GLOBAL ANALYSIS OF OFFSHORE MARICULTURE

UCLA INSTITUTE OF THE ENVIRONMENT AND SUSTAINABILITY
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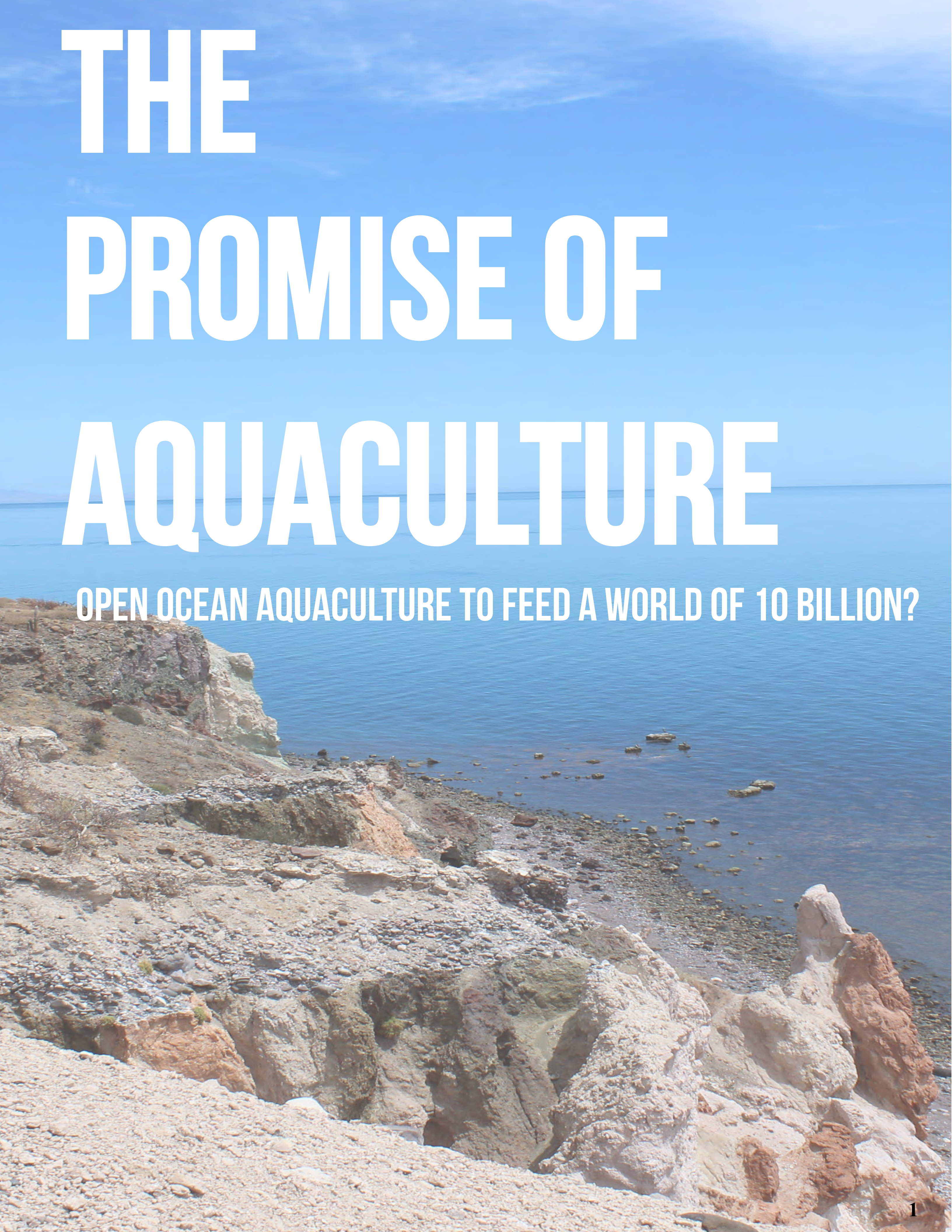
THE PROMISE OF AQUACULTURE

OPEN OCEAN AQUACULTURE TO FEED A WORLD OF 10 BILLION?



In the middle of the 20th Century, plant scientist Norman Borlaug began changing the way the world farmed its land. Hailed as "The Father of the Green Revolution," Borlaug's work on high-yielding plant species and industrial farming practices are credited with saving 1 billion lives from starvation, earning him the Nobel Peace Prize in 1970. Despite centuries of malthusians predicting mass famine and death, humanity has continued without catastrophe. Indeed, the global prevalence of undernourishment in 2015 reached 10.8%, the lowest rate in modern history. But threats remain. The global population is set to approach 10 billion by 2050, and the Green Revolution is showing long-term negative impacts on our land and health. Land-based farming is continually making advances in productivity, but our oceans must play a significant role in meeting the world's protein demands.

Half of our seafood production comes from wild fisheries, which may have reached their maximum capacity, and in some cases are severely overfished. Agriculture unlocked the potential of our land resources millennia ago, and the "Blue Revolution" of aquaculture is beginning to unlock the potential of our oceans. But as it stands, ocean aquaculture is massively underperforming. In some cases it is polluting, and in other cases vast areas of high productivity, the ocean equivalent of fertile soils, remain untouched. Seafood is currently a primary source of protein for 3 billion people, and will need to feed billions more in the coming decades. It's up to aquaculture to meet this demand. If done in the most productive places, open ocean aquaculture could, in theory, meet most of our protein needs in less than 1 or 2 % of the ocean's seascape. The key question is whether the theoretical possibilities for open ocean aquaculture could ever become a pragmatic and economically viable reality.

Currently, aquaculture production facilities are mostly coastal or inland. The problem with near shore mariculture is that it competes with recreation, and local pollution zones can form if the water is shallow and not well-mixed. These issues are solved by moving farms away from the coast and into the open ocean, where mixing and currents are stronger. Moreover, the open ocean is vast. Recent research suggests that as little as 0.015% of it is all that is needed to match today's entire global landings from wild fisheries. Of course, aquaculture brings with it a new set of challenges, such as storms, shipping lanes and untested technologies. Drawing on recent research that identifies hotspots of productivity in the open ocean, this report examines economic and ecological opportunities in six countries, as well as five key issues facing open-ocean aquaculture.

WHAT IS BIOLOGICALLY POSSIBLE

The majority of the world's aquaculture is concentrated in only a few countries – most notably, China, Indonesia, and India. Most of this production takes place either on land or in coastal habitat, where environmental impacts are often severe. Evidence shows that innovative offshore technologies can dramatically reduce the environmental impact of large-scale commercial fish farming. Our research builds off a previous study sponsored by the Science for Nature and People Partnership (SNAPP) that identified regions around the world with high biological potential for offshore farming of fish and bivalves.

IDENTIFYING BREAKTHROUGHS

Using an average growth performance index for 180 aquaculture species in combination with accumulated data on sea surface temperature, dissolved oxygen content, phytoplankton concentration, and bathymetry, a global map of potential productivity for offshore aquaculture was created. Through this map, countries with high productive potential were classified. Gentry et al. (2017) found that only a miniscule portion of the most productive seascape would be needed to farm all the seafood the world currently needs. Furthermore, if all productive ocean space were utilized, it would be possible to produce over 100 times the current global seafood demand.

DIVING DEEPER

The anaylses did not account for practical components that might be obstacles: geography, socioeconomics and political conditions all need to align to support aquaculture. Looking closer at six of the high-potential countries, we can begin to develop a roadmap to expanding open-ocean aquaculture, combining potential productivity with national realities. The countries examined were Palau, Philippines, Oman, United Arab Emirates, Morocco, and the United States. These countries were examined because in addition to high biological potential, they span a diverse range of social, economic and physical characteristics.

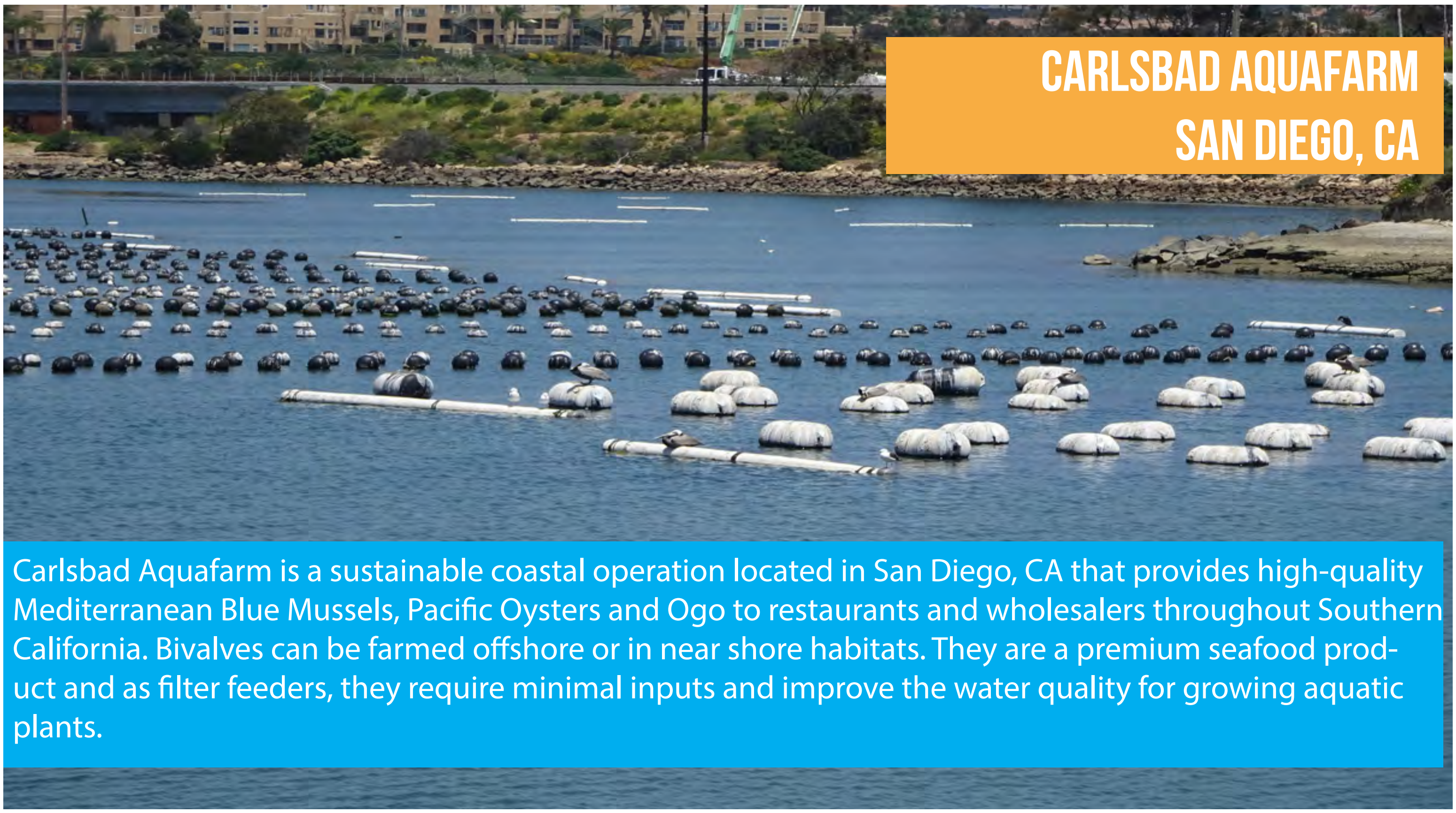
CROSS CUTTING THEMES

In addition to focal analyses of particular nations, it is also important to consider cross-cutting themes. These themes are:

1) potential interaction between climate change and marine farming
2) an assessment of factors contributing to success or failure on a national scale
3) a consideration of investments needed for individual projects
4) an overview of the various challenges associated with sustainable development
5) a look into the relationship between consumer perception and sustainable marketing.

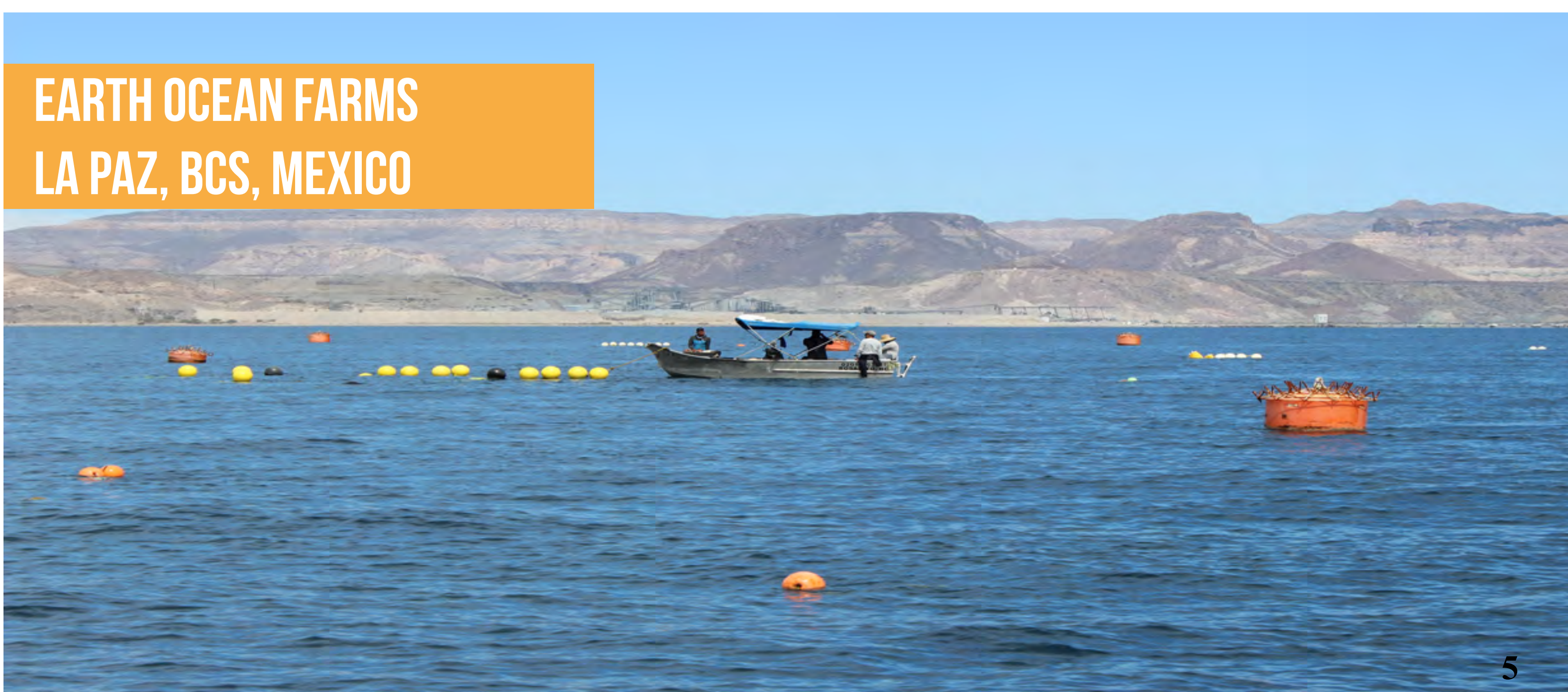
MARICULTURE IN ACTION

SPOTLIGHTS OF LOCAL FARMS



CARLSBAD AQUAFARM
SAN DIEGO, CA

Carlsbad Aquafarm is a sustainable coastal operation located in San Diego, CA that provides high-quality Mediterranean Blue Mussels, Pacific Oysters and Ogo to restaurants and wholesalers throughout Southern California. Bivalves can be farmed offshore or in near shore habitats. They are a premium seafood product and as filter feeders, they require minimal inputs and improve the water quality for growing aquatic plants.



EARTH OCEAN FARMS
LA PAZ, BCS, MEXICO

HUBBS-SEAWORLD RESEARCH INSTITUTE HATCHERY
SAN DIEGO, CA

Hubbs-Seaworld Research Institute (HSWRI) has developed efficient culturing and grow-out methods for California species of yellowtail jack, white sea bass, and striped bass. Since 1995, this hatchery has been fundamental to California's Ocean Resources Enhancement and Hatchery Program (OREHP) in restoring wild populations of white seabass, releasing over two million white seabass to date. The hatchery produces over 350,000 juveniles each year, but only a small fraction of those juveniles can be released into the wild while maintaining genetic diversity. Currently, there is no market for the remaining stock, so the unreleased population is wasted. In partnership with Cuna del Mar, HSWRI has been working to establish a farm 4 miles off the coast of San Diego. This farm could raise the excess juvenile stock as well as provide a means of growing yellowtail and striped bass.

Potential regional value of 72 direct jobs (300 overall)

Estimated $50 million in annual revenue

Could match 1/5 of California's wild catch each year

Earth Ocean Farms (EOF), off the coast of La Paz in the Sea of Cortez, is about to launch their 10th sea pod. Spread over 0.21km2 of ocean, each pod produces 30,000 totoaba fish, which are harvested at 2.5 kg, processed in town and distributed to buyers across Mexico year round. Within 4 hours of harvest, totoaba fillets are on the tables of restaurants in Guadalajara.

Totoaba was chosen due to its ease of production in the hatchery and cage system. Because totoaba is endangered, EOF obtained permission to farm it by pledging to help restore wild populations and releasing a portion of fish from their hatchery each year. Since totoaba has not been available for many years, there is the additional challenge of establishing a local market. To tap into international markets, EOF has recently begun culturing red snapper, which is in high demand all over the world.

"If we produce a million fish, we are supplementing the market with a million fish, we are then supplementing the demand and alleviating the pressure on wild fisheries. So imagine, if there were 100 companies like ours, each one producing a million fish, that would be 100 million fish supplying the market that would allow wild stocks to recover." - Pablo Konietzko, General Manager, EOF

OUR COUNTRIES

1. Palau
2. Philippines
3. Oman
4. United Arab Emirates
5. Morocco
6. United States of America


2
1
4
3

PALAU

HUGE PROMISE AND POSSIBILITY BUT NOT MUCH ACTION

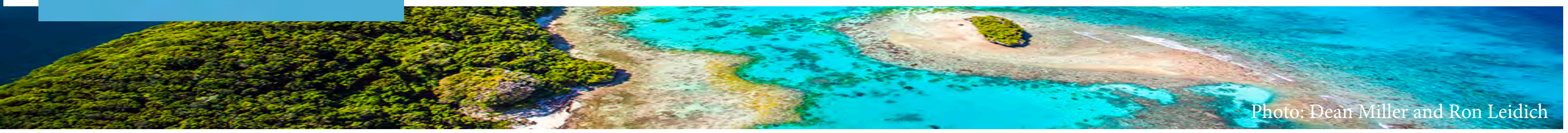


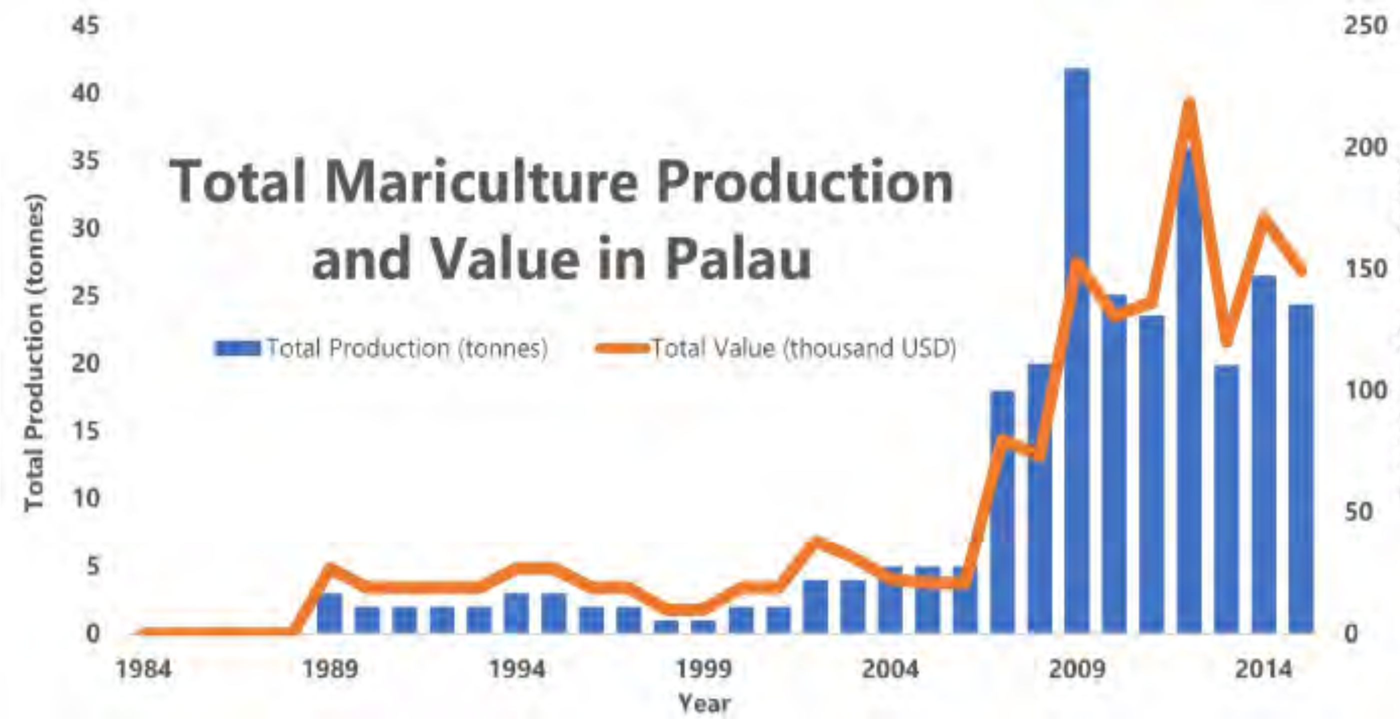
Photo: Dean Miller and Ron Leidich

Palau's Mariculture At a Glance	
Total Area for Fish (km^2)	2963
Average GPI for fish	3.5
Total Area for Bivalves(km^2)	0
Average GPI for bivalve	N/A
Current production	24.2 tonnes & 343,800 pcs
Government investment	Low
Plan for expanding production	Low
Importance for food security	High
Importance as provider of jobs	Limited potential
Large markets accessibility	Low
Technical capabilities	Low
Permitting and regulations	Low and limited
Km coast/km^2 land	1,519 km/459 km2 = 3.3
Per capita fish consumption	67.7 kg

The Republic of Palau is an archipelago of over 340 islands in the western Pacific Ocean. Consuming 67.7kg of seafood per capita, Palauans eat more seafood than almost any other people in the world (the U.S. eats 21kg). With its limited arable land and high demand, it is no surprise that Palau imports 86% of its food. What is surprising, however, is that as an island nation with over 600,000 square kilometers of resource-rich EEZ, the country nonetheless is imports more than one-third of its seafood. As an island nation, Palau is expected to be especially vulnerable to the adverse effects of climate change. Palau is projected to lose 25% of its fisheries catch potential by 2050 due to climate change. Simply from an economic and food security perspective, it would serve Palau well to develop an aquaculture industry. These aren't the only arguments for investing, however. White bread, processed foods, and canned meats such as spam are some of the top food items consumed by Palau's urban households. This diet is causing rising level of obesity and diet-related Non-Communicable Diseases (NCDs). Healthy seafood, therefore, addresses a public health issue.

"I think Palau could be the example of how to do aquaculture right blended with the coastal zone management which creates sanctuaries and management of the wild fisheries and have a unifying approach to those marine resources and optimizing the value of those marine resources."
- Jim McVey, President, Indigo Seafood

Current aquaculture production in Palau is confined to milkfish and giant clam, the only two significant commercial aquaculture commodities in the country. Other aquaculture species that have been developed but have yet to be made commercially viable are: grouper, rabbitfish, and mangrove crab. The FAO, the Center for Tropical and subtropical Aquaculture, the Secretariat of the Pacific Community, and the Micronesian Association for Sustainable Aquaculture have all provided technical assistance to Palau with respect to aquaculture. The primary government agency that manages the development of the aquaculture sector is the Bureau of Marine Resources. While aquaculture is considered essential for national development, Palau has yet to implement any policy or appropriate legislation exclusively dedicated to aquaculture management and regulation. Applications for aquaculture operations are evaluated on a case by case basis with no formal process or guidelines in place. The only current offshore aquaculture operation in Palau is a privately held company called Indigo Seafood. Indigo is currently operating two 27-foot diameter Aquapods™ from InnovaSea, in which it is growing rabbitfish. The company hopes to secure future funding to develop the expertise to farm groupers and combine fish cultures with other marine species to create a multi-trophic system. While Indigo Seafood is promising, aquaculture in Palau still faces substantial constraints. The biggest challenges are the absence of good quality seed, feed, technical marketing information, capital and skilled human resources. A solution might be the creation of a single supportive government agency and set of rules to develop and manage aquaculture.



The Republic of Palau is a world leader in marine conservation. In 2015, the island nation passed the Palau National Marine Sanctuary Act, establishing one of the world largest protected marine protected area in the world. The legislation banned all exploitation activities in 80% of Palau's Exclusive Economic Zone (EEZ). The remaining 20% was designated a Domestic Fishing Zone allowing only small-scale fishing activities for local markets and limited export.

Photo: Enric Sala

PHILIPPINES

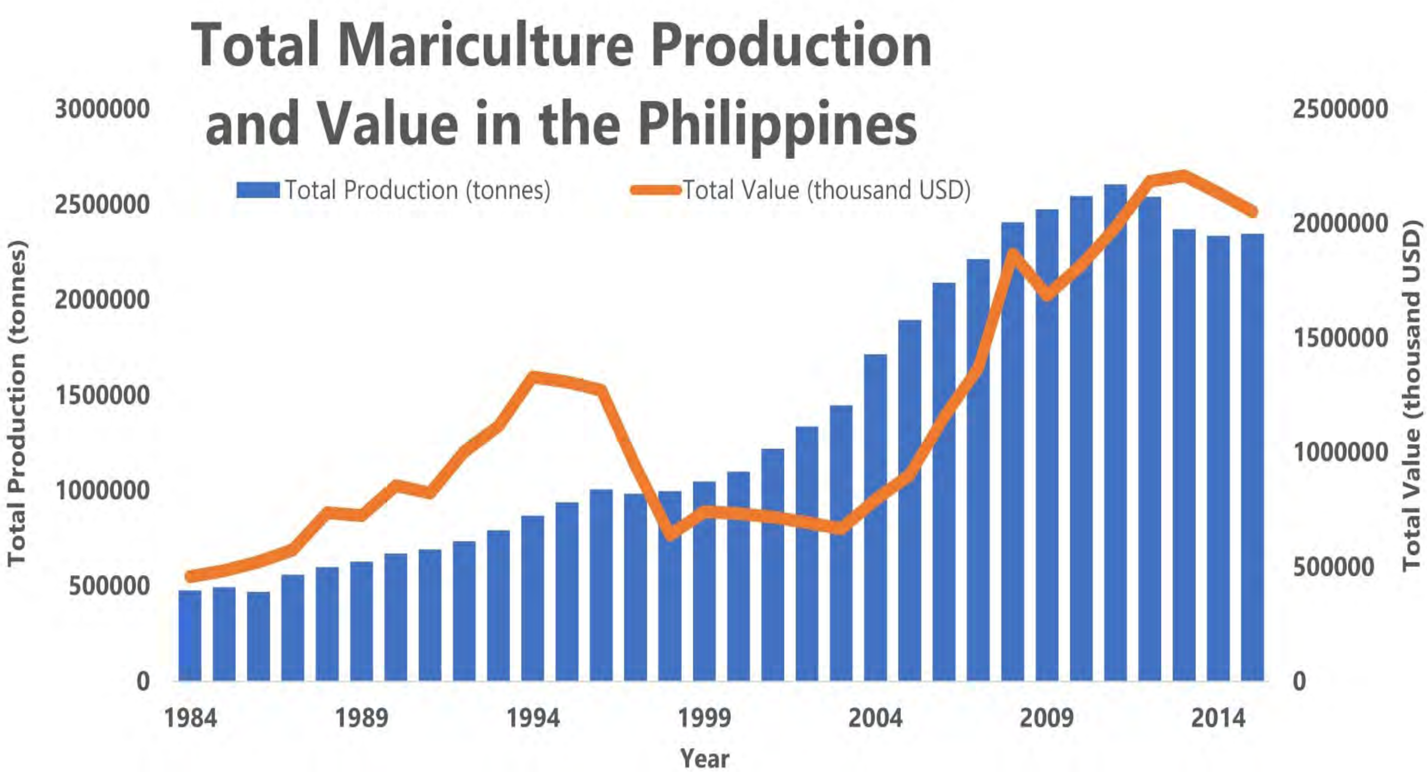
THE PHILIPPINES SEEKS TO MAKE A "HOME FOR AQUACULTURE" IN SPECIAL PARKS

The Philippines is a fishing nation and has been for generations. Today it is 8th in the world in terms of fish production, up from 11th in 2003. With 7000 islands and a coastline of 36,289 km, the Philippines' leadership in fisheries is not surprising. In-country demand is very high, with more than 70% of its catch consumed domestically in order to meet a per capita consumption rate of 40.15 kg/year.

Unlike most other fishing nations, the Philippines have been engaged in aquaculture since as far back as the 1500's. In the early days of the aquaculture process, milkfish were cultured at a low density in ponds. Milkfish has been and is still to this day a local staple in the Filipino diet, but the fish's bony qualities make it less favorable for export. Only recently (since 1970) has the Philippines' aquaculture industry begun to diversify its use of species and technology, growing seven times in size. Now farms exist inland, in brackish waters, and along the extensive coastline, where net pens and fish cages are now prominent. Additionally, typhoon-resistant rope cages are growing in use for areas of high storm susceptibility. Today, aquaculture contributes 39% of the total value of fish production in the nation, which represents around US$1.17 billion. The major export species are seaweeds, shrimp/prawns, crab, and grouper.

The aquaculture industry currently entails 226,195 operations and production has more than doubled in the past decade. Mariculture now contributes to 73% of Philippine's production. The primary species farmed in saltwater are seaweed, milkfish, green mussels, slipper cupped oysters, groupers and siganids, with seaweed contributing to over 70% of the total industry.

Aquaculture falls under the jurisdiction and management of two major government authorities. BFAR (The Bureau of Fisheries and Aquatic Resources) takes precedence over the development and management of fisheries resources, and operates in regional offices throughout the country. In addition, LGU's (Local Government Units) are responsible for supervising and licensing all aquaculture. Finally, in order to obtain necessary capital, the Philippines' national government has partnered with foreign aid organizations promoting mariculture as a means to alleviate poverty in coastal communities. These aid organizations provide loans to encourage local farmers and private investment.



The Philippines is also a leader in establishing marine protected areas (MPAs). The nation is home to more than 25% of the world's 4,800 MPAs; however, the MPAs are often small (less than 1 square kilometer), coastal and poorly managed. As part of its initiative to promote mariculture, the government has formed a system of Mariculture Parks which are designated areas of coastal water specifically dedicated to mariculture. These parks are intended to promote the mariculture industry, as well as prevent illegal fishing and piracy. They also aim to address the large issues of job generation, food security, and environmental resiliency, which are at risk because of the Philippines' exposure to typhoons. In fact, in 2017 the nation was ranked as #13 on the Global Climate Risk Index.

Although the Philippines has been promoting aquaculture for decades, success has been inconsistent at best. Sustainable offshore aquaculture equipment is expensive, particularly for low-income farmers. Much of the nation's EEZ is ineffectively managed. Fishermen lack training and capital. Lastly, the government and investors have been slow to appreciate the merits of offshore aquaculture.

Philippines's Mariculture At a Glance	
Total Area for Fish (km^2)	213,333
Average GPI for fish	3
Total Area for Bivalves(km^2)	2,733
Average GPI for bivalve	2.13
Current production	1895233 tonnes, 37% of total fish production
Government investment	High
Plan for expanding production	Industry used as a means to alleviate poverty
Importance for food security	High
Importance as provider of jobs	14% of fishing industry, 258,480 jobs since 1987
Large markets accessibility	Moderate
Technical capabilities	Moderate
Permitting and regulations	Low
Km coast/km^2 land	17,460 km/300,000 km2 = 0.0582
Per capita fish consumption	41.15 kg

MARICULTURE PARKS

The Philippines' Mariculture Parks are a successful example of collaboration between the government and private sector to coordinate action on a number of issues and set policy for conservation goals. Government guidelines do not allow fishermen to go over the carrying capacity for the health of that environment. There are now over 67 established Mariculture Parks along the coastal zone of the Philippines. Site selection for parks is based on research of the area's physical conditions as well as a socioeconomic study. Parks include an equipment rental program for fishers to experience the benefits of consistent yield. A single Mariculture Park has provided employment for a total of over 500 people, over half of which goes to local farmers and residents.

OMAN

THE DESERT COUNTRY THAT IS BETTING ON AN AQUACULTURE BOOM

Oman has a population of 4.49 million people and a GDP of 70.25 billion USD, with 3,165km of coastline on the Persian Gulf, Arabian Sea and the Gulf of Oman. Oil and natural gas extraction account for 51% of Oman's GDP. In recent years, Oman has focused on increasing national fish production. This goal is partially a means of diversifying its economy to reduce energy-dependence and partially a means of improving food security. With a per capita seafood consumption of 33.3kg (compared to 21.4kg in United States), food security for Oman means ample locally produced seafood. Today Oman is more than self-sufficient when it comes to seafood, consistently producing more seafood than it consumes. Over the last decade Oman has exported roughly half of its domestic production from aquaculture and wild-capture. The government has prioritized expanding its seafood production.

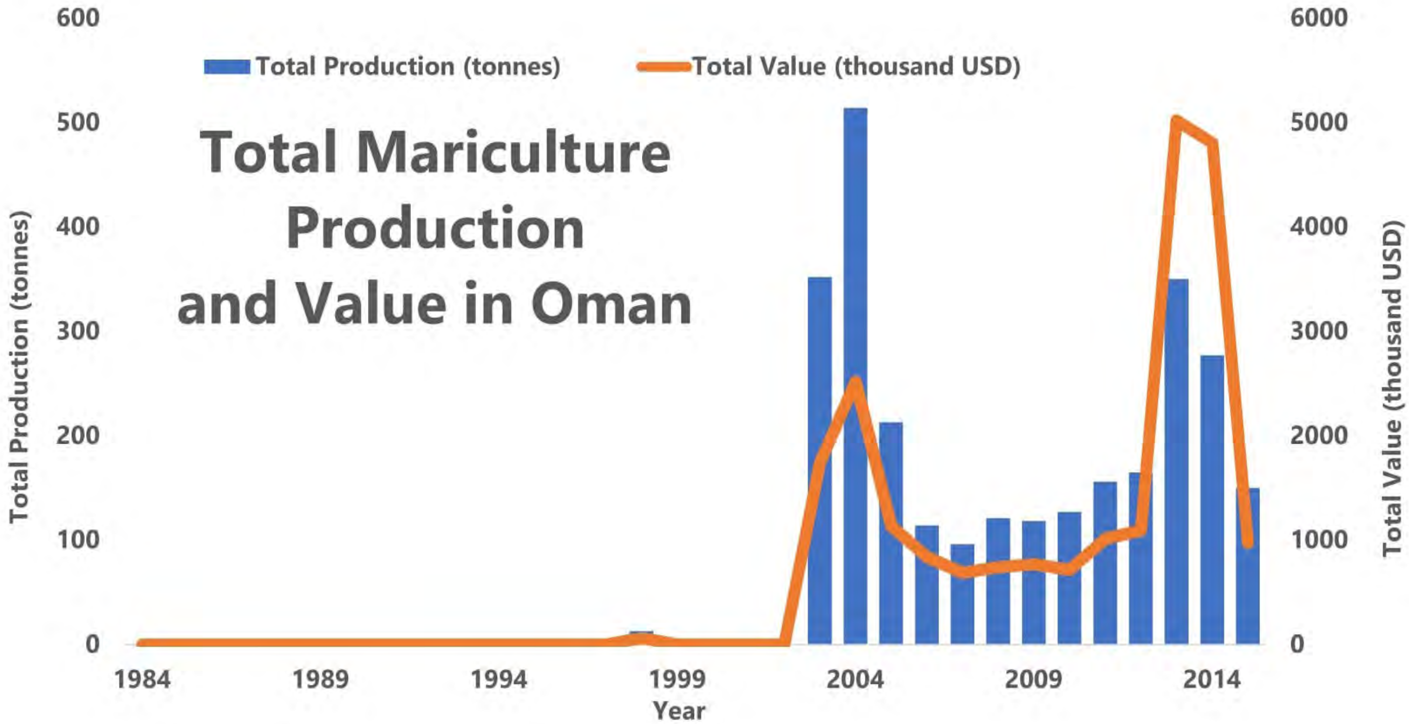
Oman produced about US$1 million in aquaculture in 2015, nearly all of it from the Indian White Prawn. The aquaculture industry has not seen any significant growth in recent years, but a recent official government report anticipates an industry that produces US$900 million of aquaculture, contributes US$5.2 billion to the GDP, and employs 11,000 by 2030-2040. This report was produced partly to encourage future investment in aquaculture and to aid potential investors. It provides an overview of Oman's regulatory framework surrounding aquaculture, serves as a guide for navigating the licensing process for new projects, and contact information for Oman's Ministry of Agriculture and Fisheries Wealth ("MAFW"). Currently, Oman is fielding 24 new applications for operations: 6 for offshore cage culture, 8 for shrimp ponds, 9 for on-land closed system farms and 1 for a shrimp hatchery.

Along with The Guidelines, Oman released the "Atlas of Suitable Sites for Aquaculture Projects in the Sultanate of Oman" ("The Atlas"). The 234-page Atlas addresses all sections of Oman's coastline and its suitability for various species and forms of aquaculture. The MAFW has already set aside many of these areas for future aquaculture projects, making the permitting process for these areas easier for companies wishing to develop there.

Oman is also working to integrate the aquaculture industry with the fisheries sector's storage and transportation infrastructure. The Omani government has research facilities for R&D regarding new culture and rearing methods. It is also providing companies with access to veterinary services, a crucial resource. Omanis looking for training and certification for aquaculture work can get that training in Oman at one of three institutes--one public institute, one private institute, and a vocational school.

Oman is clearly investing in and promoting aquaculture. The main hurdle for large expansion is the permitting process (see Box) – although hopefully the establishment of particular mapped areas for aquaculture will reduce the permitting burden.

Oman's Mariculture At a Glance	
Total Area for Fish (km^2)	33,865
Average GPI for fish	3.38
Total Area for Bivalves(km^2)	20,004
Average GPI for bivalve	1.96
Current production	24.39 tonnes (2015)
Government investment	High
Plan for expanding production	$900 million in inland and offshore production by 2030-2040
Importance for food security	High
Importance as provider of jobs	Moderate
Large markets accessibility	High
Technical capabilities	Moderate
Permitting and regulations	High
Km coast/km^2 land	3,165 km/309,500 km2 = 0.01
Per capita fish consumption	33.3 kg



ECONOMIC INCENTIVES

The Omani government has benefitted from hydrocarbons over the past decades and is now intelligently using its wealth to promote new industry development, including aquaculture. Oman offers new companies several economic incentives that should help the country promote its aquaculture industry:

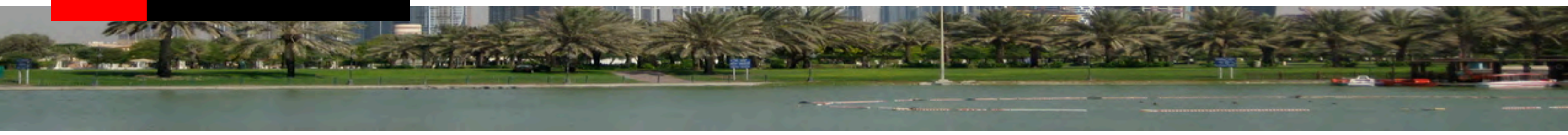
- Up to 10 years of exemption from corporate income tax
- Up to 10 years of exemption from customs duty
- Eligibility to receive soft loans from the Oman Development Bank
- Free repatriation of capital and profits

PERMITTING STRUGGLES

A Netherlands report states about gaining a permit in Oman that "Advice on applications is often difficult to receive and time-consuming. Improving the public services in this respect would enable economic growth and speed up administrative bottlenecks."

UNITED ARAB EMIRATES

COMING LATE TO THE AQUACULTURE ENDEAVOR



The United Arab Emirates (UAE) is an Arabian Peninsula nation situated along the Persian Gulf with 1,318 kilometers of coastline. It also happens to share a border with Oman. The nation is comprised of seven emirates such as Abu Dhabi and Dubai which are all united under one federation. The population was 9.3 million in 2016 and is projected to reach 10.6 million by 2030.

The UAE has long relied on fish as its main source of protein. Traditionally, anchovies and sardines were dried, salted, and then shipped inland where lack of rain prevented any agriculture. Today, per capita seafood consumption in the UAE is substantial at 28.6 kilograms per year. In the past, UAE was able to meet this demand from its own fisheries, but with rapid population growth, 80% of the nation's food is now imported which includes fish from Oman. Mariculture, therefore, has the potential to serve the nation's food security and economy.

Currently, aquaculture is only responsible for about 1% of UAE's seafood production. In 2015 the aquaculture sector produced 790 tonnes of farmed fish, valued at US$5,722,000. However, capture fishery production, which makes up the bulk of seafood produced in UAE, has been lower in recent years due to declining fish stocks. Some of the Gulf's fish stocks have declined by 80% in the last 40 years. As the country learns to manage its wild stock resources, the pressure may be put on aquaculture to help meet domestic demand.

One of the more unique obstacles to UAE's mariculture development is high ocean temperature and salinity. The country's coastal waters are relatively shallow, and the hot summer months can have a significant effect on the ocean's properties. The especially warm and salty waters present suitability and productivity issues for many potential farmed species.
The Emirati government has only recently considered mariculture a priority for development, and they are far behind most other countries in terms of developing this resource. The process for getting an operational permit is expensive and complicated, and the country lacks the essential infrastructure and technology. Serious government investment will be necessary for supporting research and training.

Only in the last few years has the government shown that it is willing to put up the money. According to the Ministry of Environment and Water, current UAE investment into aquaculture stands at US$321 million. Of that, US$20 million has gone towards the Sheikh Khalifa Bin Zayed Al Nahyan Marine Research Centre, which is focusing on hatchery research and relieving pressure on wild fish stocks.

UAE's Mariculture At a Glance	
Total Area for Fish (km^2)	14,272
Average GPI for fish	3.54
Total Area for Bivalves(km^2)	0
Average GPI for bivalve	N/A
Current production	640 tonnes
Government investment	High
Plan for expanding production	High market demand
Importance for food security	Very High
Importance as provider of jobs	Moderate
Large markets accessibility	Improving
Technical capabilities	Moderate
Permitting and regulations	High
Km coast/km^2 land	1,318 km/83,599 km2 = 0.015
Per capita fish consumption	28 kg

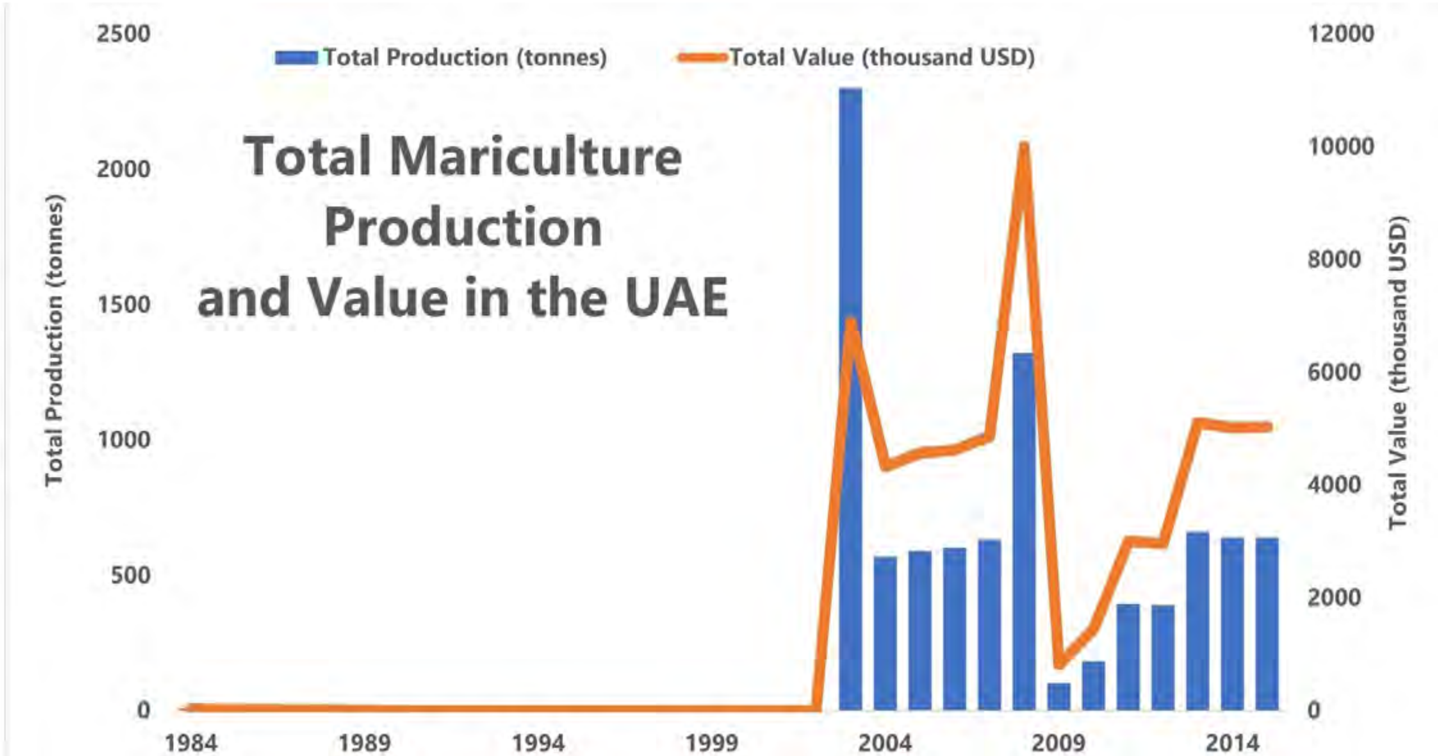

Total Production (tonnes)
Total Value (thousand USD)
Total Mariculture Production and Value in the UAE
Total Production (tonnes)
Total Value (thousand USD)
2500
2000
1500
1000
500
0
12000
10000
8000
6000
4000
2000
0
1984
1989
1994
1999
2004
2009
2014


Photo: FAO

MOROCCO

TAKING THE LEAD IN WEST AFRICA

Morocco, once a home port for the legendary Barbary pirates, has a rich history of maritime culture. While its fertile coastal lands are currently capable of producing all the food the country needs, climate change and droughts are likely to place traditional agriculture at risk of crop failures as freshwater becomes scarcer. Fortunately for Morocco, it fisheries industry is among the strongest in North Africa, accounting for 3% of national GDP. Its bountiful coasts along the eastern Atlantic and southern Mediterranean haul in nearly 1.4 million tonnes of fish each year, which is largely exported to its neighbor across the straits of Gibraltar, Spain. In 2014, the fishing and aquaculture industry provided 110,000 direct jobs and produced 1.35 million tonnes of marine fish, making it one of the world's top 25 fishing countries. From fishermen to processors to exporters, the entire supply chain of Moroccan fisheries supports the livelihoods 3 million people. But it could do much more. With the global increase in seafood demand, Morocco is not fully taking advantage of its fisheries market potential. In response, The King of Morocco launched the Halieutis Strategy in 2009 to reinvigorate Morocco's blue economy. This effort has dual functionality, creating opportunity for economic growth and promoting social and environmental sustainability.

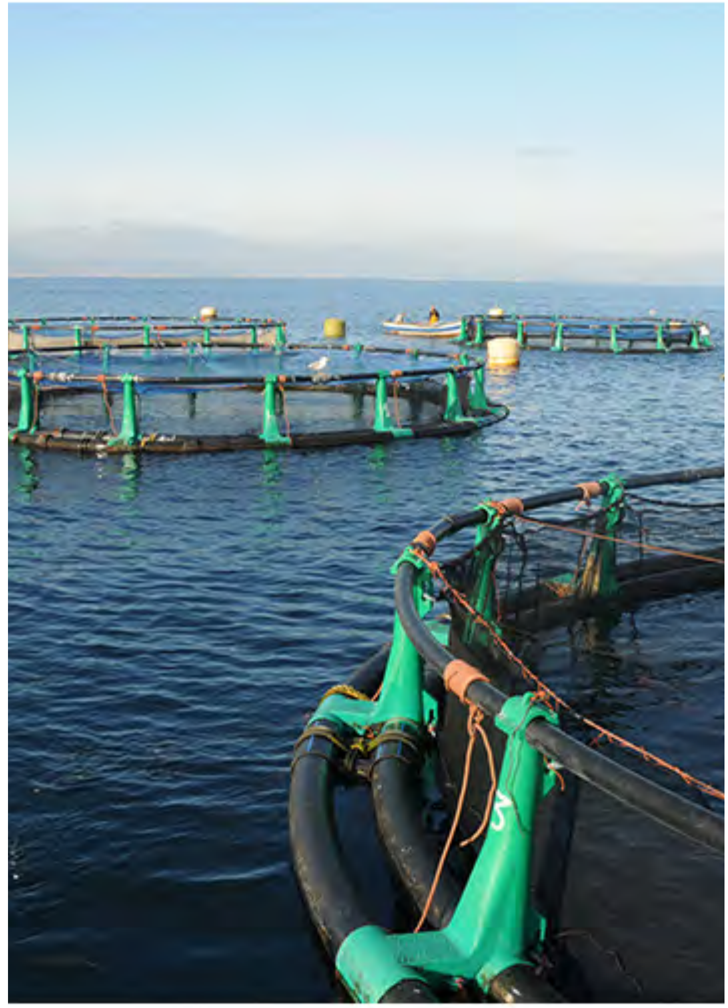
Traditionally, Morocco's fisheries have been almost entirely wild-caught (over 99%) even though its coastal habitats, with their shallow, sheltered waters and comparatively low storm risk, should be ideal for aquaculture. Though its contribution is low, aquaculture is not new to Morocco. Operations first started in the 1950s with oyster farming in Oaulidia lagoon followed by gilthead sea bream and red tuna in the 1980s and 90s in the lagoon of Nador and M'diq bay. These industries reached peak production at 1300 tonnes in 2005 until it all came crashing down in 2006 due to competition from Europe and financing problems. As part of the Halieutis Strategy, the National Aquaculture Development Agency (ANDA) was established in 2011 to rebuild the industry.

Morocco's marine aquaculture has huge potential for expansion beyond the current workforce of only 600 jobs and profit of less than 2 million USD. ANDA's goal is to increase production to 200,000 tonnes and supply 40,000 jobs by 2020 while maintaining integrated, sustainable planning standards. As it stands, three years from the target date, production is far below the target, but ANDA has lain a strong foundation for expansion. They've invested from the ground up, developing experimental and pilot coastal shellfish and seaweed farms. Their approach focuses on well-developed scientific research that, once perfected, can expand into a profitable, sustainable source of local income. ANDA cannot promote the sector on its own though. To support private investors, ANDA has streamlined the aquaculture permitting process and provided detailed outlines of start-up costs and return on investments to smooth out some of the hurdles.

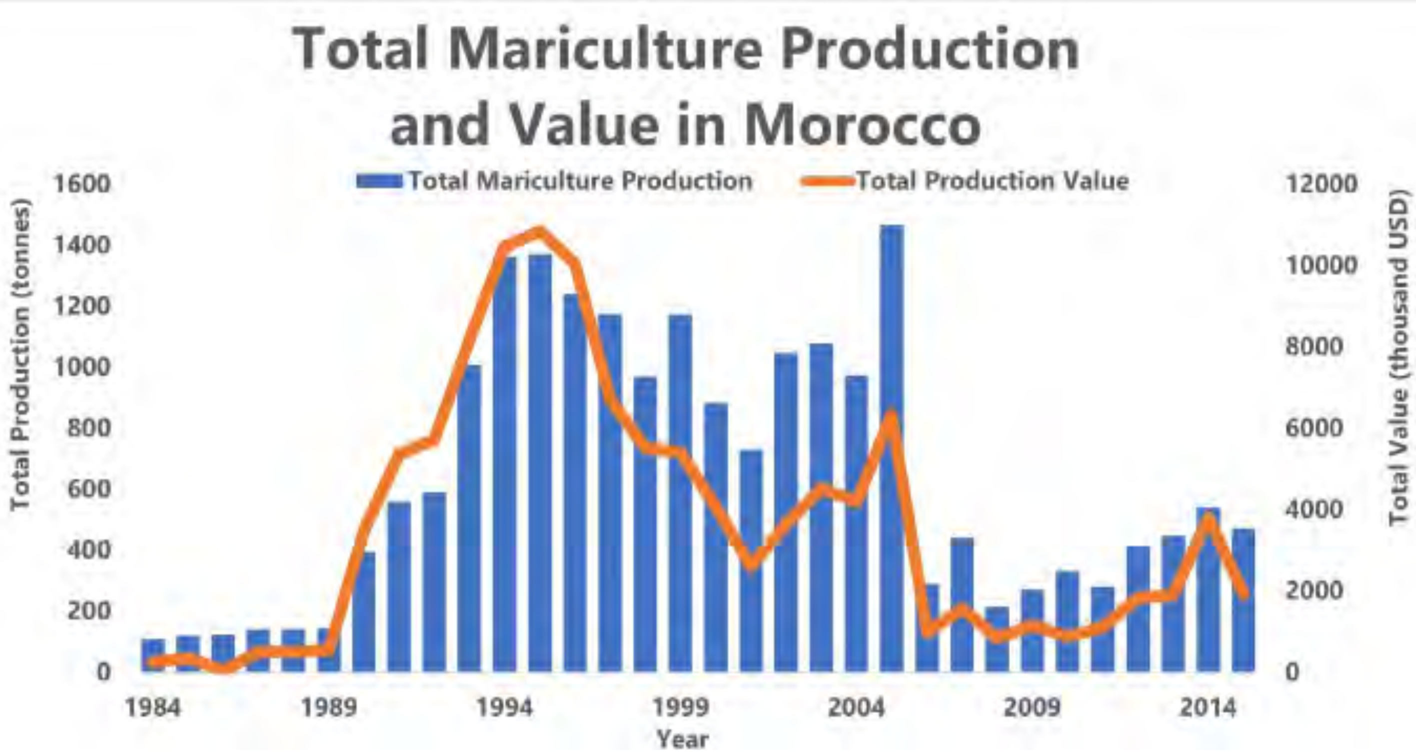
Even with private-public partnerships and simplified permitting, mariculture growth has its obstacles. Currently, Morocco doesn't provide low interest loans or other extra investment incentives for aquaculture development the way renewable energy and other green job ventures are incentivized. Since maritime industry can only be 49% dependent on foreign investment, local investors will need support entering the market. Here, ANDA will need to play a critical role in attracting Moroccan investors and potentially provide additional incentives.

Morocco's Mariculture At a Glance	
Total Area for Fish (km^2)	32,006
Average GPI for fish	3.24
Total Area for Bivalves(km^2)	13,163
Average GPI for bivalve	1.88
Current production	470 tonnes
Government investment	High
Plan for expanding production	200,000 tonnes by 2020
Importance for food security	Low
Importance as provider of jobs	Currently 600 jobs; signficant room for growth
Large markets accessibility	Moderate
Technical capabilities	Moderate
Permitting and regulations	Low
Km coast/km^2 land	3,500 km/710,850 km2 = 0.0049
Per capita fish consumption	13.4 kg

The Moroccan Ministry of Finance stated in a 2012 report that a lack of downstream infrastructure for seafood processing (such as reliable electricity for freezing) was reducing the industry's competitiveness. It is imperative that these supply chain infrastructure needs are met as aquaculture production grows; especially when competing with the high-quality standards of the EU. Part of that necessary infrastructure is human resources. There are plenty of experienced fisherman in Morocco, but there is also limited access to higher education. The Moroccan government will need to continue to invest in higher education programs in marine ecology to supply a growing demand for fish biologists and other specialists.



Morocco is uniquely situated at the junction of Europe and West Africa. Morocco's Free Trade Agreements with the United States and European Union give it access to 55% of the world's seafood consumption markets. To expand its exports in the EU, Morocco will need to compete with more advanced finfish farms in Greece and Turkey. On the other hand, West Africa is a relatively untapped market. Nigeria is the leading producer of fish but their operations focus on land-based freshwater farming. Developing mariculture off Morocco's southern coast in the western Sahara region could help reach a broader African market as well as create important rural jobs. Fish consumption is relatively low, but it is possible that Morocco could lead the way in African mariculture, relieving poverty and food security issues. Although it's quite a bit further than West Africa, Morocco has already started a partnership with Madagascar to help build technical fish farming capacity. More mariculture projects could create access to a stable source of protein and income. For West Africa, that could make all the difference.



UNITED STATES

THE COUNTRY THAT SHOULD AND COULD BUT DOES NOT

No country in the world has national control of more ocean habitat than the United States (11.7 million square kilometers of EEZ). The United States' 21.4kg of per capita seafood consumption translates to an annual seafood demand of over 7 million tonnes, more than any other country in the world but China. With its huge maritime zone and 13,000 miles of coastline, one would expect the U.S. to approach self-sufficiency in seafood, just as it imports less than 15% of its beef consumption. Remarkably, less than 10% of American seafood demand is met domestically. The vast majority of the United States' seafood, which is almost all shrimp, tilapia, tuna and salmon, is imported. This global seafood network has produced a trade deficit of more than $14 billion per year.

These would be cause for national concern if more public officials and citizens at large realized the extent to which the benefits of aquaculture are being outsourced to other countries. There is no reason that aquaculture could not be homegrown. Beyond food autonomy, the aquaculture industry presents a staggering business and economic opportunity.

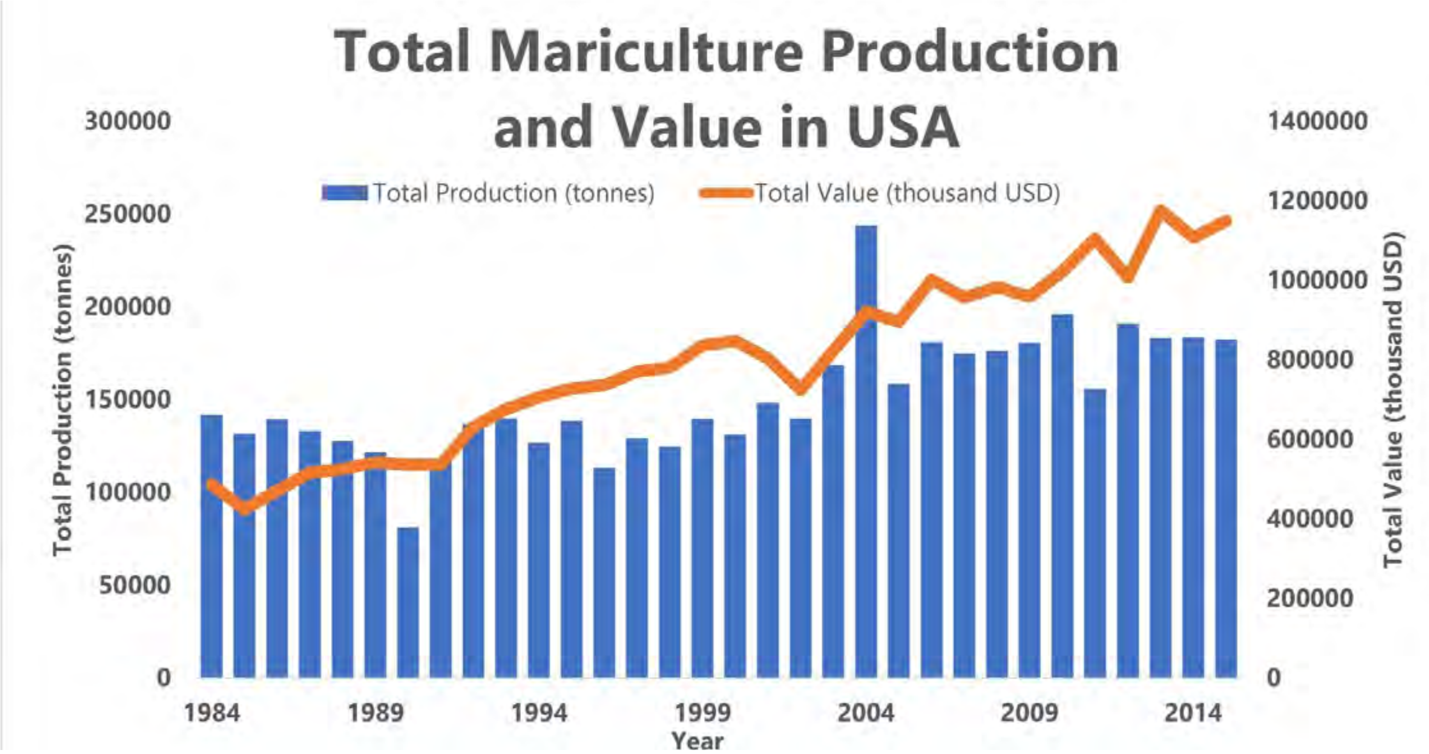
> Worldwide, aquaculture is booming and only poised to increase as seafood demand continues to grow. Yet the United States remains far behind other prominent maritime countries, ranking 17th for aquaculture production.

When it comes to seafood production, The United States has some of the highest sustainability standards in the world. More domestic aquaculture in the U.S. will guarantee an increase in the global amount of responsibly-sourced seafood. Unfortunately, the complex regulatory system in the United States is a significant hurdle for offshore development. Redundant regulations and inefficiency prevail. Each of 9 overseeing agencies has its own laws and regulations pertaining to food production standards, protection of marine species, navigation of federal waters, and more. Complying with each agency's separate set of requirements is expensive and time-consuming. Simplifying the authorization process is crucial if establishing offshore aquaculture in the United States is to become a reality.

Fortunately, the National Oceanic and Atmospheric Administration (NOAA) considers mariculture development a national priority and is partnering with the U.S. Department of Commerce to address many of the existing obstacles to growth. In 2016, the agency released the Marine Aquaculture Strategic Plan (2016-2020) outlining specific goals and steps that will be implemented to encourage domestic expansion.

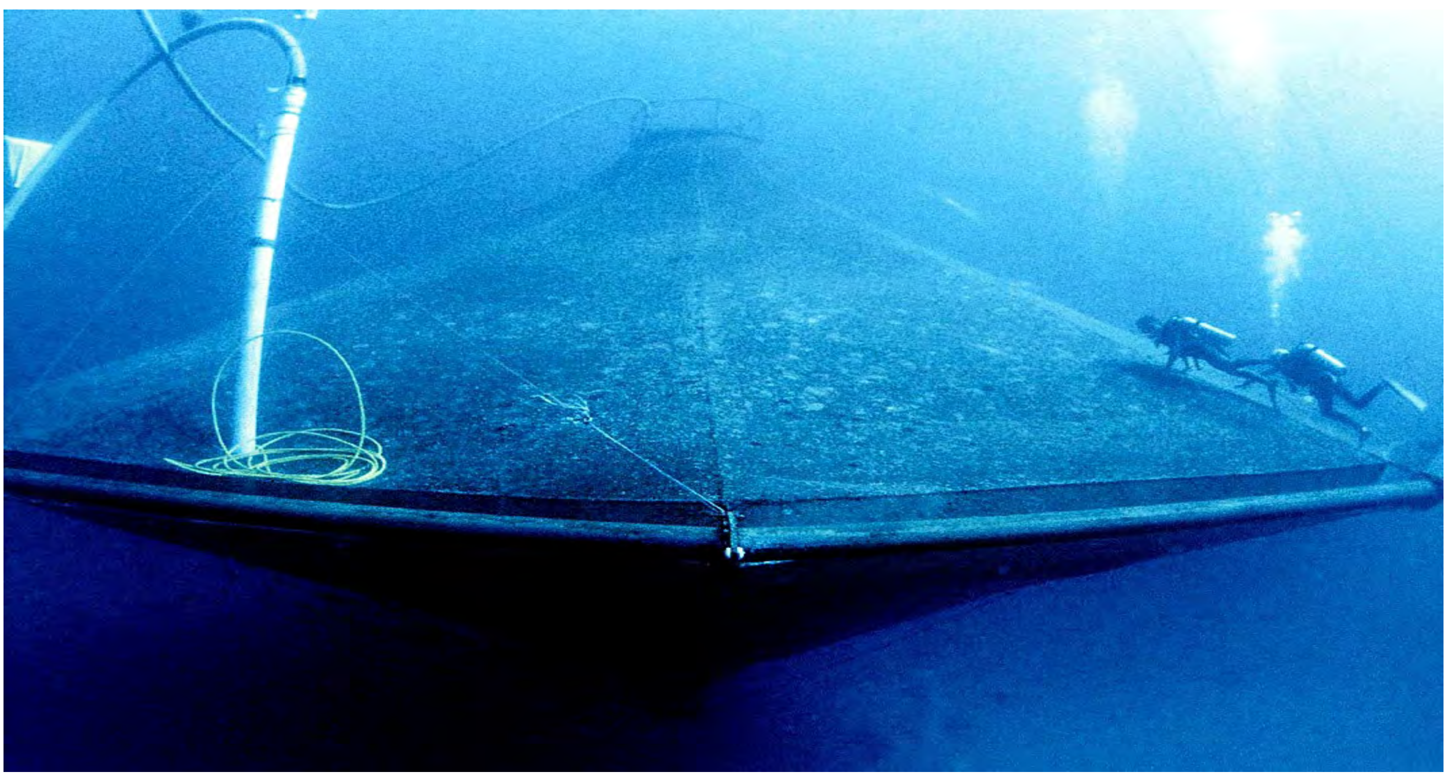
Most important are improvements to the regulatory and communication sectors, although innovation in technology, research and management practices is also necessary. In total, the U.S.'s stated goal is to increase domestic aquaculture production by 50% by 2020. The most significant strides in U.S. mariculture have been made in Alaska, Maine, and most recently in the Gulf of Mexico, but there are still huge regions of untapped potential.

USA's Mariculture At a Glance	
Total Area for Fish (km^2)	643,610
Average GPI for fish	3.36
Total Area for Bivalves(km^2)	51,933
Average GPI for bivalve	1.69
Current production	182,511 tonnes
Government investment	Moderate
Plan for expanding production	Increase 50% by 2020
Importance for food security	Low
Importance as provider of jobs	Moderate
Large markets accessibility	High
Technical capabilities	High
Permitting and regulations obstables	High
Km coast/km^2 land	20,921 km/9,147,000 km2 = 0.0023
Per capita fish consumption	21.4 kg



BRAIN DRAIN

The United States is home to some of the best scientists and engineers engaged in mariculture in the world. Industry experts are constantly working to improve location siting, feed development, and cage engineering. The United States prioritizes research to improve existing aquaculture practices and offers various grant programs to encourage innovation. But until offshore aquaculture takes hold, there is no market for these skills and technology in the U.S. Domestic progress is applied to foreign operations, where seafood is grown and then imported back to the States.



GENERAL LESSONS

01 Bright & Dark Spots

02 Economic Profitability

03 Consumer Perspectives

04 Sustainability Challenges

05 Climate Challenges

BRIGHT & DARK SPOTS OF THE WORLD

The FAO has identified 5 major factors and 15 sub factors (see below) that can affect a country's aquaculture development. To apply these conditions to offshore mariculture, we examined countries with successful industries ("bright spots") and countries that have the necessary resources for a good industry but aren't using them effectively ("dark spots") for both fish and bivalve production. We picked some characteristic features of each country to highlight how the FAO's factors play a role. It's worth noting that our research methods bias our results towards examining the environment, technology, and market factors.

- Environment
    - Physical (environment suitability)
    - Institutional (policy/regulation, assistance programs, stability)
    - Social (infrastructure, lifestyle, education)
- Space
    - Land availability
    - Water availability
- Technology
    - Culture technology
    - Product technology (handling, processing, distribution, etc.)
- Production
    - Choosing the operation system and business management
    - Input cost and availability
    - Operations and trained personnel
    - Costs
- Marketing
    - Market strategy and business management
    - Domestic and export demand
    - Trained personnel and efficient operations
    - High revenues

KEY TAKEAWAYS:

- Industrial aquaculture requires skilled workers and advanced technology. Bright spots China and Norway have excellent training programs for mariculture and systems to efficiently bring advances from research institutes to private companies.

- As highlighted by Cambodia, the mariculture industry needs strong domestic demand or a reliable export market to sell product.

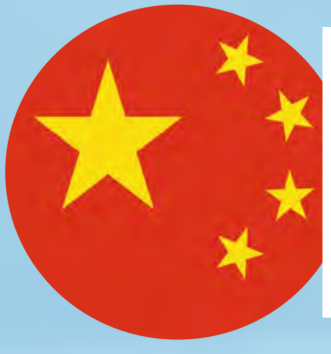
- Public perception is still an important factor for mariculture production. Italy is benefitting from improving aquaculture's public image.

- Solid infrastructure for processing and transportation is key to profitability

- Some areas like Palau may have more profitable and sustainable uses for their marine areas that they need to consider.

- Malta's designated "Aquaculture Zones" provide an option for the government to have greater control and monitoring over its aquaculture industry. These zones may also be a good tool for simplifying the permitting process.

BIVALVES

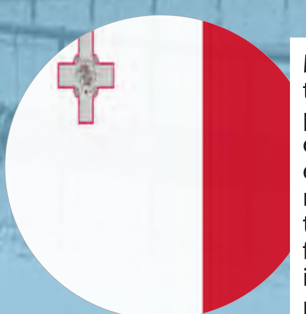


China is solely responsible for about two-thirds of global aquaculture production. The government has been deeply involved in developing its aquaculture center for more than 50 years. For instance, the government supports "Technology Extension Centers" that exist solely to assist companies and local aquaculture farmers with new technology from the country's research centers.

Italy is a major bivalve provider in the Mediterranean and European markets. Bivalves accounted for 67% of Italy's aquaculture production in 2015. The industry is working on building the "Made in Italy" brand by adopting voluntary codes and certification schemes for transparency and traceability. Land-use conflicts have started a migration from land-based farms to the open sea, but bureaucracy has slowed the transition.

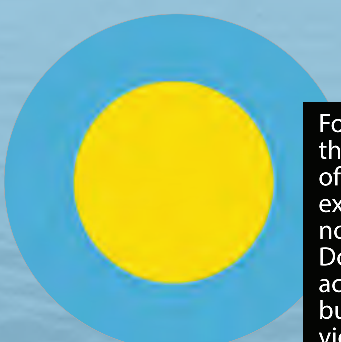
Cambodia's rich marine and freshwater resources are well-suited for farming, but success of the wild-capture fishing industry has kept aquaculture production low. Bivalve production remains nearly nonexistent partly because the standard Cambodian diet barely includes marine products. Presently, the country lacks technology and capital necessary for intensive farming. Strict regulations on product quality in the European Union create large entry-barriers for bivalve trade and Cambodia will need to heavily invest in infrastructure and health facilities before it can tap into this European demand.

FISH



Malta's small size creates a high level of competition for space and resources. Almost 80% of Malta's production comes from its capture-based farming of Atlantic Bluefin Tuna. The country is prioritizing environmental sustainability when considering new applications, but not necessarily applying those to their existing use of capture-based tuna farming. Moving forward, the government is helping fund vocational training programs and new research for species diversification centers.

Norway's salmon farms account for more than 90% of the country's produced aquaculture value and over half of all the world's salmon supply. Aquaculture in Norway is largely industrial, modern and highly competitive, and nearly all of Norway's institutions participate in aquaculture research and teach it academically. Today, Norway's technology, like its products, is exported across the globe.

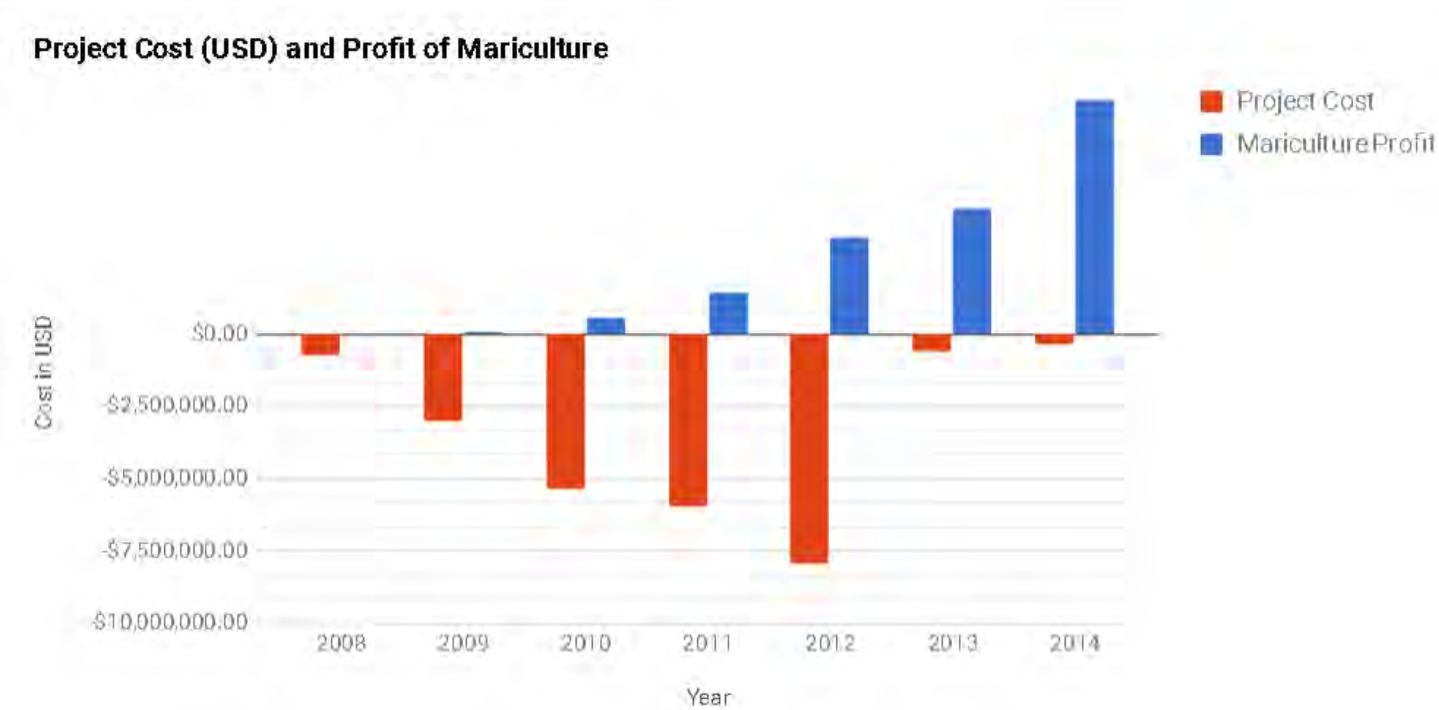


Food security is a major challenge for Palau, however the government has cut off access to the vast majority of their marine resources. In 2015, Palau banned all exploitation activities in 80% of Palau's Exclusive Economic Zone (EEZ). The remaining 20% was designated a Domestic Fishing Zone allowing only small-scale fishing activities. This is a major obstacle to aquaculture growth, but the decision has grounds. Diving tourism alone provides roughly 40% of Palau's GDP, and marine-conservation efforts will ensure that Palau remains a premiere tourist destination.

ECONOMIC PROFITABILITY

INDONESIA

PROJECT COST (USD) & PROFIT OF MARICULTURE



AMOUNT CONTRIBUTED TO AQUACULTURE PROJECT

+31.60 MILLION

The Asian Development Bank invested this amount to reduce poverty and enhance food security.

+9.49 MILLION

Funded by Indonesian and District Governments

+3.52 MILLION

Funded by Project Beneficiary Groups

+44.61 MILLION

Total Amount Contributed

BACKGROUND INFORMATION

With the global market for farmed fish rapidly developing and numerous business opportunities presenting themselves, a key question is what kind of investment is needed to accelerate the inevitable aquaculture boom. One of the most notable successes is found in Indonesia, which we examine for its development model. Mariculture development in Indonesia isn't just a business opportunity, it's a humanitarian one. Indonesia holds vast marine resources, but 28 million people living below the poverty line puts the country's poverty rate at nearly 11%. The Asian Development Bank recognized the opportunity to capitalize on Indonesia's natural resources, and from 2007 to 2013 it provided 71% of the funding for a US$44.6 million aquaculture project. For marine production, the project built over 500 marine sea cages and created 4 marine hatcheries, but part of its success also stems from its multi-faceted approach. The table below includes a breakdown of how they spent the money.

After an immediate 2 year delay while they waited for the Indonesian government to approve their budget contribution, the projectended up a massive success in both its production and humanitarian goals. Between 2009 and 2014, the project expanded the country's aquaculture production from 4.78 million tons to 14.4 million tons, over 10 million of which are produced from mariculture and brackishwater.

It's worth noting, however, that the grouper fish, the only sea-cage-farmed fish in the project, was found to be one of the least economically-viable operations of the entire project, though it was still profitable. Overall, the project created 14,000 jobs across the 5 involved districts, and significantly contributed to reducing poverty incidences in the areas from 15%-25% to 10%-16%.

Figure 2 outlines the annual total project costs and profits from the mariculture operations. Though initial costs are high, the profit earned is shown to be well worth the wait. The project achieved net profit between years 5 or 6. The project costs shown account for all enterprises, but by year 6 mariculture and brackishwater profits alone outweigh all costs.

AQUACULTURE DEVELOPMENTS

	OBJECTIVES	MAJOR PROJECT COMPONENENTS AND COSTS
INDONESIA	The Asian Development Bank (ADB) funded this project with the goal of reducing poverty and increasing food security through developing sustainable aquaculture.	-Aquaculture Production Enhancement ($30.53 million USD) Training fish farmers groups and constructing mariculture cages -Aquaculture Support Services ($5.95 million USD) Fish marketing development and research -Project Management ($4.58 million USD)
ALBANIA	The World Bank funded this to redevelop aquaculture and to experiment with further development via pilot projects.	-Community Co-Management of Fisheries ($3.35 million USD) -Aquaculture Development ($2.14 million USD) -Support for the Public Sector ($0.25 million USD) -Project Management ($0.78 million USD)
MEXICO	Funded by World Bank, this project promote sustainable aquaculture development through a regulatory framework of social consensus.	-Regulatory Framework (US$13.0 million, 25% of base costs) -Social Sector Development (US$38.4 million, 75% of base costs)

PROJECT PITFALLS

When discussing the profitability and feasibility of offshore aquaculture operations, it is important to assess the current operations to see what causes them to fail. Current data is sparse due to a lack of offshore operations on a global scale as well as poor record keeping on these details. Using the case study on Indonesia as well as an offshore operation in Maldives, data was compiled on efforts that failed as well as efforts implemented to mitigate previous failures. Implementing this feedback into future offshore mariculture systems could be extremely beneficial for building successful future programs.

PUBLIC/PRIVATE MISALIGNMENT

Mariculture is most effective when all sectors align. This means the private sector manages the enterprise, the government facilitates and provides incentives, and the local communities are given jobs and have a vested interest. The private sector needs to be placed in the management role and the public sector as the facilitator and initial funder, with a focus on quality assurance.

POOR SITING

Some aquaculture operations fail because they are established in unsuitable situations. The countries may not have access to markets or may lack the economic diversification needed to withstand economic shocks, which can result in governments abandoning their aquaculture investments prematurely

LACK OF CAPACITY

In-country conditions like skilled-worker availability, access to loan capital (especially for poor, small-scale farmers), knowledge of potential farm sites, and market exposure vary considerably. National governments should assess their capacity in each and work to address any weak areas.

CONSUMER PERSPECTIVES

Sustainability as a Marketing Strategy

While seafood is popular in the United States, Americans still eat more beef than fish. This preference for beef is neither good for personal health nor for the environment. It would be in the public interest to move towards replacing beef with seafood, especially if that seafood were sustainably produced.

The organic movement educated consumers on the environmental and health effects of pesticides, though the health effects were the main motivation. Health benefits may provide an incentive for the switch from red meat to fish, but the choice to prioritize sustainability will depend on concern for the environment, which has shown to be a weaker motivator. Efforts to educate consumers on seafood sustainability will have to tread the fine line between providing interesting, memorable information for making choices and overloading consumers to the point where they give up on trying. The public will then need to be able to easily identify sustainable versus unsustainable choices in the market, possibly through labeling, to allow them to show a preference for sustainable fish.

Promoting such a diet shift is going to require much greater consumer awareness and sophistication than is currently evident. In particular, the public is first going to need to understand what sustainable seafood is and why it is good. Then the public needs to be able to identify the differences between sustainable and unsustainable seafood and be given clearly labeled choices that allow them to show a preference for sustainable fish. All of this requires education and marketing campaigns beyond anything yet in place for seafood.

The good news is that consumer behavior has proven to be malleable and receptive to labels such as organic. Indeed, between 2002 and 2012, the organic food market grew 238% from $8.6 billion to $29 billion, while the overall food market grew by only 33%. Similarly, MSC (Marine Stewardship Council) certified fish (Marine Stewardship Council) now represents nearly 10% of the global wild-caught supply.

A Closer Look: Menus in Los Angeles

A key question is: to what extent are American consumers presented with options for sustainable fish in their everyday experiences? To answer this question, we examined a random selection of 50 menus in the Los Angeles area that turned up using a Google search for "seafood restaurants." The restaurants in our sample ranged from small taco shops to five-star restaurants. The menus were scored based on how well information about species, source and sustainability was communicated, and price range was also noted.

The results were dramatic. Only 10% of the menus had any information about sustainability. Less than a half had information about the source of the items, and one in four menus simply listed the menu item as "fish." These results reflect the lack of information available to consumers when they make decisions about which fish to buy. Clearly, a high priority is improving informative labeling of fish products.

BEHIND THE NUMBERS

Only 1 in 10 restaurants emphasized sustainability in their marketing.

90%

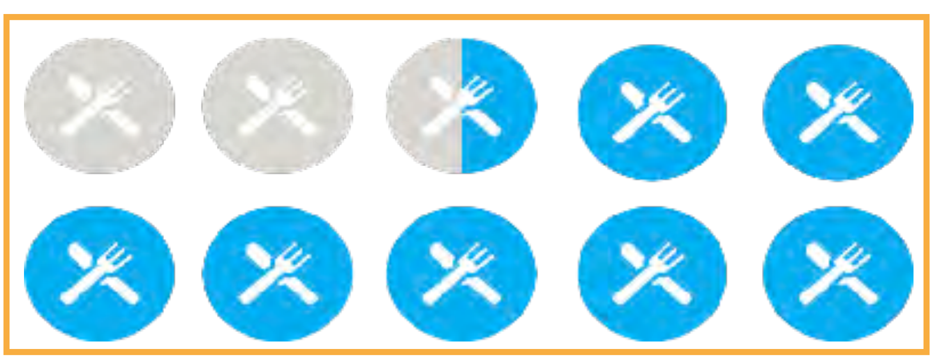
NO SUSTAINABILITY INDICATED

Less than half the menus provided the origin of their product.

56%

NO SOURCE LISTED

Nearly 1 in 4 menus had no detail besides “fish” or “seafood."



24%

NO DETAIL PROVIDED

SUSTAINABILITY CHALLENGES

The mariculture industry has historically been plagued with issues such as water pollution, fish disease outbreaks, destruction of coastal habitat and escapes and has received a fair amount of backlash. However, offshore marine farming offers a solution to the environmental risks of conventional systems. Studies have shown that, when sited properly with adequate flushing rates, offshore mariculture operations had an insignificant nutrient impact on the water column and had diminished water and benthic pollution. By producing fish in less polluted marine environments, offshore operations can improve the quality of the product, market access, and profit. Still, offshore mariculture faces a number of sustainability challenges that can jeopardize the sector's ecological and economical integrity.

Sustainability has come to mean a lot of things, now encompassing economic, environmental, and social elements. Offshore aquaculture has the potential to be sustainable by any definition, and its growing contribution to global food production presents an opportunity to really address these issues and become the most sustainable form of protein production we have available.

IMPACTS ON MARINE ECOSYSTEMS: While technology has developed to mitigate fish escape risk, factors such as human maintenance error, vandalism, and ship collisions still exist. Escaped fish can harm the surrounding marine ecosystem through increased competition and genetic impacts. Some species still need juvenile wild fish to supply farmed stock, which can lead to over-exploitation and wild stock shortages. Catching these juveniles can lead to by-catch of other species as well.

FEED: ¼ of wild catch goes towards fish meal and fish oil for carnivorous fish. Although feed systems have become more efficient in the past decades, it is important that feed production does not compete with direct human consumption. Herbaceous fish feed on land based products, so transitioning into alternative waste or marine sources will be necessary to reduce agricultural impact.

DISEASES: Even though there is no current issue of disease outbreak in offshore mariculture, looking towards a larger industry will require research to better understand how expansion might affect disease outbreak. There is also little research on the pathogen exchange between farmed and wild caught fish.

CARBON FOOTPRINT: Mariculture farms are based miles offshore and therefore release large amounts of carbon dioxide both through transportation and fuel demands on harvesting, distribution, and maintenance.

EMPLOYMENT AND COMMUNITY INVOLVEMENT: Offshore mariculture operations can provide employment but need large capital investment and technological knowledge within the local economies. Large multinational companies often end up establishing operations without the interest of the local community in mind.

GENDER EQUALITY: There is a huge potential for employment opportunities and access to nutritious food for women, particularly in developing countries. However, currently gender is largely excluded from development considerations.

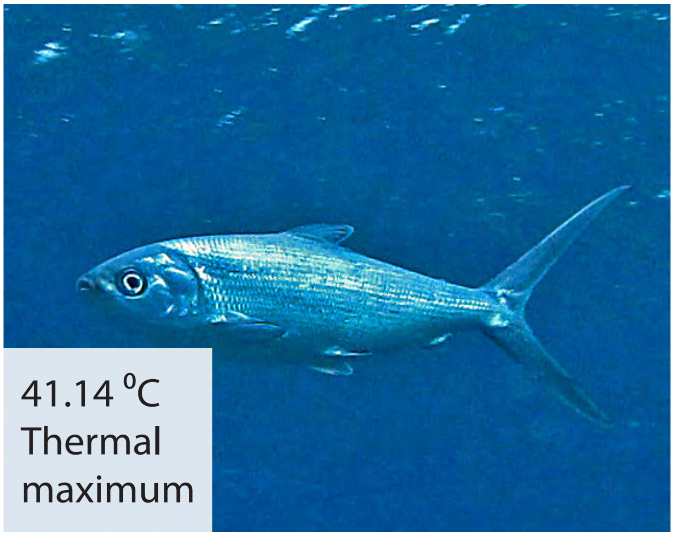
CLIMATE CHANGE CHALLENGES

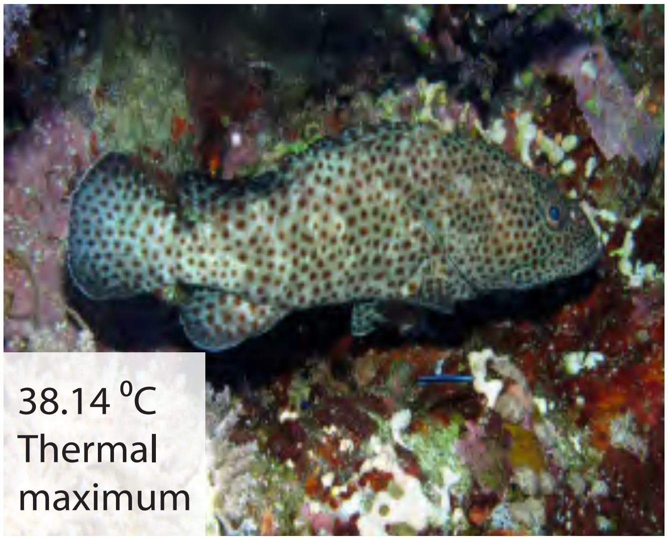
Climate change is impacting every habitat and every species on the planet. Some species might benefit from increased growth rates and availability of feed. But for many species, there is a risk of reduced population, lack of suitable habitat, and greater vulnerability to natural disaster. The spatial resolution of climate models and uncertainty surrounding feedback loops (positive and negative) makes it impossible to generate precise forecasts. We can, however, identify major "risk pathways" and consider how aquaculture might fare with respect to these pathways.

The Intergovernmental Panel on Climate Change (IPCC) projects that the sea temperatures will warm up to 1 kilometer below the surface come 2100 by

0.5-1.0 ^{o}C

> While [tropical] species can grow more quickly in warmer waters, they may not be as robust to more extreme environmental conditions. Long-term, expanding tropical production may be less adaptable compared to development of temperate and subtropical areas and species.
>
> Froehlich et. al, 2017



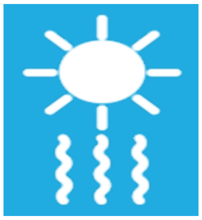


Milk fish and Grouper are 2 popular tropically farmed fish potentially at risk due to future climate change.

IMPACT OF CLIMATE CHANGE

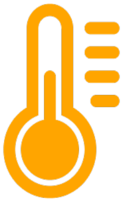
SEA LEVEL RISE (SLR)

May damage coastal infrastructure, reduce fish feed stocks, and cause loss of ecosystems that buffer the coast from storm damage.



SALINITY

Salty areas like the Red Sea or brackish water areas will get saltier as evaporation increases and freshwater input decreases.



TEMPERATURE

Marine species generally have narrow optimal thermal ranges. Temperatures that exceed thermal limits can decrease performance has already been observed in some salmon species.

NUTRIENT AVAILABILITY

Ocean circulation patterns may shift, changing the amount of upwelling which directly affects filter feeders and may impact fed species indirectly.

ACIDIFICATION

Greater ocean acidity weakens shell formation in shellfish. Finfish have a higher acidification threshold.

STORMS

Storm frequency will likely stay constant but warmer water increases available energy, increasing storm intensity, endangering infrastructure and farm stocks.

There are key differences between how climate change will impact marine aquaculture in comparison to global wild fisheries. Most marine finfish farms provide feed, eliminating the direct threat of nutrient availability in ocean areas that may become less productive. However, increased nutrient upwelling in other areas may cause algal blooms which can lead to the development of dead zones where there is a lack of dissolved oxygen in the water. Algae blooms can also be toxic, causing problems with shellfish food poisoning and reducing farm revenue. While wild fish may be able to migrate north as sea temperature increases, penned fish obviously cannot escape temperature increases via dispersal. Mapping the migration of wild populations and understanding these trends will be essential to informed aquaculture farm design, siting, and species produced as certain areas become more or less ideal.

Understanding all the physical constraints of farmed species will be important for ensuring long term success. These factors vary greatly between species. Filter-feeding species will be far more reliant on nutrient availability than fed species. Carnivorous fish further up the food chain also tend to have a higher thermal tolerance, but their higher input requirements makes sustainable production challenging. An in-depth study of the compounding effects of temperature change and dissolved oxygen availability across 178 mariculture species found that "tropical species appear more limited in their ability to withstand simultaneously wider temperature extremes and lower minimum DO levels" (Froehlich et. al, 2016). Since tropical areas are currently the main source of mariculture, adaptation strategies will be crucial moving forward. Additionally, "larger, slower growing species, tend to have increased temperature plasticity and lower minimum DO levels" (Froehlich et. al, 2016). Slower growing species may not be ideal for farm production rates, but fast growing species face decreasing performance with climate variability. Understanding how specific regions will develop aquaculture under the increased stress of climate change requires further study into species' specific growth constraints.

KEY TAKEAWAYS & CONCLUSIONS

Integrated Economy

Patient Investors

Government Support

Offshore mariculture is not the end-all be-all of fish production, but it has the potential for expansion unmatched by any other technique. It will be most beneficial within a greater network of capture fisheries, polyculture farms, and conservation areas. For now, production from offshore mariculture is small, and it will take a concerted and coordinated effort across sectors to achieve the ocean's potential for sustainable protein production.

Government commitment and support is foundational to a country's development. They must provide the initial research and infrastructure that is too expensive for the private sector. They're also responsible for establishing an attractive economic environment for governments.

Offshore farming is technologically demanding, and properly trained personnel and advanced technology are necessary for operations to run efficiently and sustainably. Getting advances from research institutions out to the operations must be a deliberate process.

Finally, we need to change the story surrounding aquaculture. Fish farming is a necessary part of meeting the seafood and protein demands of the future, and opportunities for sustainability lie offshore

APPENDIX

Supplemental Tables for Country Profile Graphs of Total Mariculture Production and Value Data

Total Mariculture Production (tonnes)						
Year	Morocco	USA	UAE	Oman	Philippines	Palau
1984	110	142019	7	0	478345	0
1985	120	131760	7	0	495184	0
1986	125	139802	7	0	470923	0
1987	140	133444	8	0	560970	0
1988	140	127813	6	0	599464	0
1989	144	121853	2	0	629323	3
1990	395	81519	0	0	671116	2
1991	559	118497	0	0	692401	2
1992	591	137081	0	0	736381	2
1993	1008	140304	0	0	793620	2
1994	1363	126924	0	0	869083	3
1995	1372	138738	0	0	940619	3
1996	1241	113480	0	0	1007677	2
1997	1174	129606	0	0	984437	2
1998	971	124975	0	13	997841	1
1999	1173	139879	0	0	1048679	1
2000	884	131520	0	0	1100902	2
2001	731	148405	0	0	1220456	2
2002	1047	140151	0	0	1338394	4
2003	1078	168623	2300	352	1448504	4
2004	975	243864	570	514	1717028	5
2005	1467	158574	590	213	1895848	5
2006	291	181040	602	114	2092274	5
2007	441	174865	632	96	2214785	18
2008	214	176421	1322	121	2407698.1	20
2009	272	180776	102	118.4	2477392.44	41.88
2010	332	196053	182	127	2545967	25.11
2011	279	155958	395	156	2608120	23.58
2012	412	191201	390	165	2541965	35.91
2013	448	183348	660	350	2373386	19.9
2014	539	183892	640	277	2337605	26.53
2015	470	182511	640	150	2348159	24.39

Total Mariculture Value (thousand USD)						
Year	Morocco	USA	UAE	Oman	Philippines	Palau
1984	251	487139.45	32.42	0	458547.07	0
1985	358	425253.01	19.07	0	464902.72	0
1986	41	471310.69	19.07	0	522689.45	0
1987	505	517301.32	11.14	0	575438.26	0
1988	512	525670.97	18.5	0	738446.2	0
1989	540	543371.6	6	0	725118.73	27
1990	3489	537508.84	0	0	856535.06	19
1991	5369	537248.84	0	0	823712.58	19
1992	5726	632215.83	0	0	1004935.3	19
1993	8171	677058.57	0	0	1115651.41	19
1994	10470	706915.89	0	0	1331636.28	27
1995	10849	729186.51	0	0	1309372.64	27
1996	10056	736555.88	0	0	1272871.8	19
1997	6710	771401.91	0	0	942036.42	19
1998	5520	781039.65	0	62.94	640592.1	10
1999	5410	836936.85	0	0	742098.06	10
2000	4059	848064.98	0	0	734011.85	19
2001	3606	804166.47	0	0	719177.12	19
2002	3648	725370.13	0	0	695407.2	38.3
2003	4519	823347.41	6900	1737.5	668510.08	31.5
2004	4197	922112.05	4332	1518.41	794717.15	12.56
2005	6536	896336.25	4572	1136.28	903380.53	21
2006	985	1001601.29	4628	840.16	1155467.28	21
2007	1563	957232.2	4868	688.43	1371049.19	79.84
2008	844	983582.72	10003.08	742.52	1867180.71	73.14
2009	1156	958881.73	816	769.83	1686860.58	152.89
2010	875	1023272.14	1456	716.75	1819797.05	130.56
2011	1109	1104836.69	3005.2	1014.5	1965813.36	186.42
2012	1832	1007282.23	2967	1094.28	2186348.12	218.22
2013	1906	1176006.76	5107	5021.07	2210515.85	120.34
2014	3809	1108087.49	3016	4805.18	2135872.85	170.86
2015	1928	1149612.21	5082	975.29	2052751.51	149.68

Country Profile “Mariculture At a Glance” Category Definitions:

Total Area for Fish – the square kilometers of Exclusive Economic Zone available for finfish mariculture operations based on biological, physical, and ocean chemistry factors

Average GPI for fish – weighted Growth Potential Index for finfish production published in Gentry et. al, 2017

Total Area for Bivalves – the square kilometers of Exclusive Economic Zone available for bivalve mariculture operations based on biological, physical, and ocean chemistry factors

Average GPI for bivalve – weighted Growth Potential Index for bivalve production published in Gentry et. al, 2017

Current Production – the total annual tonnage of mariculture production in-country based on the mosty recent available FAO data (2015)

Government Investment – a ranking (low, moderate, high) of the country’s national level investment in mariculture research, development, technology, and production

Plan for expanding production – the government’s currently stated future plan for mariculture development

Importance for food security – a ranking (low, moderate, high) of the country’s necessity for mariculture to meet in-country food security

Importance as provider of jobs – in-country jobs currently provided by in-country mariculture industry

Large markets accessibility – a ranking (low, moderate, high) of the ability of the country to access large markets for seafood

Technical capabilities – a ranking (low, moderate, high) of the technology and human technical skill sets available in-country

Permitting and regulations – a ranking (low, moderate, high) of the current permitting and regulatory environment as a hindrance to offshore mariculture expansion

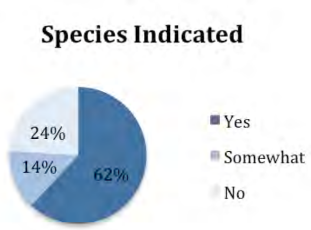
Km coast/km^2 land – the ratio of coastline to country area in kilometers

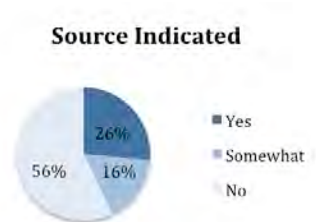
Per capita fish consumption – the current number of kilograms of seafood consumed annually by the in-country population expressed as kilograms per person based on FAO data

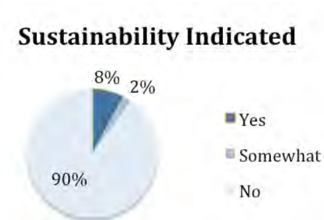
Explanation of Consumer Prespectives - Behind the Numbers Methods and Figures

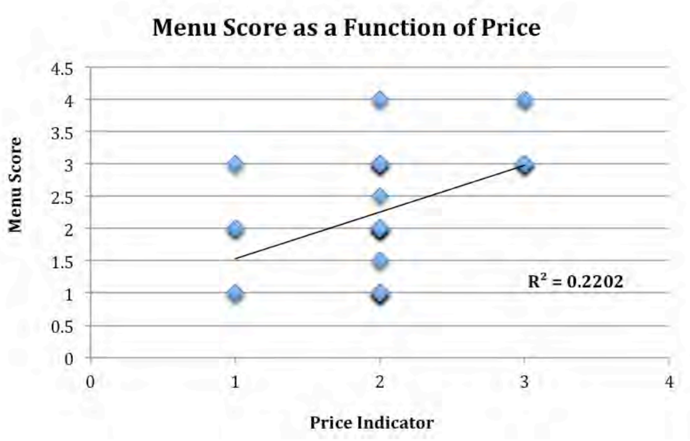
A Google search query for “seafood restaurants” in the Los Angeles area was used to conduct this analysis. A random number sequence of zeros and ones was generated to randomly select 50 restaurants - the results corresponding to zeros were omitted, as well as restaurants that did not have websites or menu information online. The menus were subjectively analyzed for details about the species and source of the seafood, as well as sustainability information. A qualitative value of Yes = 1, Somewhat = 0.5, or No = 0 was assigned for each category. These values were summed to give an overall score for each restaurant. All restaurants were given a default score of 1. Price was also given a qualitative value of ($) = 1, ($$) = 2, ($$$) = 3, or ($$$$) = 4.

Consumer Prespectives - Behind the Numbers Additional Figures









Explanation of Bright & Dark Spots Methods
Bright spots were countries with high fish or bivalve production rates scaled by the area available for production. Dark spots were countries that biophysically have the potential for high aquaculture production, but dramatically underperform relative to that potential. Data came from SNAPP.

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Palau's dark spot profile was written in consultation with Mochi Li, the team's Palau expert.

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