Offshore Finfish Aquaculture

Global Review and U.S. Prospects

the David & Lucile Packard Foundation

CEA California Environmental Associates

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1 Executive Summary

This report summarizes the findings of a rapid appraisal of trends in global offshore finfish aquaculture. We assess the track record of a dozen producer countries to understand the drivers, constraints, and risks of offshore operations. Based on these findings, we try to evaluate the potential of a U.S.-based offshore sector, from a purely economic standpoint.

Our findings suggest that offshore finfish aquaculture will remain more expensive than nearshore marine aquaculture but it is likely to grow globally. With envisioned technologies, any offshore solution will be 15-30 percent higher in cost than conventional production, barring exponential increases in scale. Economies of scale can bring costs down a bit, but they likely won't move beneath the 10-15 percent cost premium over coastal net pens in the near term. However, a growing population and increasing demand for fish will continue to drive aquaculture production. Given land-based and nearshore constraints in areas that are already densely populated by net pens, a move to offshore is likely.

Norway and China are at the forefront of the industry with massive infrastructure developments. Between Norway and China, US$ 1.5-2 billion have been invested in offshore aquaculture in the past three to four years, or are currently being invested into massive offshore rigs with capacities of 1-2 million fish. Not unlike oil rigs, these infrastructures can withstand high-energy systems, can be largely operated from shore, and might eventually reach economies of scale that offset some of the additional costs of offshore locations. These pilots will likely drive the development of the sector for decades to come.

Technological solutions will converge to two or three models in the next decade. The salmon industry in Norway is driving most of the research and development in the offshore aquaculture field at the moment. The recent development licenses of the Norwegian government are incentivizing (and effectively subsidizing) R&D and have led to dozens of potentially interesting engineering solutions which are now being implemented. Groups like SalMar and Marine Harvest will use these pilots to fine-tune technological solutions and select for the most robust and profitable models over time.

More and more countries will join the race. Besides the countries and region discussed here (Norway, China, Panama, Mexico, Turkey, Japan, and Southeast Asia), a dozen or so more countries have also joined the race, or will join it in the next decade, including India, Australia, the U.K., Chile and a handful of EU member countries.

The small farm ideal is unlikely to survive in U.S. federal waters. The large majority of offshore operations that have been piloted in Hawaii and Latin America (mostly with U.S. capital, technology, and leadership) seems challenging in the high-energy context of U.S. offshore waters. U.S. federal waters are exposed to severe winds and wave action for large parts of the year, making it unpractical (diving in cages, supplying feed every few days) and costly (capital-intensive and risky) for small facilities to be economically viable.

The U.S. is not in a competitive advantage to develop the industry by itself, but market proximity will attract large investors from outside. The past 10 years of trial and error suggest that the U.S. will not be a major player in this industry. The meager attempts by U.S.-based practitioners are dwarfed by the vertically integrated high-tech solutions in Norway, Turkey, and China, and the U.S. lacks the experience and infrastructure to get started on large operations. With appropriate conditions, foreign investors (most likely Norwegians) may try to establish a presence close to U.S. markets (most likely in the northeast of the country), but that will depend fundamentally on the economics of production.

If it happens in the U.S., it will likely not be before 2030. The offshore aquaculture world is now in R&D mode. Investors will closely watch the performance of existing trials and then react to it. This will take time. Scoping for the right sites, identification of species-mix, development of infrastructure, and talent and risk assessments (among others) suggests that even in the most aggressive scenarios, U.S.-based offshore aquaculture starts being commercially viable only 10 to 15 years from now. By then, other countries might have pushed the prices to a level that makes it exceedingly unattractive for an expensive U.S. site. Furthermore, land-based recirculating aquaculture systems in the U.S. are attracting heavy investment at the moment and will likely gain a significant competitive head start in the meantime.

None of this analysis precludes the importance of establishing appropriate regulatory frameworks now, as those frameworks will be critical to establishing at the outset an environmentally sound and sustainable industry that could develop over the next 20 to 50 years. However, for the United States in the next decade at least, a profitable offshore aquaculture industry operating at scale is likely to remain a vision rather than an economic reality.

2 Background

Aquaculture is increasingly meeting the growing demand for seafood. Global demand for seafood has been surging for decades due to population growth and strong economic conditions in both developed and developing regions. While capture fishery landings have been flat since the late 1980s, due to fully exploited and overexploited fish stocks, aquaculture continues to increase its contribution to the world's seafood supply, with a compound annual growth rate of 7.5 percent since 1990 (Figure 1).

Aquaculture is the fastest-growing food sector; spatial conflicts and environmental concerns might soon constrain the continued expansion of freshwater and coastal operations.

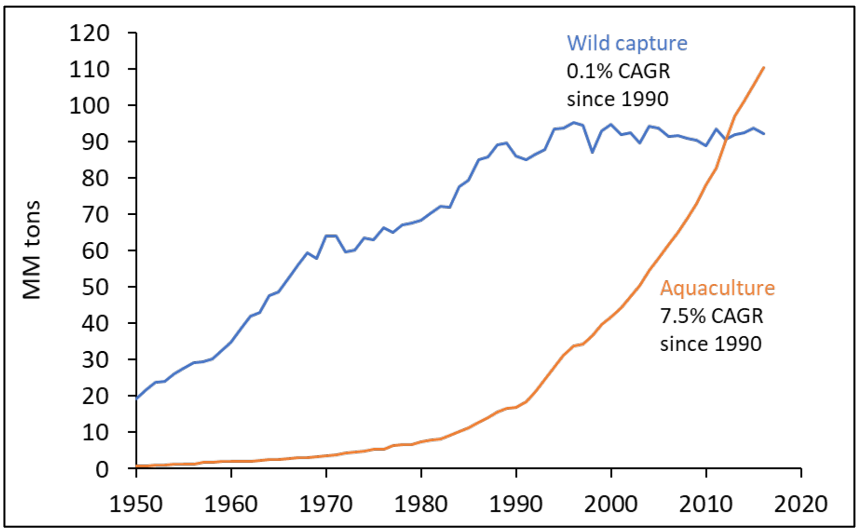

Figure 1: Global capture and culture production of seafood[1]

The fast growth of aquaculture is at least partially constrained by spatial conflicts and environmental concerns. Coastal and land-based aquaculture is the fastest-growing food sector in the world and will continue to grow significantly. While still predominantly concentrated in Asia, fish farming has now spread to all continents, including unlikely regions such as sub-Saharan Africa. However, the limited availability – and the competition for natural resources – in the nearshore environment, the increasing significance of environment protection, and advances in marine engineering have raised expectations that the sector will gradually be moved further offshore, where spatial conflicts might be

[1] FAO 2011-2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series.

mitigated, environmental concerns are less concentrated, and expansion seems less limited.[2]

Offshore aquaculture is particularly driven by the limitation of suitable nearshore areas and spatial conflicts. Despite long coastlines in major producing countries, nearshore finfish aquaculture is constrained by a host of factors:[3,4,5,6]

<u>Oceanic conditions</u> need to be favorable for high productivity (such as water temperatures, currents, and oxygen availability).

<u>Spatial conflicts</u>: Profitability of aquaculture increases with proximity to markets, proximity to infrastructure, and proximity to the coast. All of these factors also drive the profitability of other sectors, such as tourism, coastal real estate, and shipping.

<u>Ecological carrying capacity</u>: Nutrient overload can quickly lead to disease and collapse of farmed fish. Boom and bust cycles around the world have highlighted the ecological response of inadequate farm management.

<u>Government licenses</u> restrict the availability of nearshore permits.

Offshore aquaculture has been receiving increasing attention, but its commercial potential and economic risks remain poorly understood. The practice of offshore aquaculture is still young, and research in the field remains thin. The few studies focusing specifically on offshore aquaculture emphasize the increased dissipation of nutrients in offshore settings, the reduced need for antibiotics, and the general oceanographic potential of offshore production.[7] [8] Proponents have pointed to the vast extent of marine waters, the potential economies of scale, and even the better taste of fish farmed offshore;[9] sceptics have pointed to the high complexities, capital costs, and economic risks associated with more intense environments.

Offshore aquaculture is only in its infancy; this report reviews global trends and assesses the commercial viability of U.S. operations.

[2] Aguilar-Manjarrez et al. (2010). The potential of spatial planning tools to support the ecosystem approach to aquaculture. FAO Fisheries and Aquaculture Proceedings. No.17. Rome, Italy: FAO. p176.
[3] Gentry et al. (2017). Mapping the global potential for marine aquaculture. Nature Ecology and Evolution.
[4] Hofherr et al. (2015). Is lack of space a limiting factor for the development of aquaculture in EU coastal areas? Ocean & Coastal Management V.116.
[5] Froehlich et al. (2017). Public Perceptions of Aquaculture: Evaluating Spatiotemporal Patterns of Sentiment around the World. PlosOne.
[6] Walsh, B. (2011). Can the U.S. Close Its Seafood Trade Deficit? Time Magazine.
[7] Froehlich, H.A. et al. (2017). Offshore Aquaculture: I Know It When I See It. Frontiers in Marine Science.
[8] Gentry et al. (2017). Mapping the global potential for marine aquaculture. Nature Ecology and Evolution.
[9] Rubino, M. edit. (2008). Offshore Aquaculture in the United States: Economic Considerations, Implications & Opportunities. NOAA Technical Memorandum.

This report reviews recent developments in global offshore finfish aquaculture and assesses the opportunities and constraints of an emerging industry in the U.S. Much still remains to be learned about the industry's societal benefits, environmental concerns, and potential spatial conflicts. This report focuses on aggregating information about the track record of offshore finfish aquaculture globally and the potential commercial viability of the industry in the U.S. Offshore aquaculture is still in its infancy and the typical key performance indicators of well-established industries are missing. In the absence of hard data, we rely heavily on (grey) literature review, expert consultation, and some data analysis. A list of interviewees is provided below:

Table 1: Interviewees consulted

<u>**Seafood industry**</u> **John Connelly** President, National Fisheries Institute **Harlon Pearce** President, Gulf Seafood Institute **Margaret Henderson** Stronger America Through Seafood campaign **Michael King** Purchasing Manager, King Seafood <u>**Investors**</u> **Trip O'Shea** Vice President, Encourage Capital **Dexter Paine** Chairman, Paine Schwartz Partners <u>**NOAA**</u> **Michael Rubino** Director of Aquaculture **Mike Rust** Aquaculture Science Advisor	<u>**Practitioners**</u> **Don Kent** CEO at Hubbs-SeaWorld **Todd Madsen** President, Blue Ocean Mariculture **Neil Sims** Co-Founder, Kampachi Farms **David Kelly** CEO & CTO, InnovaSea Systems <u>**Other**</u> **Paul Greenberg** Author of "Four Fish" and "American Catch" **Rebecca Gentry** University of California, Santa Barbara **Sarah Lester** Florida State University

This report is focused on finfish aquaculture. Offshore aquaculture can involve farming bivalves, macroalgae, and/or finfish. Bivalves are filter feeders living on naturally occurring plankton and dissolved organic matter, and macroalgae live on photosynthesis alone. Apart from issues of non-indigenous species or disease amplification, and issues associated with the physical siting of gear (e.g., whale entanglements), both are thought to have a relatively modest environmental footprint in exposed water. Finfish aquaculture is generally thought to have a more significant potential to disrupt marine ecosystems. While it is commonly agreed that offshore aquaculture poses a lower environmental risk than coastal aquaculture with respect to effluent (nutrients are better dissipated by constant throughflow and antibiotics are less important to guarantee high survival rates), potential concerns include a higher risk of escapements, the spreading of disease and parasites and benthic biodiversity (e.g., ocean floor destruction of mooring or larger-scale constructions), wildlife interactions with the physical structure, and the general ecological concerns around the use of fishmeal/fish oil and energy intensity of production.[10]

Offshore aquaculture is understood differently across nations and stakeholders; a 2010 workshop on the potential and limitations of offshore aquaculture defined it as follows:

> "When it is located > 2 km or out of sight from the coast, in water depths > 50 m, with waves heights of 5 m or more, ocean swells, variable winds and strong ocean currents, in locations that are exposed (open sea, e.g. ≥ 180o open) and where there is a requirement for remote operations, automated feeding, and where remote monitoring of operating system may be required."[11]

In the U.S. context, offshore aquaculture is typically defined as taking place "in federal waters" (generally defined as from three to 200 miles offshore [4.8 to 322 kilometers]).[12] H.R. 2010: National Offshore Aquaculture Act of 2007 defined offshore aquaculture as:

> "All activities, including the operation of offshore aquaculture facilities, involved in the propagation and rearing, or attempted propagation and rearing, of marine species in the United States Exclusive Economic Zone."[13]

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[10] Holmer (2010). Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs. Aquacult Environ Interact, Vol 1.
[11] FAO (2010). Expanding mariculture farther offshore Technical, environmental, spatial and governance challenges. Fisheries and Aquaculture proceedings 24.
[12] Knapp and Rubino (2016). The Political Economics of Marine Aquaculture in the United States. REVIEWS IN FISHERIES SCIENCE & AQUACULTURE 24 (3).
[13] S. 1609 — 110th Congress: National Offshore Aquaculture Act of 2007.

Coastal and land-based aquaculture can still be a profitable business due to low capital costs and quick returns. At the farm level, aquaculture can be a profitable business and is typically characterized as high risk, high return (particularly for species that are prone to disease such as shrimp, salmon, sea bass). To generalize, the major cost points in coastal and land-based operations are feed (>50 percent), followed by brood stock, labor, and electricity. The track record of aquaculture around the world speaks to the past profit margins and the quick amortization of operations. A quick amortization (often within one to two years) is due to low capital costs, which in many cases simply consist of the excavation of ponds or the construction of small dams and a few aeration devices. Due to the hefty increases in production, feed costs have gone up significantly, driving down profitability margins below 10 percent in most operations around the world (estimate based on literature and interviews).

"The logistics of deep-water aquaculture require expensive boats, bigger anchors, and better planning to avoid endangered species, which makes it too expensive for small businesses."

Barry Costa Pierce, Director of the Center for Excellence in the Marine Sciences at the University of New England

Figure 2: Low-capital catfish farm. Photo credit: Getty Images

Costs of marine aquaculture are likely to significantly increase as you move offshore. There is no doubt that the cost of producing a kg of fish offshore exceeds the cost of producing a kg in a nearshore facility. This is a key take-away from a number of interviews. As complexities and risks increase, associated costs to manage and mitigate them will increase. Three reasons stand out:

<u>Capital expenses go up considerably</u>. This includes cage materiality and construction, shoreside infrastructure (port infrastructure, hatcheries, nurseries), specialized ships and machinery for transport and feeding. Barry Costa Pierce, director of the University of New England's Center of Excellence in the Marine Sciences, told Bloomberg

news that "the logistics of deep-water aquaculture require expensive boats, bigger anchors, and better planning to avoid endangered species, which makes it too expensive for small businesses."[14]

New and higher variable costs will drive down profitability. A number of costs will decrease when moving offshore. Among them are land purchase, lice management (example salmon), and water management in ponds and runways. However, the large majority of traditional variable costs will increase: Feeding is less efficient in the open ocean, and labor costs go up significantly. In addition, a number of new variable costs are added to the equation, most importantly the transport, maintenance, and harvest. FAO's "global assessment of offshore mariculture potential from a spatial perspective"[15] estimates that any offshore aquaculture facility operating outside a 25 nautical mile radius from a port (based on port index definition) will not be economical.

Insurance costs will increase. The influence of insurance firms in setting up offshore operations will be considerable. Investors will only be attracted if they are reassured that technical risks do not affect their returns. However, insurances will be coy to jump into an unknown and complex industry too fast. The past two decades of offshore wind power serve as an example: "The need to reassure potential investors that technology defects, delays in start-up or unplanned downtime will not affect their returns is growing and, along with it, the influence of the insurance industry."[16] In 2013, Swiss RE predicted that premiums paid by renewable-energy producers for insurance and other risk-mitigation products will increase from the current $850 million (€782 million) to anywhere between $1.5 billion and $2.8 billion by 2020. In addition to insurance, other financial costs will also increase. A 2015 review of wind energy costs by the national laboratory of the U.S. Department of Energy estimates that financial costs (insurance, construction finance, and contingencies) are 9 percent of total costs for land-based wind farms and 21 percent for fixed-bottom offshore plant projects.

"The need to reassure potential investors [of offshore wind] that technology defects, delays in start-up or unplanned downtime will not affect their returns is growing and, along with it, the influence of the insurance industry."

Jatin Sharma (2015) in WindPower[16]

Offshore aquaculture must withstand high-energy environments. Even near-shore operations suffer from weathering, salt water erosion, and wave energy, which can lead to capital losses. The most recent large-scale escapement of 300,000 salmon in Puget Sound occurred when

[14] Bloomberg (Oct, 2016). The $100 Million U.S. Government Fish Farm Nobody wants.

[15] FAO (2013). A global assessment of offshore mariculture potential from a spatial perspective. Technical paper 549.

[16] WindPower (Aug, 2015). Is insurance killing innovation? Quote from Jatin Sharma, head of business development for GCube, an underwriter active in the renewables sector.

anchor lines on a commercial net pen gave way and net pens folded (onlookers said it looked like hurricane debris).[17] And while Puget Sound is relatively well-protected from waves and storms, offshore sites are not. Wave energy, winds, biological risks, and distance to the shore increase the complexity and costs that go into the planning, design, and implementation of offshore projects. The Global Aquaculture Insurance Consortium, which offers insurance up to $2M for stock mortality and equipment, evaluates their premium based on wave height, tidal range, winds, algal blooms, the amount of days per year that feeding would be impossible due to weather conditions, fallowing/rotation practices, shipping activities, the distance between independently moored cage groups, and so on. Inland farms, on the other hand, are requested to provide far less detail; the perceived risk for these farms seems to be mainly disease as is reflected in the need for land-based operations to provide information about the minimum water current velocities and whether members of the general public are allowed on the premises.[18]

Market preference and price premiums increase with quality. An important selling point for offshore aquaculture is the quality of the fish. The constant throughflow of water makes for a more active and cleaner-tasting fish than the more stagnant nearshore pens (personal communication with one interviewee managing an offshore operation). Since quality is a key driver of prices in seafood markets (more for differentiated products, less for volume commodities), it is possible that offshore products at some point get preferential treatment in local and higher-paying markets (including, for example, pre-purchase agreements at Whole Foods). However, this is hardly a strong argument from an economic perspective since it is unlikely that price premiums can offset any of the increased costs of offshore production.

4 Track record of offshore finfish aquaculture outside the U.S.

Depending on its definition, global offshore aquaculture currently contributes somewhere between 5,000-200,000 tons of fish (in the low 10,000s without Turkey). Most existing operations that self-identify as "offshore" are located in the protected vicinity of the coast (typically one-half mile to four miles from shore), are protected by islands, and/or are located in ocean areas with low wave heights and minimal winds (such as the Aegean Sea and the Sea of Cortez). However, a wave of ambitious investments is underway in Norway, China, and Japan, and to a lesser extent in Singapore, Indonesia, and Chile. While some of these investments are heavily subsidized or even state-run, others have real private skin in the game and are betting on the economic viability of their models.

[17] www.npr.org (Aug, 2017). 'Environmental Nightmare' After Thousands Of Atlantic Salmon Escape Fish Farm.
[18] GAIC (accessed June 2018). Application form for stocks of fish and shellfish held in offshore enclosures.

Figure 3 provides an overview of the geographic extent of offshore finfish aquaculture; Table 2 provides a more detailed summary of major existing and prospective offshore operations. The remainder of this chapter provides more detail about key operations.

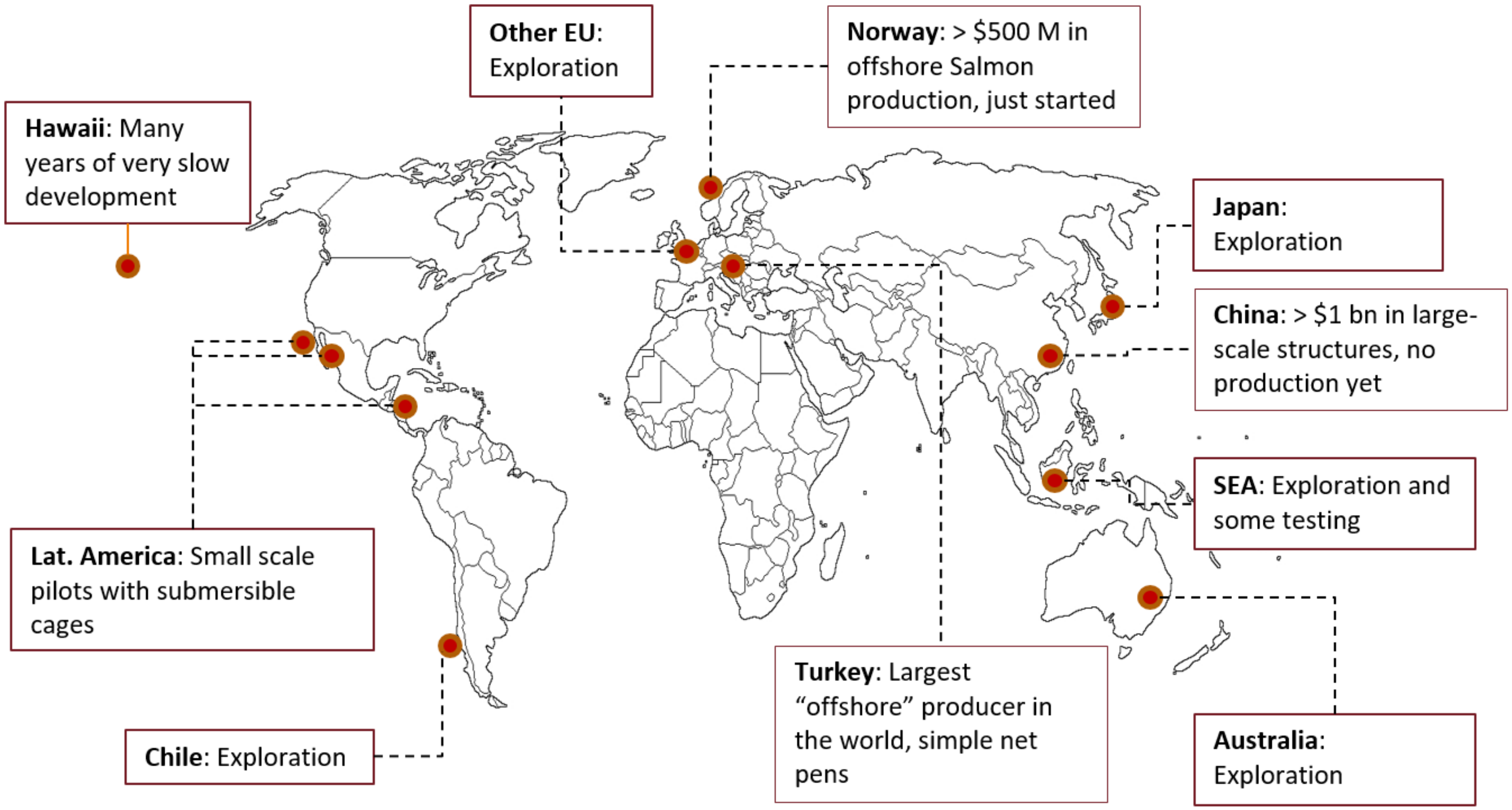

Figure 3: Geographic extent of offshore finfish aquaculture (not comprehensive). "Exploration" refers to current private sector and/or public sector scoping of offshore developments.

Table 2: Selection of current and prospective offshore operations

Operation	Description	Investor	Geography	Species	Annual production in tons
InnovaSea	Launched in 2015 with the merger of *OceanSpar* and *Ocean Farm Technologies.* Develops net pen technologies including the **Aquapod** (open ocean conditions) and the **SeaStation** (low-medium energy systems). Has worked with Open Blue, Earth Ocean Farms and Blue Ocean Aquaculture.	Cuna del Mar	Boston	N/A	N/A, producer of cages
Blue Ocean Mariculture	Founded in 2009, currently the only open ocean finfish farm in the United States. Uses InnovaSea **SeaStation** cages.	Self-financed through Todd Madsen's family fund	Hawaii, in state waters	Hawaiian Kanpachi	500
Rose Canyon	A partnership between Hubbs-SeaWorld Research Institute and Cuna del Mar; supported by two marine fish hatcheries in southern California. Cages include **SeaStation**, **Aquapod,** and traditional gravity-type surface cages.	Cuna del Mar	4.5 miles (7 kilometers) west of Mission Bay off the San Diego coast, in federal waters	Yellowtail Jack	0 to date, target volume is 5,000
Manna Fish Farms	Seeking permit to operate a 1.5 square mile (388.5 hectares) farm located 8 miles (12.8 kilometers) from shore, using the **SeaStation** 40-60 feet (12 to 18 meters) beneath the surface.	No information	Off the south shore of eastern Long Island	Striped Bass and Steelhead Trout	0
Earth Ocean Farms	Uses submersible **Aquapods** at an offshore site in the Sea of Cortez, Baja, Mexico.	Cuna del Mar	Baja, Mexico	Totoaba and Red Snapper	200
Open Blue	Started in 2009, now the largest deep-water open ocean farm in the world; Uses submersible **SeaStations** from Ocean Spar	Cuna del Mar	Panama	Cobia	2,000-3,000

	7 miles (11 miles) off the north coast of Panama, in 60-70-meter (197-230 foot) depths.				
Marine Harvest	World's largest producer of Atlantic salmon; in 2016, Norwegian authorities granted six farming licenses for the development of **the Egg** concept.	Marine Harvest	Norway	Salmon	0 to date; soon to exceed 100,000
SalMar	One of world's largest salmon producers; owns well in excess of 100 salmon licenses across Norway and U.K. In 2016, the Norwegian Directorate of Fisheries awarded the first **eight development licenses** of offshore aquaculture **to Ocean Farming AS** (a subsidiary of SalMar).	SalMar	Norway	Salmon	0 to date; soon to exceed 100,000
De Maas	As part of China's national mariculture demonstration zone construction plan (2017-2025), De Maas is constructing offshore submergible pens based on SalMar design.	Fujian province government	Fujian Province, China	Yellow Croaker	0 to date; soon to exceed 100,000
Pacifico	PACIFICO AQUACULTURE operates in 179 hectares (442 acres) near the shores of Isla de Todos Santos, an island, eight miles west of Ensenada, off the coast of Baja California. The farm was recently bought by Butterfly, a seafood industry investor that aims at vertical integration "from seed to fork."	Butterfly;	Ensenada, Mexico	Striped Bass	500 tons in 2013[19], since then doubled-tripled production[20]
Orza	The Chilean engineering company Orza is partnering with Chilean's Production Development Corporation CORFO to develop the "engineering and materiality"	CORFO (Chile)	Los Lagos, Chile	Salmon	0 to date, no estimate for future capacity yet

[19] El Vigia (Aug, 2013). Producen en Todos Santos 450 toneladas de corvina.
[20] Panorama aquicola (Oct, 2017). Pacifico Aquaculture Lobina rayada pura, criada en mar abierto (p. 28-33).

	that makes it possible to build a "60 by 60 meter (197 by 197 foot) metal fish farming cage, intended to operate in locations suitable for greater energy aquaculture."[21]				
Kühlbarra	Firm was funded in 2006 as "Asia Barramundi" by Joep Kleine Staarman who was previously in charge of the SEA market development for Marine Harvest.	Commonwealth Capital Group	Singapore, Brunei	Barramundi	500 today, planned 6,000 in 2020
Perikanan Indonesia (state-owned Indonesian company	Equipped with Norwegian technology, offshore cages will be located 1 to 3 kilometers (0.6 to 1.9 miles) from the shore using round fish pens with a diameter of 10 to 30 meters (33 to 98 feet) and a depth of 4 to 6 meters (13 to 20 feet) with full extruded slow-sinking pellet feed.	Collaboration between Norway and Indonesia's Ministry of Marine Affairs and Fisheries	Aceh (Sumatra), West Java, Sulawesi, and Papua provinces in Indonesia	Snapper, Grouper, other coral reef fish	0 to date, initial production target of around 15,000 tons per year
The Kilic group.	Turkey's largest offshore producer (approx. 25 percent of total offshore volume) uses automated net pens 1-3 miles (1.6 to 4.8 kilometers) from shore.	Various private financiers	Aegean Sea, Turkey	Trout, Sea Bass, Seabream	Approximately 40,000 tons offshore
Nippon Steel & Sumikin Engineering Co. Ltd.	Launched a demonstration experiment on offshore farming in a pen some 3 kilometers (2 miles) off Sakaiminato, Tottori Prefecture, in December 2016. With feed provided through a pipe from a silo on the sea by remote control, feed needs replenishing only about once a week, and there is almost no need to sail in rough weather.	No information	Japan	Coho Salmon	No estimates yet

[21] FIS (June, 2017). Corfo to finance large-scale salmon cage designing project.

4.1 Norway

Norway is the leader in salmon aquaculture and is supporting offshore operations through development licenses. With 1.2 million tons of annual production, Norway is by far the largest producer of farmed salmon globally. The technology, skill set and capital that the industry has accumulated over the past decades makes Norway the most competitive and efficient producer in the world. Norway has seen a strong and steady growth of Atlantic salmon since the 1990s (compound annual growth rate = 7 percent, 1998-2018) and continues to operate on profit margins of 20-40 percent (higher in the north where water temperatures disfavor lice growth).[22] However, diminishing growth is expected in the near future as the biological boundaries of salmon farming are being pushed.[23] Norwegian authorities have acknowledged the growth limitations facing the Norwegian aquaculture industry – namely sea lice, fish escapes, and shortage of coastal acreage – and introduced free development concessions to "pave the way for ocean farming possibilities" that are not constrained by the same limitations.[24] Between 1994 and 2017, the number of ordinary grow-out licenses for salmon increased from 811 to only 1,015 licenses; licenses are tied to a maximum allowable biomass, which controls overall production and sales volume in the sector. Development licenses, as granted for offshore production, are different. The development license system aims at facilitating development of technology for solving either environmental or territorial challenges in the aquaculture industry. The system is a temporary arrangement (15 years) that offers licenses to certain projects based on innovation and resource requirements, and it requires sharing of developed technology in order to generate industry-wide improvements. If the project fulfills a set of fixed criteria, the licenses can be converted into commercial licenses at a cost of NOK 10 million ($1.2M). This is significantly below the NOK 50-60 million ($6-7.4M) price tag during the previous round of commercial license concessions.

"Aquaculture in Norway is #2 after oil [in terms of export value]; three guys grow 1,000 tons of salmon with a remote control and you can select from a list of contract feed suppliers online who will show up the next day with quality stuff. Economies of scale are reached but they still have to ship it over the ocean. That gives us [the U.S.] an edge, potentially."

Anonymous interviewee

The prospect of free salmon licenses led to dozens of proposed offshore concepts. The promise of being awarded commercial licenses after 15 years has spurred applications from the leading salmon producers, which have struggled to increase their production in the face of the Norwegian government's output license cap: Within a little over a year, more than 50 companies have submitted applications for offshore farming development licenses to the Norwegian Fisheries Directorate. Concepts range from submerged egg-shaped chambers, to floating mega-tankers, to donut-shaped platforms that are fixed to oil rigs. So far, only a handful of licenses have been granted. Among the

[22] Earnst and Young (2017). The Norwegian aquaculture analysis 2017.
[23] Marine Harvest (2018). Salmon Farming Industry Handbook 2018.
[24] Norway exports (2016). New Development Licenses Spur Ocean Farming.

grantees are the largest salmon producers in the world, Marine Harvest and SalMar.

SalMar In February 2016, the Norwegian Directorate of Fisheries awarded the first eight development licenses to Ocean Farming AS, a part of the SalMar Group. In this project, SalMar is collaborating with other aquaculture and offshore industry players. The development licenses have been granted for a period of seven years but may be converted into ordinary production licenses before that time if the objectives and the criteria stipulated by the Directorate of Fisheries have been met. Under the designation **Ocean Farm 1**, the pilot facility arrived at its destination in Frohavet, off the coast of Trøndelag, on 5 September 2017. The project has now entered a pilot operational phase, and initial results were promising enough to go a large step further: On the last day of the development license scheme, the company applied for 16 development licenses to develop its "Smart Fishfarm." At an estimated €157 million cost, the 160-meter (525 foot) diameter facility will host closed-containment grow-out space for up to 3 million fish. At 70m (230 feet) tall, the unit is designed to withstand waves of 15m (49 feet), utilizing semi-submersible cage technology. The 16 licenses applied for would allow for an annual 12,480 metric tons of production.[25]

"The Norwegian model would be a scary idea for a stand-alone company. These guys are publicly traded and well-hedged against the risks of offshore. We are talking 20 miles offshore here; these are some pretty nasty weather situations."

Anonymous interviewee

[25] Undercurrent News (June 2018). SalMar's biggest offshore rig yet in line for development licenses.

Figure 4: Ocean Farm 1 (picture) is already in operation. The Proposed concept of the largest yet to be built offshore aquaculture facility by SalMar ("Smart FishFarm") will dwarf Ocean Farm 1. Photo credit: Getty Images

Marine Harvest has applied for four different concepts and has already been awarded with six farming licenses for the development of *the Egg* concept. Construction of a prototype "egg" will start in 2018, in cooperation with *Hauge Aqua (see figure below)*. Other concepts that were filed by Marine Harvest include "Aquastorm" (large clusters of fully submerged nets), the "*Beck cage*" (a submersible tubular pen that withstands high wave energy), the "Marine Doughnut" (round platform fixed to sediment like an oil rig), and "*the Ship*" (a floating cage platform).

Despite heavy investments, it remains unclear whether new concepts will emerge as profitable business models. There is little doubt that the next decade will see investments in the hundreds of millions of dollars toward offshore aquaculture in Norway. Joint ventures with oil companies are already in place, construction has started, and a few offshore farms are already stocked with salmon. Based on three interviewees with knowledge about the Norwegian model, one SalMar Ocean 1 platform costs $70M with mooring systems up to $30M. Annual capital expenses and depreciation are approximately $2M (excluding high operating costs). The business model works only if capital losses are minimal and if stocking densities allow for an annual production of 6,000-8,000 tons of salmon per year. Given uncertainties associated with the offshore sector, a stand-alone investment "would therefore be madness." The expected surge in investments should therefore not be mistaken for investors' unwavering trust in immediate returns. Development licenses de-risk these investments as they effectively promise long-term production quotas even if offshore concepts fail. From the outside, it seems that these companies' long-term strategies are still focused on nearshore production: In the strategy outlook of Marine Harvest's 2017 annual report, they unmistakably recognize nearshore net pens as the core business of the sector: "Even with our significant efforts in developing feasible platforms for large-scale closed or semi-closed containment salmon farming, we realize that salmon will mainly be farmed using coastal net pen systems for the foreseeable future."

"Even with our significant efforts in developing feasible platforms for large-scale closed or semi-closed containment salmon farming, we realize that salmon will mainly be farmed using coastal net pen systems for the foreseeable future."

Marine Harvest 2017 strategy outlook

4.2 China

China's growing middle class has massive demand for finfish. The government has long promoted aquaculture growth, including offshore finfish aquaculture. More than half of all farmed finfish (30 million tons annually) are grown in China, with production increasing by 5.5 percent annually since 2010.[26] At the same time, China has gradually increased finfish imports from other countries from $500M in 2002 to $3Bn in 2016 and has become a net importer for several key seafood

[26] FAO Fisheries and Aquaculture Department, online query.

commodities.[27] China's growing middle class is only further increasing the domestic demand for seafood. Consequently, China's growth strategy has a heavy focus on increased production from the aquaculture sector, including offshore mariculture. In late 2016, China's ministry of agriculture announced a "national mariculture demonstration zone construction plan (2017-2025)," which targets 178 pilot mariculture farms to be built in China by 2025.[28] In its attempt to increasing its aquaculture production by 15.4 million metric tons by 2025, the country is exploring large-scale finfish aquaculture production.

De Maas SMC, a firm operating in the offshore oil and gas services industry, is partner in a CNY 1 billion ($151m) local Chinese government-backed project to build a deep-water aquaculture farm off the coast of China. Under the terms of the deal, De Maas will design and build five **SSFF150 pens** (Semi-submersible Spar Fish Farm), each 139 meters in diameter and 12 meters high (456 x 39 feet). The central tower (the "spar") will house machinery spaces, feed storage, and provide accommodation for operators. Submersion under water allows the pens to withstand typhoon-force winds. The move to industrialized aquaculture follows a trend in China that can be observed in the pork, poultry, and dairy sectors.

"The Chinese government is really driving this development."

Philip Schreven, De Maas, China.

Profitability is not the foremost concern for government-backed developments in China. The investment into industrialized offshore aquaculture in China might be an opportunistic rather than profit-driven decision. An *Undercurrent* article covering the story[29] mentions food security, environmental concerns, a slowing oil and gas industry, and surplus capacity in the building sector as reasons for the investment. Although the partnering developer in China, Mawei Shipbuilding, suggests that the project promises high returns on investment,[30] no data is made available to substantiate these claims.

New plans in the making. In addition to the SSFF150 pens, China is likely to invest large sums into offshore aquaculture. *Undercurrent News* reports that "a consortium of mainly state-owned Chinese firms have signed a framework agreement to build three 'super fish farms' as part of a CNY 6 billion ($955 million) offshore development in the South China Sea." Little information is available about the investment so far, but China seems to be serious about offshore investments.

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[27] The observatory of economic complexity (2018) Chinese imports of animal products.

[28] Undercurrent news (Dec. 2017). $150m deep-water aquaculture farm backed by Chinese gov't.

[29] Ibid.

[30] CNSS.COM (Jan 2018): Mawei Shipbuilding SSFF150 Single Column Semi-submersible Deepwater Fisheries Project Started.

4.3 Panama

Panama is still the largest offshore producer in the world. While Norway is rearing its first cohort of offshore salmon and China is following in its footsteps with yellow croaker, Panama still holds the record in offshore production with a single cluster of submersible SeaStations, managed by Open Blue, rearing 2,000-3,000 tons of cobia per year (unless Turkey – below – is considered truly "offshore"). The business model has neither been proven nor disproven yet. Production sites are located off the north coast of Panama, eight miles (12.9 kilometers) into the ocean; land-based infrastructure and supply chains are challenging. While one interviewee suggested that the market niche of Open Blue might be risky (new market for a new product with a production method that is still unproven), others pointed at Open Blue's growth aspirations. This would at least point at the confidence of operators and financiers that the current model (if replicated or at scale) is an investable proposition. However, we were not able to connect to either Open Blue or to investors.

4.4 Mexico

Mexico has welcomed the piloting and development of offshore aquaculture facilities with open arms through their licensing processes and a recent commitment to significant development subsidies. This has created a welcoming environment for developers such as Pacifico Aquaculture in Ensenada (sea bass in net pens), Earth Ocean Farms (totoaba in *Aquapods*), Kampachi farms (kampachi in net pens), and Rancheros del Mar (yellowfin tuna in net pens) to test and expand their production. Baja California and Baja California Sur are well-suited for offshore aquaculture given the warm water and the proximity to the U.S. market. Interviewees familiar with the operations suggested that it is unlikely that they are already making profits but that they are getting to a point where they can hope to break even. All of these pilots have either received patient capital from Cuna del Mar or research contributions from NOAA's Sea Grant program. The slow growth of the open ocean aquaculture operations in what are arguably the ideal conditions for cultivating some of the most valuable fish species in the world (constant warm temperatures and calm waters of the Sea of Cortez) points at a yet unproven business model.

"Mexico welcomes offshore operators with open arms."

Anonymous interviewee

4.5 Turkey

Offshore aquaculture is booming in Turkey. Aquaculture is the fastest-growing sector in Turkey, which is now the largest fish-producing country in the Mediterranean Basin and the second-largest fish producer in Europe after Norway.[31] In 2017, Turkey featured 425 marine farms, a large majority of which were located offshore. Of these, most farms are dedicated to sea bass and sea bream (total offshore

[31] Hayri Deniz (2017). Blue growth offshore mariculture and recent advances in Turkish Aquaculture & Kilic seafood company. The 8th Offshore Mariculture Conference, May 15 - 17, 2018, Singapore.

production in 2016 = 150,000 tons). More than half of marine offshore farms in Turkey are located in Muglia in the Aegean Sea.[32] Turkey's offshore sectors can certainly be considered a success story in terms of growth, profitability, and market share; every year, over 50 new facilities are installed and the often vertically integrated producers are celebrating record exports to more than 60 countries globally.[33,34]

The Kilic group is a case study with important lessons learned. With dozens of fish-growing units, the Kılıç Group is Turkey's most successful producer and exporter of offshore aquaculture (export mainly to U.S. and Russia). The group produces 40,000 tons of fish annually, all of which are equipped with automatic feeding systems and underwater and surface cameras.[35] The Kilic group provides a good example of what it takes to be economically successful in marine finfish aquaculture: A vertically integrated business model (feed, larvae, hatcheries, farms, processing, value-adding, and sales), a high-priced fish (trout, sea bream, and sea bass), 30 years of trial and error, courageous investments, and cheap production sites (Turkey, Albania, Dominican Republic, and potentially soon Morocco and Tunisia).[36]

"Every third bream and bass consumed in Europe comes from Turkey under a Turkish brand. This is a big source of pride for us."

Sinan Kızıltan, deputy CEO of Kilic Deniz[33]

The Turkish "offshore" does not compare to U.S. federal waters. The Turkish definition of "offshore" differs greatly from the high-energy systems that might be encountered 3 miles (4.8 kilometers) off the U.S. east coast or west coast. The Aegean Sea is a relatively calm water body with minor winter storms and moderate wave heights. An "offshore aquaculture" operation in Turkey is defined as one in waters of >40 meters (131 feet), which can be found within the first nautical mile from shore. Sites only have to be at least 0.6 miles (1 kilometer) from shore and with currents exceeding 0.1 meters/second.[37,38] These oceanographic conditions are more amenable to aquaculture operations than conditions found in U.S. federal waters.

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[32] Republic of Turkey (2017). Turkish Fisheries. Ministry of food agriculture and livestock

[33] The Fish Site (Feb, 2018). Record year for Turkish aquaculture exporter.

[34] Kilic (accessed June 2018). Sustainable Production Chain.

[35] Kilic Holding (accessed June 2018). Fish Farming.

[36] Hayri Deniz (2017). Blue growth offshore mariculture and recent advances in Turkish Aquaculture & Kilic seafood company. The 8th Offshore Mariculture Conference, May 15 - 17, 2018, Singapore.

[37] Hayri Deniz (see above)

[38] Yucel-Gier et al. (2009). Regulating and monitoring marine finfish aquaculture in Turkey. Journal of Applied Ichthyology 25(6).

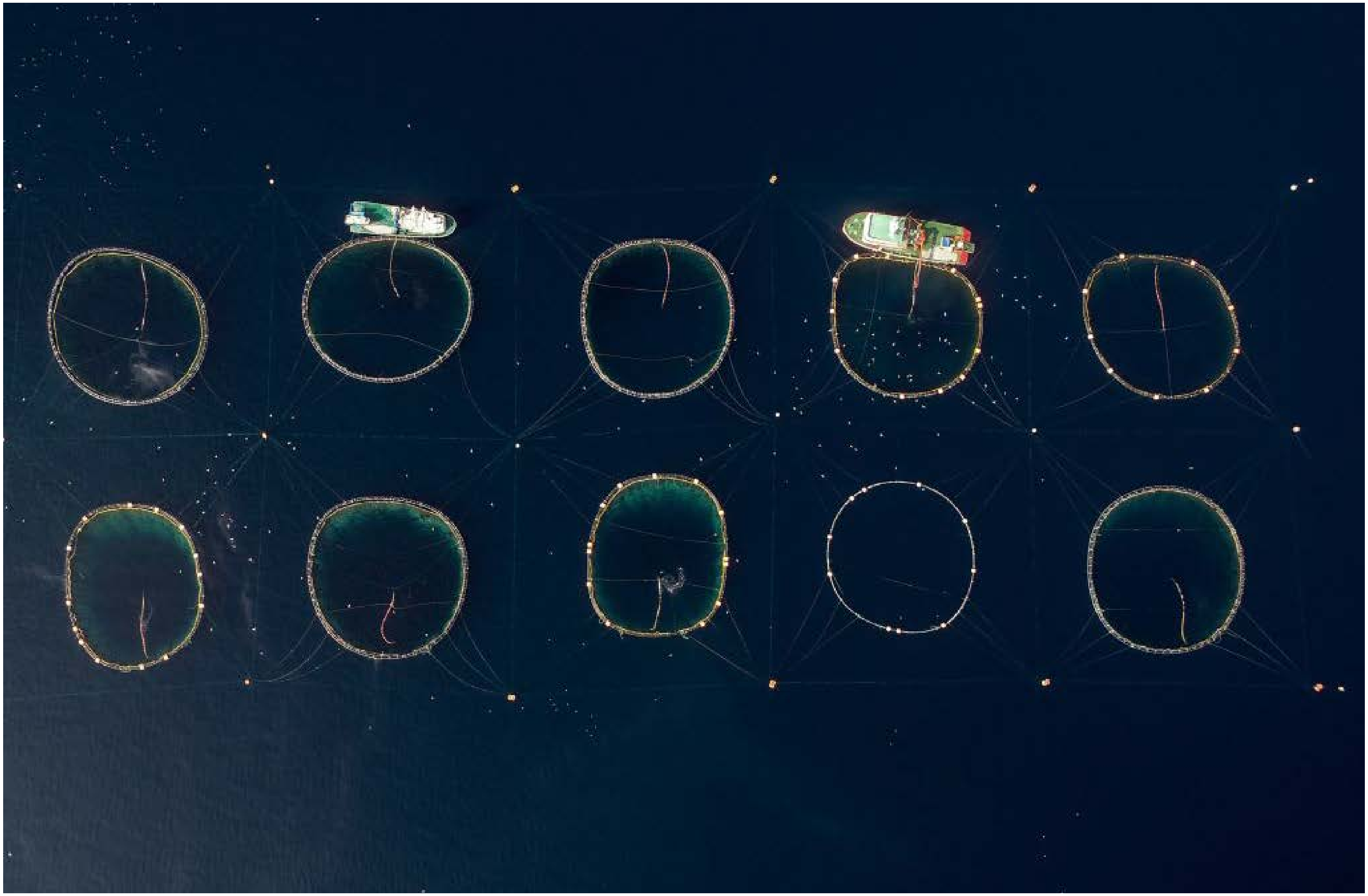

Figure 5: Offshore aquaculture units in the Aegean Sea. Photo credit: Getty Images

4.6 Japan

In 2016, Nippon Steel & Sumikin Engineering Co. Ltd., which designs and installs offshore platforms for oil and gas development projects, announced a plan to build the world's first large-scale offshore aquaculture system 3 km (1.9 miles) off the coast. The prototype features a platform with an 18-meter (59 foot) steel tower that contains enough feed for one week. Feed is transported through an undersea piping system at the bottom of the ocean that sends out food through air pressure. The pipes are linked to automatic feeders that serve five circular fish pens, each 25 meters (82 feet) in diameter. Feeding frequency can be automated based on the biting frequency (proxy for appetite) of fish in the pens.[39,40] The construction has not yet been finalized and it is unclear whether it was successful or what its target tonnage is. Based on its size and technical pedigree, it might aim to produce >10,000 tons of salmon per year.

4.7 Southeast Asia

Southeast Asia has recently become a projection screen for offshore hopefuls but it might take a long time to scale operations. The region is not a newcomer to the logistical complexities that are required for feed, brood stock, cooling chains, and processing. Land-based and coastal aquaculture production in Southeast Asia has skyrocketed in the past two decades, including for internationally traded products like shrimp, tilapia, and pangasius. In addition, the region features an enormous (and growing) domestic seafood market. Per capita consumption of fish in Southeast Asia is a multiple of that in the EU or the U.S. As land-based aquaculture becomes seriously constrained by available space, Southeast Asia has jumped on the train of offshore hopefuls. Across Southeast Asia, only a handful of marine finfish farms exist at the moment, producing an estimated total of 1,000 tons per year.[41] While there are few operations to look at, a number of interesting developments are described below.

"You do need governments, maybe even in collaboration with the private sector, to establish demonstration projects so that [investors] can see that it really works in their own area."

Alessandro Lovatelli, FAO regional Sinan Kızıltan,

4.7.1 Singapore

With 500 tons of barramundi, Kühlbarra is the largest offshore operation in Southeast Asia. With 7.5 hectares (18.5 acres) of licensed pen area and an annual output of 500 tons of barramundi, Kühlbarra (previously *Barramundi Asia*) is the most productive offshore operation in Southeast Asia.[42] Kühlbarra's operations currently look makeshift when compared to European equivalents. However, Kühlbarra envisions

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[39] The Fish Site (Dec, 2016). Japan builds first offshore aqua-farming system.
[40] Nikkei Asian Review (Nov, 2016). Automated offshore farming is aquaculture's new frontier.
[41] Southeast Asia Globe (May, 2018). Why Southeast Asia is perfectly placed to embrace large-scale fish farming. Quote from aquaculture expert Niels Svennevig.
[42] Enterprise Singapore (date unknown). Barramundi Asia: Super fish from Singapore swim out to the world.

a 12-fold increase in production within the next few years. It is questionable whether this is a realistic outlook as Southeast Asia lags behind all other offshore producers at the moment. Kühlbarra's President Joep Staarman is cited in a local newspaper describing the business environment even 10 years ago in Singapore: "At that time there was no infrastructure for aquaculture in Singapore and the region. From changing nets, to cleaning cages to managing hatcheries – we couldn't get quality that was just right."[43]

4.7.2 Indonesia

The Ministry of Marine Affairs and Fisheries (MMAF) is piloting offshore finfish production at three sites. Indonesia's offshore aquaculture sector is at a very early stage. As part of MMAFs recent efforts to boost marine productivity, the Ministry's Secretary of Aquaculture was charged with overseeing three pilots in Sabang, Aceh province, the southern waters of Java Island, and the Karimun Java Island in Central Java province (each about 4 miles [6.4 kilometers] from shore). The facilities are jointly operated by the state-owned fishery firm Perikanan Indonesia and local fisherfolk associations. Eight mechanized net pens were purchased from Norway for the pilots (25 m [82 ft] in diameter), including the necessary technology transfer for key aspects of the operation (seeding, feeding, harvesting, and processing).[44] The target production is an ambitious 3,000 tons of barramundi.

5 United States

To date, there is no offshore finfish aquaculture in the U.S., with the exception of Blue Ocean Mariculture, which is located in Hawaii state waters and relatively close to shore but considered "offshore" by NOAA. Blue Ocean produces kanpachi (Hawaiian yellowtail) in InnovaSea SeaStations. Established in 2009, Blue Ocean Mariculture is a small, growing company that hopes growth will bring costs down over time, once economies of scale are reached. Two prospective offshore farms are i) the Rose Canyon project off the coast of San Diego (a partnership between the Hubbs-SeaWorld Research Institute and Cuna del Mar) and ii) Manna Fish Farms off the south shore of Long Island, NY. Both businesses have put considerable time and effort into the design, development, and communication of their operations but have not yet started production as they lack necessary permits. It is therefore impossible to judge the viability of their operations directly. Kona Blue Water Farms (founded in Hawaii in 2001), was dissolved in 2011 and moved to Mexico under its new name Kampachi Farms.

"10 years ago, the National Fisheries Institute told us: 'We're not fighting offshore but why should we support it? We are importing from 50 countries and it is working.' Now things are changing; the Chinese are keeping their fish and are even increasing their imports"

Anonymous interviewee

[43] Ibid.

[44] MMAF (Apr, 2018). Mengenal Sistem Budidaya KJA Offshore Pertama di Indonesia.

Small-scale projects will be challenged to be profitable, given increased costs of operating offshore. The small farm ideal that has been piloted for over a decade in U.S. state waters and nearshore waters in Latin America now seems challenging in the context of a U.S. business environment and U.S. offshore conditions; federal waters are exposed to severe winds and wave action for large parts of the year, making it unpractical (diving in cages, supplying feed every few days) and costly (capital-intensive and risky) for small facilities to be economically viable. The high capital costs, intense oceanographic conditions, and an unclear path to economies of scale make it at least questionable if this model can be profitable without significant subsidies in the U.S. Just as small farms struggle economically, small aquaculture does not look like a winning proposition, economically speaking (at least not as a widely replicable model); this is not to say that they do not have social, cultural, and environmental merits. Massive industrialization and automation could provide a more profitable alternative, but that model has yet to bear out anywhere internationally to this point as previously discussed.

"There is no doubt in the world that it costs more to produce a fish in a high-tech offshore cage than it is to raise a fish in a simple net pen close to the coast."

Anonymous interviewee

Proponents claim that burdensome regulations are at the core of a slow sector development. While that might have contributed to slow uptake of operations in the U.S., the larger hurdle will be to reach economies of scale. Practitioners and industry representatives have repeatedly pointed at the complicated permitting processes for offshore aquaculture (as compared to Latin America and Southeast Asia) as the source of a poor track record for mariculture in the U.S. While the financial and administrative burdens with current regulatory systems may be significant, we believe that high capital costs and financial risks are more likely root causes of mariculture's growth problems in the U.S. Small farms operate at extremely thin margins. A single storm or even one Galapagos shark ripping through the nets (as was the case in the Hawaiian Kona Blue Water Farms) can set profitability back significantly.

5.1 Profitability of traditional U.S.-based aquaculture

It is generally agreed that nearshore aquaculture is structurally more profitable than offshore aquaculture. If you can viably farm something offshore, moving that same operation closer to shore only reduces transportation and infrastructure costs and the risk of storm damage, increasing profitability. Although much depends on the species that are farmed, a quick exploration of U.S.-based aquaculture performance is a useful reality check and proxy for the potential profitability of offshore production.

The U.S. contributes to 1 percent of global aquaculture production because it lacks the competitive advantage. With $1.3B in annual farmgate sales, U.S. aquaculture is a drop in the bucket in terms of global production values. The U.S. is not a competitive player internationally and we lack the expertise and industry backing to be a significant innovator. Moreover, U.S. production has been flat to declining over the last 15 years, despite massive growth in aquaculture globally. This includes not just mariculture, but long-permitted freshwater sectors such as catfish, crayfish, and trout. Catfish makes up half of both volume and value for freshwater species (140 tons and $350 M in revenues), and salmon is the only finfish to speak of in the marine environment, with 22,000 tons of production and farmgate sales of $90M.[45] It is conceivable that restricted nearshore licenses and environmental regulations have kept a lid on domestic production. However, even permitted salmon operations in the U.S. have struggled to remain economically competitive in the face of cheap imports from Chile and Norway. For most other species, however, input costs are the limitation. Land, labor, and capital are simply far higher in the U.S. than they are in Latin America and Southeast Asia.

Catfish aquaculture struggles with import competition and high feed prices. Land-based catfish in ponds is the U.S.' signature farmed species. Mississippi, Alabama, Arkansas, and Texas used to be profitable production sites of catfish aquaculture, but they lost ground to increasing imports from substitutable white fish such as pangasius and tilapia. Competition with foreign producers has led to a 50 percent decrease in production from 225,000 tons in 2009 to 107,000 tons in 2017. In and of itself, catfish production can still be profitable when demand is high and input costs are low, but overall, the industry has decreased its pond size at a rate of almost 10 percent every year in the past decade. While sales data suggest that the same period was accompanied by increasing profits per remaining acre of pond, sales/acre are now constant.[46] Feed inputs into catfish aquaculture make up well above half of input costs, and prices of the key ingredients (fishmeal and fish oil) have quadrupled in the past 20 years and will continue to increase. It is unlikely that catfish aquaculture will see a comeback in the U.S. anytime soon.[47]

"A lot of it was from China, originally. And then the Vietnamese brought in the pangasius (fish) product. And they're the largest – they're bringing in now twice what we're raising here."

Solon Scott III, president of catfish-farming and processing company America's Catch in Itta Bena, Mississippi[47]

Figure 13 shows that i) the rate of loss of cultivated pond area has decreased since 2010; that ii) the growth in overall sales has decreased in the same time period; all while iii) the average productivity per acre was relatively stagnant. The most likely explanation is that overall profit margins have decreased and less profitable farms have dropped out of the business, leaving only about 50 percent of farmers (and production volume) in the industry today. It is likely that this development was driven by imports and could be repeated for a domestic offshore aquaculture industry unless strict tariffs are put in place. Overall, the example of catfish production points at the vulnerability of a U.S.-based aquaculture sector with direct substitutes (same product and same

[45] NOAA (2017). Fisheries of the United States 2016.
[46] USDA (2018). Catfish Production. Economics, Statistics and Market Information System.
[47] U.S. News (April, 2018). The Catfishing of America.

quality in the eyes of the consumer) that are produced at a significantly lower price outside the U.S.

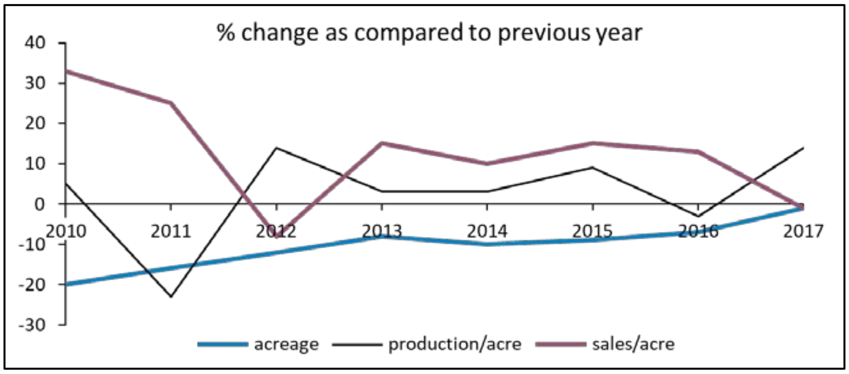

Figure 6: Change in catfish acreage, sales, and productivity over time

5.2 Suitability of U.S. federal waters for profitable offshore operations

The U.S. has the second largest Exclusive Economic Zone in the world but potentially few suitable ocean areas for offshore aquaculture. Finding the optimal species-site combination is what will ultimately drive the commercial viability and competitiveness of global offshore aquaculture. In 2010, the FAO identified six criteria and their threshold ranges to "estimate near-future offshore mariculture potential."[49] Among them are:

- Distance to port not to exceed 25 nautical miles
- Competing, conflicting, and complementary uses of ocean space is minimal
- Favorable offshore grow-out environment based on temperature requirements of representative fish is provided
- Reliable access between shore and offshore facilities

In addition to these, interviewees have pointed to the importance of shoreside infrastructure and market proximity. The latter is a major argument of proponents: It costs $0.5-2 per pound of salmon to be shipped from Norway to New York. This is the margin that U.S. operations could operate within.

The Gulf of Mexico is suggested as a high-potential area for offshore aquaculture development, but it might be a logistical nightmare. From a biological standpoint, the Gulf of Mexico features the highest productivity potential for finfish aquaculture due to constant and warm

"There is no clear candidate species of finfish available that has proved both economic and physiological feasibility for offshore production."

FAO (2010)[48]

[48] FAO (2010). Expanding mariculture farther offshore Technical, environmental, spatial and governance challenges. Fisheries and Aquaculture proceedings 24.
[49] FAO (2010). A global assessment of offshore mariculture potential from a spatial perspective.

water temperatures.[50] The Gulf is among the busiest ocean areas of the U.S.: 2,000 oil rigs share the waters with heavy marine traffic and the region is still recovering from the 2010 BP Deepwater Horizon oil spill. Large parts of the Gulf regularly experience hypoxic zones resulting from the agrochemicals draining into it from the Mississippi River, and the region is increasingly vulnerable to severe hurricanes.[51] NOAA has recently created the Gulf AquaMapper to support prospective permit seekers; a brief exploration of the tool provides a sense for the activity and infrastructure in the Gulf, particularly within the shelf area of < 50 meter (164 foot) depth. It is difficult to imagine that the conflicts for space in the area are attracting investors to it. While decommissioned oil rigs have been floated as promising, an excerpt of Virginia Gewin's "GreenBiz" article is eye-opening:

> "Matt McCarroll, president and CEO of Fieldwood Energy, LLC, in Houston, said his company is the largest owner of offshore platforms in the U.S. and actively has been decommissioning them in recent years. He said he's been contacted five or six times in the past 10 years by potential aquaculture investors interested in using the platforms. But the conversations end, he said, as soon as he explains that it will cost $2 million to $10 million, depending on size and water depth, to take over maintenance, liability and responsibility for decommissioning the platforms."[52]

[50] Gentry et al. (2017). Mapping the global potential for marine aquaculture. Nature Ecology and Evolution.
[51] GreenBiz (May, 2017). The tide is changing for offshore aquaculture. By V. Gewin
[52] Ibid.

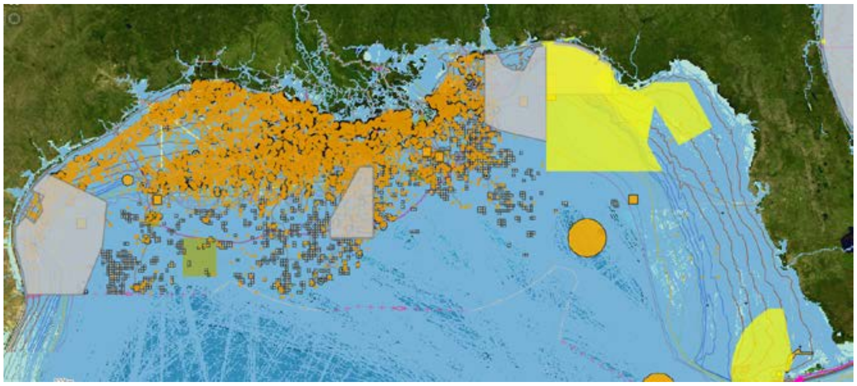

Figure 7: The Gulf of Mexico through the lens of the Gulf Aquamapper. Layers include oil infrastructure, military and danger zones, and navigation density

5.3 Competitive advantage of a U.S. offshore industry

A main advantage of the U.S. would be the proximity to its own markets. The U.S. is one of the largest seafood markets in the world, with a growing and affluent consumer basis that increasingly appreciates seafood. Per capita consumption of seafood went up from 12.5 pounds in the 1990s to almost 15 pounds per person per year in 2017. The transport of fish (particularly when fresh) is expensive and could put U.S. producers in a competitive position for high-valued fresh fish products such as salmon, tuna, seabass, yellowtail, cod, or even snapper or grouper. This advantage might increase if international supply drops (e.g., from China due to growing middle class) but current signs are not pointing at a significant drop in international seafood supply. The counter-argument is that this logic has not held true for domestically caught seafood. The U.S. exports roughly 80 percent of its catch and imports a comparable amount, in part because of the international nature of seafood processing. Transportation costs are generally low for frozen product (sashimi-grade salmon being an exception, because of the need for air shipment). For this logic to hold, the farmed product would need to be sold fresh (e.g., salmon, barramundi) and consumed at massive scale to support the economies of scale.

The U.S. has a technological edge but lacks an experienced practitioner and investor environment. Scaling up offshore aquaculture will require high levels of technological know-how and talent. Interviewees all agreed that the U.S. cannot easily catch up with the technology and expertise that Norway has developed in the past four decades in the sector. In addition, the combination of technical expertise and business mindset that is required for large-scale operations is painfully lacking, and technology transfers from European counterparts is time-consuming and inefficient. Despite a technological edge in a number of relevant industries, several interviewees suggested that the U.S. generally lacks the expertise that is required to design, plan, and oversee large-scale offshore aquaculture operations. That includes equipment

"The conversations [With aquaculture investors] end as soon as I explain that it will cost $2 million to $10 million, depending on size and water depth, to take over maintenance, liability and responsibility for decommissioning the platforms."

Matt McCarroll, president and CEO of Fieldwood Energy, LLC

"A fish that's head-on gutted selling for $8, and $2 of that is freight, that's significant."

Anonymous interviewee

suppliers, feed producers, and also capital providers who understand the space. Some large investors with long histories and ties to the seafood industry exist in the U.S., but offshore aquaculture remains an area of cautious exploration for them. One interviewee said that both institutions and investors in the U.S. still assign a lot of risk to offshore aquaculture, “whereas in Norway, it is like cattle in Omaha.”

Shoreside infrastructure has to be developed from scratch. Offshore aquaculture must be supported by an efficient upstream and downstream supply chain including, most importantly, hatcheries and nurseries. These are almost entirely lacking in the U.S. and would have to be built from scratch. The development of brood stock takes many years, particularly in the quantities that would be required to run large facilities at full capacity.

Tariffs could be a tool to artificially increase the competitive advantage of the sector: Liam Campling, a veteran expert on international fish markets, writes: “US tariffs on fish and fish products are generally zero or very low except for products of commercial significance to US interests, such as fish fillets for certain species (6 percent); canned sardines (15-20 percent); canned tuna (6-35 percent); clam products (8.5 percent); ‘fish sticks’ (7.5-10 percent); and processed crab, other crustaceans, mollusks, etc. (7.5-10 percent)”[…] For raw material (fresh, chilled, or frozen fish), the normal trade relations (NTR) tariff is generally zero, indicating a classic policy of tariff escalation, except for 3 percent on a handful of species such as Alaska pollock, hake, sea bass, and tilapia.[53,54] The 3-6 percent tariff for fresh fillets or sea bass marginally increases U.S.’ competitive advantage over other producer countries.

[53] Liam Campling (2015). Tariff Escalation and Preferences in International Fish Production and Trade.

[54] Flexport: Fish, Crustaceans & Aquatic Invertebrates (HS Chapter 03).

5.4 Land-based competition from within the U.S.

Even if offshore aquaculture was profitable in U.S. federal waters, it might soon be outcompeted by land-based aquaculture. Recirculating aquaculture systems (RAS) have recently improved in efficiency and productivity. This report does not focus on the commercial viability of land-based RAS but it is worth pointing out that major investments are being made. An example is *Whole Oceans*, which announced a plan to establish a land-based salmon farm in Maine with investments of over $250M. At full capacity, the farm would produce 50,000 tons of salmon annually; the construction was planned to start in August 2018. The company claims that it has already pre-sold 100 percent of production for the next 10 years.[55] In January, Nordic Aquafarms announced plans for a land-based salmon farm in Belfast, Maine, to be built in two phases. Phase 1, with a capacity of 13,000 tons and an estimated value of $150 million, is currently being designed in Norway. Construction is expected to start in 2019, with operations commencing in 2020-21.[56]

"The economic viability of U.S. offshore fish farms depends on both supply and demand conditions both for U.S. offshore fish farms and for all other competing sources of supply."

Gunnar Knapp (2008) "Economic Potential for U.S. Offshore Aquaculture: An Analytical Approach."

[55] Mainebiz (2018). Whole Oceans announces plan to establish a land-based salmon farm in Maine.

[56] Mainebiz (2018). Nordic Aquafarms hires first two employees in Maine for Belfast project.