focuses on the supply component of 20 marine species identified as having potential for commercialization in the United States (Rexroad et al., 2021). Additional work will be needed to address other components of the requirements for economically feasible production of these species. The first step is to understand effective market demand, the volume of each species sold, and temporal trends of the volume sold. The present study focuses on this first step that will identify the relative sizes of the markets for each of these species. The trends in commercial landings, farmed production in the United States, and import volumes will shed light on near-term market sizes for each species. Other studies needed will include: (1) a better understanding of consumer preferences for these species by geographic region and demographic groups; (2) insight into perspectives of seafood distributors on these species and potential future market demand for each; and (3) estimated costs of production for various scales of production. This article addresses the first step to lay the foundation of understanding the current market size and volumes and sources of supply that prospective producers will need to compete with for economically feasible production of these 20 marine finfish candidates for commercialization.

Most studies on markets for marine species have focused on consumer preferences for various attributes such as wild versus farmed, locally harvested versus imported, harvesting methods, production practices, certification and labeling, appearance of product and packaging, or species (Cantillo et al., 2020). The species studied in the Cantillo et al. (2020) review primarily focused on salmon, tilapia, trout, turbot, seabass, and seabream, but included a few references to amberjack and cod. Garlock et al. (2020), in a contingent choice experiment with a few large US seafood wholesalers, concluded that Gulf farmed fish would substitute more for imports than for domestic wild-caught fish because US wholesale buyers prefer domestic to imported fish, but had no significant preference for wild-caught over farmed fish.

Consumer preferences, however, are only one of the determinants of demand. Formal demand estimations have been published for finfish generally (Yen & Huang, 1996), Indian major carps in India (Kumar et al., 2005), salmon (Asche, 1996; Xie et al., 2009), and shrimp (Keefe & Jolly, 2006). Recent examples of studies that have estimated both demand and supply for aquaculture products include Kobayashi et al. (2015) and Cai and Leung (2017).

Few studies have focused primarily on market supply characteristics of specific aquaculture species. For US catfish, Kouka and Engle (1998) used time-series data to develop a multi-stage supply model that accounted for fry/fingerling, foodfish, and wholesale stages of production. Catfish foodfish supply was found to be relatively inelastic, largely because of the length of the growing season. In contrast to the time-series data available for the US catfish industry, the data available for many other emerging species are frequently insufficient for quantitative supply analyses.

The objective of this analysis was to analyze the current supply of marine finfish species considered to be candidates for commercial farmed production (Rexroad et al., 2021). Specific objectives were to assess commercial supplies from wild capture, domestic aquaculture production, and international trade for each species. While existing data are not adequate for quantitative analyses of supply, this descriptive analysis summarizes effective demand for the marine finfish species considered to be candidates for commercial farmed production and is expected to be of interest to prospective producers, investors, and researchers interested in commercial farming of these species.

2 | METHODS

Rexroad et al. (2021) summarized the results of a series of workshops held to identify marine finfish species with potential for commercial farmed production in the United States. These include: almaco jack, *Seriola rivoliana*, Atlantic cod, *Gadus morhua* (Nardi et al., 2021), black drum, *Pogonias cromis*, black sea bass, *Centropristis striata* (Watanabe et al., 2021), California flounder, *Paralichthys californicus* (Stuart et al., 2021), California yellowtail, *Seriola lalandi* (*formerly S. dorsalis*) (Rotman et al., 2021), cobia, *Rachycentron canadum* (Benetti et al., 2021), Florida pompano, *Trachinotus carolinus* (Weirich et al., 2021), greater amberjack, *Seriola dumerili*, olive flounder, *Paralichthys olivaceus* (Stieglitz et al., 2021), red drum, *Sciaenops ocellatus*, red snapper, *Lutjanus campechanus*, sablefish, *Anoplopoma fimbria* (Goetz et al., 2021), southern flounder, *Paralichthys lethostigma*, spotted seatrout, *Cynoscion nebulosus* (Blaylock et al., 2021), spotted wolffish, *Anarhichas minor*, striped bass,[1] *Morone saxatilis* (Andersen et al., 2021), summer flounder, *Paralichthys dentatus*, tripletail, *Lobotes surinamensis* (Saillant et al., 2021), and white seabass, *Atractoscion nobilis* (Drawbridge et al., 2021).

Secondary data from 1950 (where available) through 2019 were compiled for each species to evaluate: (1) global aquaculture production; (2) US aquaculture production; (3) US commercial landings; (4) US recreational landings; and (5) imports. No attempt was made to include information for the year 2020 because of the reduced volumes of supply from all sources that resulted from the severe economic disruptions caused by the COVID-19 pandemic (van Senten et al., 2021; van Senten, Engle, & Smith, 2020).

Aquaculture data were obtained from FAO (2021) for global production and from the 2018 Census of Aquaculture (USDA-NASS, 2019) for US farmed production. Additional data were collected through a literature search of major aquaculture science journals. Information on aquaculture regulations for specific species were summarized where available and relevant to either the supply or marketing of each species.

[1]Hybrid striped bass (female white bass *Morone chrysops* × male striped bass *Morone saxatilis*) are well established in freshwater aquaculture production in the U.S., but are sold as a smaller finfish into markets distinct from those that purchase wild-caught striped bass. All references to striped bass in this article refer to *Morone saxatilis*, not the hybrid striped bass.

Data on imported volumes of the 20 species under consideration in this analysis were obtained from the NOAA Foreign Trade Database (NOAA, 2021a). The NOAA database assembles data collected from the U.S. Customs and Border Protection that receives data from importers submitting transactions using the international Harmonized Commodity Description and Coding System (https://usitc.gob/harmonized_tariff_information). Typical categories for finfish imports included: "fresh," "fresh fillet," "other fresh meat," "frozen," "frozen fillet," and "frozen fillet blocks."

Commercial and recreational landing data of these 20 species were collected from NOAA (2021b). Information on quotas, fishing seasons, and other regulations that affect the volume and seasonality of supply were compiled for commercial and recreational landings from marine fisheries council and commission websites (ASMFC 2002, 2011, 2018, 2019a, 2019b; CDFG, 2002; CFMC, 1985; GOMFMC, 1984, 2001; NCDEQ, 2021a; NEFMC, 1985; NPFMC, 2020a, 2020b; PFMC, 2019; SAFMC, 2020), and state agencies involved in fisheries management (ADCNR, 2021; CDFW, 2021a, 2021b; CT DEEP, 2021; DDNREC, 2021; FWC, 2021a, 2021b, 2021c; GADNR, 2021; LDWF, 2021a, 2021b; MDMR, 2021a, 2021b; MDNR, 2021; NCDEQ, 2021a, 2021b; NYS DEC, 2021; ODFW, 2021; SCDNR, 2021; TPWD, 2021; VMRC, 2021).

3 | RESULTS

3.1 | Aquaculture of emerging marine species with potential for commercialization in the United States

For the majority of the marine species considered to have potential for commercialization in the United States, there is currently little to no aquaculture production in the United States for sale as foodfish (Table 1). In the United States, there are measurable volumes of marine finfish production for only two species: Atlantic salmon, *Salmo salar* and red drum (USDA-NASS, 2019). Atlantic salmon, however, was not included in this analysis because it has been a well-established aquaculture species for decades, both globally and in the United States. Farmed red drum production was 3.3 million kg in 2018 (USDA-NASS, 2019). In addition, there was 0.4 million kg of almaco jack (Seafood Watch, 2020), less than 11,400 kg of black sea bass (FAO 2021) and anecdotal reports of commercial production of Florida pompano (Weirich et al., 2021) and possibly flounder (species unspecified) (USDA-NASS, 2019). In addition to the above production levels for foodfish markets, stock enhancement programs have been developed in the United States to enhance wild populations of California flounder, cobia, red drum, spotted seatrout, striped bass, and white seabass. Stock enhancement management practices provide a source of fingerlings, but fish raised for stock enhancement are not typically grown to the size of those sold as foodfish. Regulatory considerations for fish raised for stocking purposes differ substantially for fingerlings raised by state and federal hatcheries for stocking purposes in the wild as compared with those of commercial finfish farms.

Of the species considered to have potential for commercialization in the United States, global production volumes have been reported for 10 of these species (Table 1). The greatest volume reported in 2019 was for red drum, at 77 million kg globally, followed by that of cobia and olive flounder. Much lower volumes of commercial farmed production were reported for Atlantic cod, Florida pompano, almaco jack, sablefish, striped bass, greater amberjack, and black sea bass. Farmed production of spotted wolffish was reported in the past in Ireland, on one commercial farm in Norway, with a reported plan for a spotted wolffish pilot farm in Canada (LeFrançois et al., 2021).

3.2 | US aquaculture regulations for emerging marine species

Aquaculture farms in the United States are regulated by a combination of local authorities and state and federal agencies. More than 1300 laws that apply to US aquaculture have been identified and categorized as regulating environmental, food safety, legal and labor standards, interstate transport, fish health, and culture of commercially

TABLE 1 Farmed production volumes[a] (United States[b] and world[c]) of emerging marine species with potential for commercialization in the United States

Species	2018 production (United State) (kg)	Farmed in the past in the United States	2019 farmed production globally (kg)[c]	Global production trends[d]
Specific species				
Red drum	3.3 M	Yes	77.0 M	Increasing
Cobia	0	Yes	48.2 M	Increasing
Olive flounder	0	No	45.3 M	Stable
Atlantic cod	0	Yes	1.98 M	Increasing since 2015
Florida pompano	Anecdotal	Yes	0.5 M	Fluctuating
Almaco jack	0.4 M	Yes	0.4 M	Stable
Sablefish	0	Yes	<0.3 M	Stable
Striped bass[e]	0	No	0.2 M	Declining
Greater amberjack	0	No	0.1 M	Increasing slightly
Black sea bass	<11,400	Yes	<11,400	Stable
Spotted wolffish[f]	0	No	0	Stable
Generic categories				
Flounder	Anecdotal	Anecdotal	0.015 M	Increasing
Snapper	0	No	8.9 M	Increasing

[a]Atlantic salmon is farmed in the United States and around the world. Its aquaculture success excludes it from consideration as an emerging species.
[b]The most recent data in the United States were from the 2018 Census of Aquaculture (USDA-NASS, 2019).
[c]FAO (2021).
[d]"Increasing slightly" refers to increases of approximately ≤100,000 lb/year; "increasing" refers to annual increases >100,000 lb/year.
[e]"Striped bass refers to *Morone saxatilis*, not its hybrid with *Morone chrysops* that is farmed in the United States in freshwater ponds and cages.
[f]Past production in Ireland; anecdotal report of one commercial farm in Norway, and one pilot farm planned in Canada (LeFrançois et al., 2021).

harvested species (Engle & Stone, 2013). At the federal level, leading regulatory agencies include the Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration (NOAA), the Food and Drug Administration (FDA), Animal Plant and Health Inspection Service (APHIS), and the U.S. Department of Transportation. State and local authorities also have jurisdiction over water use, discharge, access to coastal and offshore use, predator control, aquatic animal health, choice of species, sales of gamefish, processing and food safety, and trade.

The effects of the total regulatory framework have been examined based on detailed farm records collected from national surveys for US aquaculture sectors that have included baitfish/sportfish (van Senten & Engle, 2017), salmonids (Engle et al., 2019), Pacific Coast shellfish (van Senten, Engle, Hudson, & Conte, 2020), Florida tropical fish (Boldt et al., 2022), and catfish (Hegde et al., 2022). These various studies have shown high on-farm compliance costs and severe constraints to growth to meet increasing demand for aquaculture products. Moreover, the regulatory framework as implemented has resulted in inefficiencies on farms (van Senten, Dey, & Engle, 2018). Innovative approaches to regulating aquaculture have been shown to have potential to achieve equivalent oversight at lower cost (Engle, van Senten, Schwarz, Hartman, et al., 2021; van Senten, Engle, et al., 2018).

Aquaculture in marine and coastal areas faces even more challenging regulatory issues in the United States that originate from the complex jurisdictional issues. In some states in the United States, the regulatory authority for local coastal water bodies can be with either local, county, state, or federal agencies, sometimes in various combinations of overlapping jurisdictions (van Senten, Engle, Hudson, & Conte, 2020). In addition, many marine species with potential to be farmed are also game or sportfish species. Laws to prohibit illegal catch and sale of gamefish and sportfish, when applied to farmed fish without modification, constrain access to markets for farmed fish. Lengthy, multi-year delays in obtaining permits have created a strong disincentive for investors to consider aquaculture ventures. The lack of a clear regulatory authority for offshore farming of marine finfish, and attempts to develop farms in marine waters have resulted in various legal challenges. Thus, the regulatory framework in the United States is one of the major constraints to increased farming of marine finfish in the United States. The Presidential Executive Order of May 2020 mandated changes to the regulatory system for commercial aquaculture to streamline the process (85 C.F.R. § 28471) that may have a positive impact in the future on finfish regulations.

3.3 | Imports of emerging marine species with potential for commercialization in the United States

The United States is a leading global importer of seafood. Imported seafood makes up approximately 90% of the volume of seafood available for consumption in the United States, and of this, estimates suggest roughly half of the imports are from aquaculture (NOAA, 2021c). The trade deficit for US seafood was $16.9 billion in 2019 (National Marine Fisheries Service, 2021). For the species of interest in this study, species-specific import data were found only for: Atlantic cod, cobia, sablefish, and spotted wolffish. The NOAA Foreign Trade Database utilizes broad categories that aggregate data from several species into single groups. For example, the category of "Snapper" includes all species (i.e., red, Pacific, gray, and other snappers) in the *Lutjanidae* family, "Flounder" includes all species of the *Pleuronectidae*, *Bothidae*, and *Citharidae* families, and "Seabass" includes fish in the Dicentrarchus genus only (thus, not including white or black sea bass or striped bass and their hybrids) (Michael Liddel, personal communication). Import volumes for the flounder species considered in this analysis (California, olive, southern, and summer) likely are included in the generic "Flounder" category, but the data include imports of other flatfish species as well. No import data were found for almaco jack, black drum, California yellowtail, greater amberjack, red drum, spotted seatrout, tripletail, or spotted wolffish after 2018.

The greatest volume of imports of the species considered in this analysis was of Atlantic cod (62.2 million kg), followed by sablefish, and then cobia (Table 2). Of the generic categories of imports, the "snapper" category had the greatest volume (20 million kg), followed by the "flounder" (10.3 million kg), "seabass," (9.6 million kg), and "bass" (1.0 million kg) categories.

3.4 | Commercial and recreational fisheries landings of emerging marine species with potential for commercialization in the United States

The 20 species considered in this analysis are characterized by very different volumes of US commercial fisheries landings, ranging from less than 10,000 kg a year to nearly 17 million kg a year (Table 3). Sablefish commercial landings exceeded all others, with a 5-year average of 16.9 million kg/year. Summer flounder followed, with 3.5 million kg, red snapper (2.7 million kg), black drum (2.7 million kg), striped bass (2.5 million kg), Atlantic cod (2.1 million kg), black sea bass (1.4 million kg), greater amberjack (0.6 million kg), and southern flounder (0.5 million kg). The following species had 5-year average volumes less than 250,000 kg: California flounder, spotted seatrout, white seabass,

TABLE 2 Imported volumes[a] (2019) of emerging marine species with potential for commercialization in the US[a] source: NOAA Foreign Trade Database (NOAA, 2021a)

Species	Imports	
	Volume (kg)	Value ($)
Specific species		
Atlantic cod[b]	62,245,073	$509,978,046
Sablefish	320,164	$5,109,471
Cobia[c]	301,339	$3,088,033
Generic categories		
Snapper[d]	20,030,899	$144,080,471
Flounder[e]	10,272,484	$53,368,632
Seabass[f]	9,643,026	$56,909,773
Bass[f]	979,137	$9,065,343

[a]No import data were found on: almaco jack, black drum, California yellowtail, greater amberjack, red drum, spotted seatrout, tripletail, or spotted wolffish after 2018.
[b]Includes "fresh fillet," "fresh," "frozen fillet" and "frozen categories.
[c]Includes "fresh" and "frozen."
[d]The "Snapper" category includes all species in the *Lutjanidae* family, thus likely includes imports of red snapper along with other snapper species such as Pacific snapper, gray snapper, and others.
[e]The "Flounder" category includes all species of the *Pleuronectidae*, *Bothidae*, and *Citharidae* families; thus, likely includes California flounder, olive flounder, southern flounder, and summer flounder, along with other flatfish species.
[f]Imports are reported for "Bass" and "Seabass." Species are not specified, but the "Seabass" category includes fish of the Dicentrarchus genus. These import categories likely do not include black sea bass, striped bass, or white seabass.

Florida pompano, cobia, red drum, almaco jack, California yellowtail, and tripletail. No US commercial landings were reported for olive flounder or spotted wolffish.

Recreational fishery landings showed very different rankings from those of commercial fisheries landings (Figure 1). The greatest volume of recreational landings was of striped bass (15.5 million kg), followed by red drum (9.5 million kg), spotted seatrout (8.1 million kg), red snapper (6.7 million kg), summer flounder (6.1 million kg), black sea bass (4.6 million kg), black drum (4.3 million kg), cobia (2.4 million kg), greater amberjack (1.7 million kg), southern flounder (1.2 million kg), Florida pompano (1.2 million kg), Atlantic cod (1.1 million kg), California yellowtail (0.3 million kg), tripletail (0.3 million kg), almaco jack (0.2 million kg), California flounder (0.1 million kg), and sablefish (0.001 million kg) (Table 3). No recreational fishing landings were reported in the United States for either olive flounder or spotted wolffish.

The majority of the species considered in this analysis were caught in the Atlantic Ocean or the Gulf of Mexico. The state of Florida had the greatest commercial landings for six of these species (almaco jack, cobia, Florida pompano, greater amberjack, red snapper, and tripletail) (Table 4). Louisiana landed the most black drum, Mississippi red drum, and North Carolina southern flounder and spotted seatrout. Four of the species were landed mostly in the northeast Atlantic, including Atlantic cod (Massachusetts), black sea bass (New Jersey), striped bass (Maryland), and summer flounder (Virginia). Four of the species were landed only on the west coast, with California the top state for California flounder, California yellowtail, and white seabass. Alaska was the top landing state for sablefish. Landings were not recorded in any US states for olive flounder or spotted wolffish.

Florida was also the top state for recreational landings of eight species (almaco jack, black drum, Florida pompano, greater amberjack, red snapper, southern flounder, spotted seatrout, and tripletail; Table 5). For cobia, Virginia had the most recreational landings, New York for black sea bass and striped bass, and New Jersey for summer flounder. California flounder, California yellowtail, and white seabass were mostly caught recreationally in California, and sablefish in Oregon. Recreational landings were not recorded in any state for olive flounder or spotted wolffish.

TABLE 3 US commercial and recreational landings of warmwater marine finfish species ranked in order of average annual commercial landings for the 5-year period between 2015 and 2019

Species	Commercial landings 5-year average (kg)	Recreational landings 5-year average (kg)
Sablefish	16,941,354	1423
Summer flounder	3,493,626	6,083,402
Red snapper	2,713,996	6,673,736
Black drum	2,656,994	4,264,424
Striped bass	2,458,193	15,459,254
Atlantic cod	2,105,741	1,064,571
Black sea bass	1,415,966	4,573,922
Greater amberjack	564,806	1,714,703
Southern flounder	515,919	1,221,804
California flounder	206,754	112,970
Spotted seatrout	171,326	8,059,345
White seabass	120,369	41,649
Florida pompano	113,592	1,203,810
Cobia	91,439	2,378,753
Red drum	86,860	9,544,468
Almaco jack	82,494	168,529
California yellowtail	25,272	320,441
Tripletail	8527	282,263
Olive flounder	N/A	N/A
Spotted wolffish	N/A	N/A

Source: NOAA landings database (NOAA, 2021b).

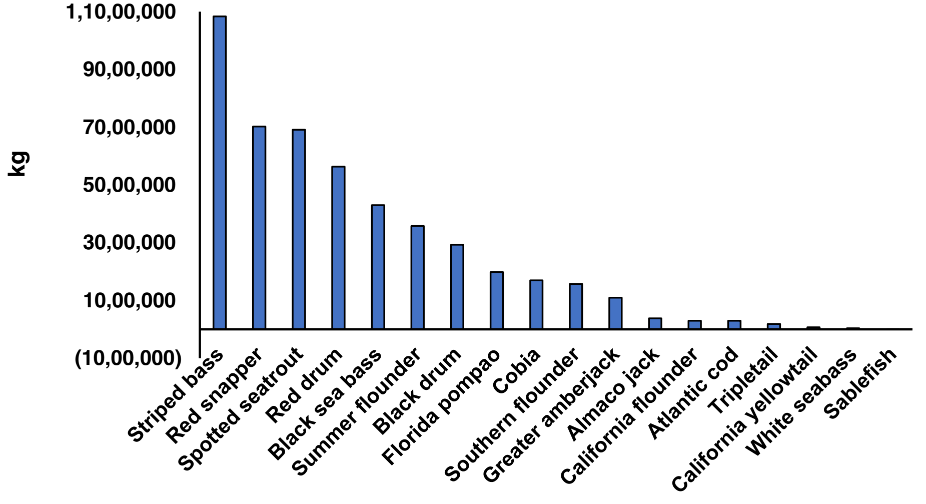

FIGURE 1 US recreational landings, 2019, of the 18 species for which recreational landings data were available (there were no recreational landings reported in the United States of olive flounder or spotted wolffish). "Striped bass" refers to *Morone saxatilis*, not its hybrid with *Morone chrysops* that is farmed in the United States in freshwater ponds and cages.

TABLE 4 Top three states for commercial landings with percentage of overall commercial catch in 2019

Species	State with most landings	State with second most landings	State with third most landings
Almaco jack	Florida (50%)	North Carolina (30%)	South Carolina (17%)
Atlantic cod	Massachusetts (91%)	New Hampshire (4.4%)	Maine (3.9%)
Black drum	Louisiana (59%)	Texas (33%)	Virginia (2%)
Black sea bass	New Jersey (19%)	Virginia (17%)	Massachusetts (14%)
California flounder	California (100%)	N/A	N/A
California yellowtail	California (100%)	N/A	N/A
Cobia	Florida (43%)	Virginia (28%)	North Carolina (16%)
Florida pompano	Florida (90%)	North Carolina (6%)	Louisiana (2%)
Greater amberjack	Florida (70%)	Alabama (8.2%)	South Carolina (7.8%)
Olive flounder	N/A	N/A	N/A
Red drum	Mississippi (51%)	North Carolina (47%)	Virginia (2%)
Red snapper	Florida (39%)	Texas (34%)	Louisiana (18%)
Sablefish	Alaska (71%)	Oregon (14%)	California (8%)
Southern flounder	North Carolina (90%)	Florida (10%)	N/A
Spotted seatrout	North Carolina (66%)	Virginia (24%)	Mississippi (6%)
Spotted wolffish	N/A	N/A	N/A
Striped bass	Maryland (39%)	Virginia (31%)	Massachusetts (13%)
Summer flounder	Virginia (27%)	Rhode Island (24%)	New Jersey (23%)
Tripletail	Florida (67%)	North Carolina (13%)	Mississippi (12%)
White seabass	California (100%)	N/A	N/A

Source: NOAA landings database (NOAA, 2021b).

3.5 | Commercial and recreational fisheries regulation of emerging marine species with potential for commercialization in the U.S.

Commercial and recreational fisheries regulations affect the availability of these species for sale into commercial markets, recreational angling opportunities, and home consumption. Federal and state regulations vary widely and change based on fisheries population estimates. In federal waters, Fisheries Management Councils establish annual catch limits, minimum sizes, bag limits, or total allowable catches with tradable quotas in different areas. States establish commercial and recreational catch limits and seasons for state waters.

Commercial fishing seasons for almaco jack, black drum, California yellowtail, cobia, Florida pompano, and tripletail are open year-round for harvest from state and federal waters (Table 6). The commercial Atlantic cod season is open year-round, but is subject to quota shares allocated to permit-holders. Fishing seasons for black sea bass, greater amberjack, spotted seatrout, striped bass, and summer flounder are open year-round, but with quotas set each year that result in closure of the fishery when the quota is met. California flounder is subject to a short trawling season in California waters but is open year-round elsewhere. The seasons for red snapper and sablefish are closed for parts of the year in state and federal waters. Commercial red drum harvest is allowed only in Mississippi, Maryland, and Massachusetts, with varying seasons and quotas. Commercial harvests of red drum in the Gulf of Mexico were prohibited in 1990 and have remained so in federal waters. The commercial harvest of southern flounder is heavily regulated, with a month-long season in North Carolina and strict vessel limits in Florida. Lastly, a federal harvest moratorium on spotted wolffish has closed both commercial and recreational seasons year-round. Greater detail on regulations for these various species can be found in Engle, van Senten, Schwarz, and Watkins (2021).

TABLE 5 Top three states for recreational landings with percent share of total recreational catch in 2019

Species	State with most landings	State with second most landings	State with third most landings
Almaco jack	Florida (93%)	North Carolina (4%)	Alabama (1%)
Atlantic cod	Connecticut (41%)	Rhode Island (22%)	New York (18%)
Black drum	Florida (40%)	Mississippi (23%)	South Carolina (14%)
Black sea bass	New York (33%)	Massachusetts (14%)	Rhode Island (13%)
California flounder	California (99%)	Oregon (<1%)	N/A
California yellowtail	California (99%)	Oregon (<1%)	N/A
Cobia	Virginia (41%)	Florida (36%)	Alabama (11%)
Florida pompano	Florida (76%)	North Carolina (18%)	South Carolina (5%)
Greater amberjack	Florida (81%)	Alabama (6%)	Louisiana (4%)
Olive flounder	N/A	N/A	N/A
Red drum	Louisiana (29%)	Florida (17%)	Mississippi (21%)
Red snapper	Florida (51%)	Alabama (39%)	Mississippi (7%)
Sablefish	Oregon (100%)	N/A	N/A
Southern flounder	Florida (66%)	North Carolina (11%)	Mississippi (8%)
Spotted seatrout	Florida (32%)	North Carolina (19%)	Louisiana (12%)
Spotted wolffish	N/A	N/A	N/A
Striped bass	New York (30%)	New Jersey (29%)	Maryland (14%)
Summer flounder	New Jersey (41%)	New York (31%)	Rhode Island (11%)
Tripletail	Florida (75.5%)	Alabama (12%)	Mississippi (6%)
White seabass	California (100%)	N/A	N/A

Source: NOAA landings database (NOAA, 2021b).

TABLE 6 Restrictions on commercial fishing seasons in the United States[a]

Open year-round	Open year-round, w/catch shares/quotas	Closed part of year w/catch shares/quotas	Closed all but a few months of year	Closed year-round
Almaco jack	Atlantic cod	Red drum	Southern flounder	Spotted wolffish
Black drum	Black sea bass	Red snapper		
California yellowtail	California flounder	Sablefish		
Cobia	Greater amberjack			
Florida pompano	Spotted seatrout			
Tripletail	Striped bass			
	Summer flounder			

[a]Olive flounder is not native to US waters; therefore there is no commercial olive flounder fishery (Stieglitz et al., 2021).

Regulations on recreational harvests also vary widely by species and state in the United States. Recreational seasons for almaco jack, California flounder, California yellowtail, Florida pompano, red drum, sablefish, spotted seatrout, tripletail, and white seabass are open year-round (Table 7). Strict quotas and catch shares for several other species (black sea bass, cobia, greater amberjack, southern flounder, striped bass, and summer flounder) can lead to early season closings when quotas are met despite the season nominally considered to be open year-round. The black drum recreational fishery is closed for part of the year and is also subject to quotas or catch shares. Atlantic cod and red snapper have seasons that are only open for parts of the year, and the federal harvest moratorium on spotted wolffish has closed that fishery year-round. Detailed information on the opening and closing dates for these seasons can be found in Engle, van Senten, Schwarz, and Watkins (2021).

3.6 | Total commercial supply

The total commercial supply of the marine finfish species considered as candidates for commercialization is the sum of the volume supplied from aquaculture, from commercial fishing landings, and the volume of imports in the United States. Of the species considered as candidates for commercialization, the total commercial supply is greatest for sablefish, followed by red snapper, red drum, summer flounder, black drum, striped bass, black sea bass, and Atlantic cod (Table 8). The rankings by volume likely would change with the addition of species-specific import data. California yellowtail, spotted wolffish, tripletail, and white seabass have relatively insignificant supplies in the United States.

From an aquaculture perspective, the total volume of commercial supply of the 20 species under consideration is fairly low, at 36.6 million kg, only 23% of the total volume sold of US farmed catfish alone. The volume of sablefish approached that of only the second largest sector of US aquaculture, trout (22 million kg in 2019), but the majority of sablefish is exported, not consumed in the US market. More than half of the marine species considered in this study had annual supplies that were less than the average production from a single US catfish farm (340,198 kg). A single large catfish farm of 405 hectares produces a greater volume than all but the commercial supply of sablefish.

Commercial landings of 17 of the 20 species considered as candidates for commercialization showed declining volumes over time (Table 8). In some cases, the declines occurred many years ago followed by very low landings, and in others the decline occurred in recent years. One species (black drum) showed relatively stable commercial landings and two (red snapper and tripletail) showed increasing trends. Species with restricted fishing seasons may offer market opportunities for aquaculture farms that can provide a consistent supply of fish to customers.

TABLE 7 Restrictions on recreational fishing seasons in the United States

Open year-round	Open year-round, w/catch shares/quotas	Closed part of year w/catch shares/quotas	Closed all but a few months of year	Closed year-round
Almaco jack	Black sea bass	Black drum	Atlantic cod	Spotted wolffish
California flounder	Cobia		Red snapper	
California yellowtail	Greater amberjack			
Florida pompano	Southern flounder			
Red drum	Striped bass			
Sablefish	Summer flounder			
Spotted seatrout				
Tripletail				
White seabass				

TABLE 8 Total commercial supply of marine finfish in the United States in 2019

Species	Commercial landings (kg)	Farmed production (kg)	Total commercial supply (kg)	Trend of commercial landings[a]
Sablefish	18,526,377	-	18,526,377	Decline
Red snapper	3,428,352	-	3,428,352	Recent increase
Red drum	54,691	3,244,580	3,299,271	Decline
Summer flounder	3,195,544	-	3,195,544	Decline
Black drum	2,430,419	-	2,430,419	Stable
Striped bass	2,035,563	-	2,035,563	Recent decline
Black sea bass	1,725,004	-	1,725,004	Decline
Atlantic cod	1,016,775	-	1,016,775	Decline
Southern flounder	409,310	-	409,310	Decline
Greater amberjack	368,039	-	368,039	Decline
CA flounder	332,103	-	332,103	Decline
Spotted seatrout	258,949	-	258,949	Decline
Florida pompano	182,808	-	182,808	Decline
Almaco jack	83,173	-	83,173	Recent decline
White seabass	72,901	-	72,901	Decline
Cobia	62,439	-	62,439	Decline
CA yellowtail	12,000	-	12,000	Very low
Tripletail	10,951	-	10,951	Increasing
Olive flounder	0	-	0	No U.S. landings
Spotted wolffish	0	-	0	Decline
Total	33,332,197	3,244,580	36,576,777	

Source: NOAA landings database (NOAA, 2021b); NOAA foreign trade database (NOAA, 2021a); Census of Aquaculture 2018 (USDA-NASS, 2019).

[a]"Decline refers to decreasing landings over a long period of time; "recent decline" refers to landings that have been decreasing in only the last few years; "very low" refers to landings that have been relatively stable but at very low levels over a number of years as compared with much higher levels historically.

The low supply volumes of most of these species mean that effective demand is low and likely consists of small, niche markets. Such markets would support only a small number of farms initially and would require substantial effort to build either new or larger markets. It is important to note that Table 8 does not include import data for the species combined in the "snapper," "flounder," and "bass/seabass" categories.

The recreationally harvested landings were greater than commercially harvested landings for 14 of the 20 species considered for commercialization. Commercially harvested landings exceeded those of recreationally harvested fish only for sablefish, Atlantic cod, California flounder, and white seabass. There has been little research attention to the effect on consumer demand for marine finfish species of substantial recreational landings. Nevertheless, it is likely that recreational landings create awareness and potentially positive perceptions of a given species in the geographic areas where caught. In addition, political pressure from sportfishermen has been reported to result in greater

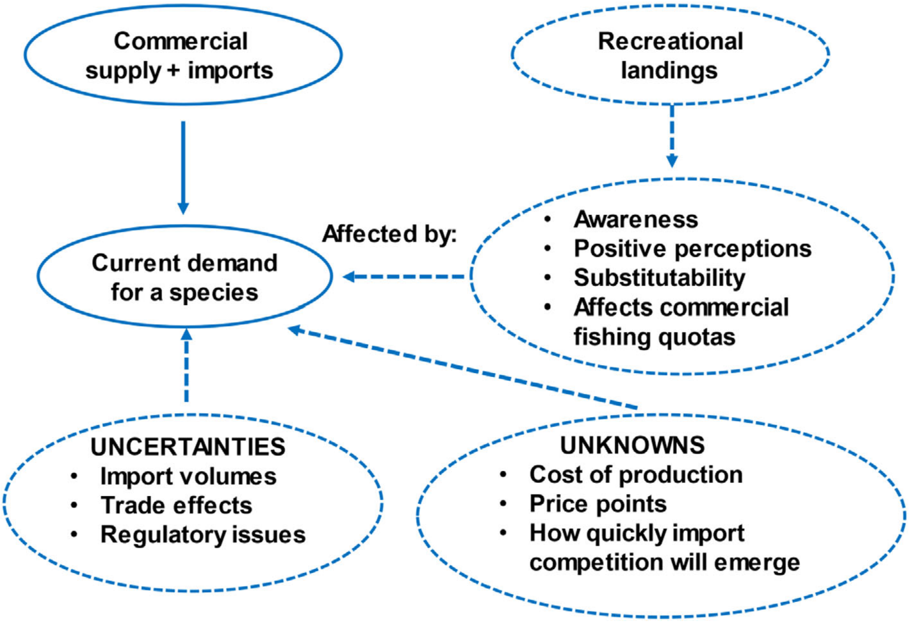

FIGURE 2 Factors that affect effective demand for a marine finfish species

percentages of catch quotas assigned to recreational as compared to commercial landings (Carter & Conathan, 2018; Smith & Jepson, 1993). Such trends may continue, given the overall importance of recreational fishing to the economies of a number of coastal states (Southwick Associates, 2013) The extent to which recreational catch quotas substitute for commercial quotas may further reduce the market supply of those species, and potentially increase demand for farmed product of that species.

4 | DISCUSSION

For most of the species identified as candidates for commercialization, there are few or no farms from which to estimate revenues and costs to assess economic feasibility. The present study analyzed existing supply as a proxy for effective demand (the volume of a product sold at the market equilibrium price) and overall market size in the United States. Understanding the relative market size of the species considered to be candidates for commercialization is the first step toward identifying feasible business models. Additional studies will be needed that provide a more detailed understanding of consumer preferences and estimates of costs of production for these species.

For the species considered in this analysis, the factors that affect the current supply available to the market include commercial fisheries landings, imported volumes of that species, and the limited amount of farmed production (Figure 2). The volume of available supply clearly establishes a baseline of the volume that is currently being purchased by consumers and the current size of the market for each species. To estimate market prices, however, information on demand relationships in any given market must also be considered. Factors that affect demand include, among others, awareness of the product and the degree to which consumers readily substitute among various species of marine finfish. Additional analyses are needed to understand these important determinants of demand for marine finfish species considered to be candidates for commercialization.

This supply analysis of marine finfish species showed that the current volume of commercial supply (landings plus imports) of these 20 species is quite low. Such low volumes would support only a relatively small number of commercial-scale farms that likely would also be fairly small scale. Given the economies of scale that are common in much of aquaculture, such smaller-scale farms would likely operate at relatively high costs of production and would need to target upscale markets to search for premium prices. More cost-efficient, larger-scale production of these species would require that much larger markets be created and developed. Studies such as those done for well-established US aquaculture sectors (Engle et al., 1990; Kumar et al., 2008) would provide guidance for selecting markets to target and for further research studies.

Larger markets for these species would require either that US consumers increase the proportion of their diet that is seafood or that farms effectively capture market share from other finfish species (i.e., pollock, tuna, salmon, tilapia). Alternatively, existing marine finfish farms could potentially add an additional species to the overall farm business model and plan.

Commercial landings for the species considered as candidates for commercialization are highly variable and subject to catch quotas and other constraints imposed by individual states and by fisheries management councils. Year-to-year variation in landings is affected by the weather, changing quotas and other regulations, and often longer-term, multi-year spawning and production cycles. Thus, it is important to give greater consideration to longer-term than shorter-term trends. Additional variability in the data arises from changes made over time in the population models used to estimate overall landings (NOAA 2021a, 2021b).

The variability in commercial landings may offer an important advantage for aquaculture farms. Fish farming offers consistent volumes, sizes, and quality that are attractive to distributors, restaurants, and supermarkets. Declining commercial landings and seasonal supplies of wild-caught fish may offer opportunities to penetrate markets with farmed supply of those species, but taking advantage of such opportunities will require adequate logistical infrastructure on farms to provide a very consistent volume, size, and quality of that species.

Recreational fisheries landings create some important questions and unknowns for commercialization of marine finfish farms. Recreational landings have increased in importance over time when compared with commercial landings. Yet the effect of increased recreational landings on US consumer demand does not appear to be well understood. No studies were found in the research literature that directly address this effect. Species that are popular and prized by recreational anglers would be expected to be well known in the region and perhaps perceived in a positive manner by consumers. Whether an angler who fishes primarily for the thrill of catching fish would be willing to pay high prices for that fish in a restaurant or supermarket is a key question.

The research literature on seafood demand in the United States shows regional variation in consumer preferences (Engle et al., 1990) and a fairly high degree of substitutability among species that varies across geographic markets (Dey et al., 2017). Yet such substitutability for emerging species, such as those in this study, has not been estimated nor are data available currently to do so. For example, questions such as whether seafood consumers would generally substitute sablefish for Chilean sea bass or whether flounder consumers prefer certain specific species of flounder over others is not known. Additional research on these important questions is necessary to provide sound guidance for marketing efforts.

The lack of readily available data on imported quantities of marine finfish is an important limitation to this analysis, but more importantly to prospective farmers considering investing in farmed production of these species. Competition from low-priced imports, often raised under less stringent regulatory enforcement frameworks (Abate et al., 2016), can be a critical factor in the success of early farm enterprises for that species. Garlock et al. (2020) concluded that the major competition for farmed marine finfish in the U.S. Gulf of Mexico would likely be from imported fish, not commercial wild-caught landings. Moreover, as has been shown in the US catfish industry, commercial farming success and market development in the United States will almost certainly attract competition from other countries (Engle, Kumar, & Hanson, 2022). Thus, US farming businesses for these species will need to develop and implement effective strategies to not just compete with current imported supplies but also to prepare for inevitable increases in imported quantities of the species for which they have developed efficient farm management practices.

Unfortunately, the aggregated data in the “flounder,” “bass,” and “snapper” categories obscure the degree of competition from imports for those species raised in the United States. For example, more than 8 million pounds of unspecified species of flounder were imported as frozen product in 2019. Imported fish of the same species may well be the major type of competition for development of successful aquaculture businesses for these species. New, startup, and prospective aquaculture producers will need to have access to data on imported volumes, prices, and country of origin to be able to design effective strategies to compete with what most often are lower-priced products entering the United States. Therefore, to support growth and development of marine finfish aquaculture, it is important that the Foreign Trade Database of the Office of Science and Technology of NOAA (NOAA, 2021a) be expanded to provide detailed data by species of flounder, bass, and snapper.

5 | CONCLUSIONS

The commercially available supply of the marine finfish identified as candidates for commercialization was found to be generally declining for all but three species: black drum with stable supply and red snapper and tripletail for which supply was increasing. Declining commercial supply may offer windows of market opportunity for startup farms to begin establishing their products in those markets. It may be possible for the volumes of farmed supply to reach previous levels of demand for species that have been in decline, but the extent to which that happens will depend on various dynamics of the determinants of demand and supply.

With the exception of sablefish and Atlantic cod, the volumes of commercial supply for the species analyzed in this study were low, which in turn indicates that effective market demand for these species is also low. Low effective demand means that startup farms for these species will also need to be small scale until farmers are able to develop new markets that support growth of the farm. Market strategies of farmers raising these species will need to balance promotion and market development with increasing volumes of farmed production to attempt to maintain stable prices and avoid drastic price declines that occur with sudden increases in supply without adequate market development.

One well-discussed advantage of fish farms is the ability to offer consistent sizes, quality, volumes, and frequency of delivery to customers. The high degree of variability of commercial landings and supply amplifies the advantage of farming the species studied in this project.

Recreational landings were greater than commercial landings for 14 of the 20 marine finfish species identified as candidates for commercialization. Nevertheless, recreational landings are unlikely to have a direct effect on demand, although there may be indirect effects. Part of the reason for increasing recreational landings is the increasing market share of the catch quota allocations being transferred to recreational from commercial landings. The political strength of recreational anglers has grown over time and likely explains the increases in recreational landings. If this trend continues, commercial landings (which constitute market supply) will likely continue to decrease, offering more opportunities for farmed production to gain a foothold in markets. Recreational landings also likely provide indirect benefits in the form of awareness of these different species and likely positive perceptions of them.

The lack of data on the volume of imports and trends for many of these specific species is problematic. Imported marine finfish will likely be the largest proportion of the competition faced by US marine fish farmers. Thus, having access to data to monitor those trends will become ever more important over time.

The markets that will need to be developed for these species will be low volume, high-cost markets, at least in the short term. Farms will need to develop strong logistical support to consistently deliver extremely fresh product in very consistent sizes, quality, and frequency of delivery year-round to upscale markets for farms to be economically viable.

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