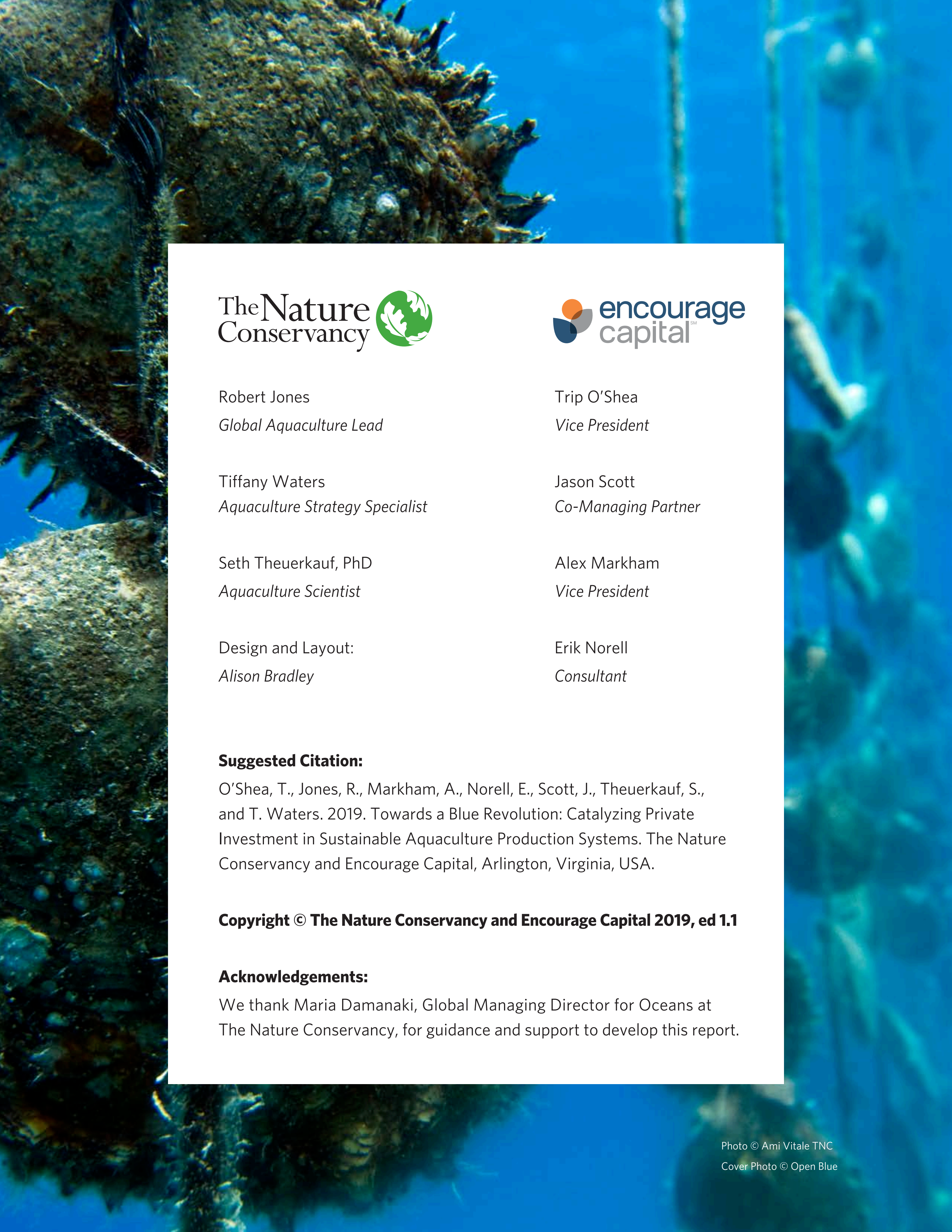
TOWARDS A BLUE REVOLUTION:

CATALYZING PRIVATE INVESTMENT IN SUSTAINABLE AQUACULTURE PRODUCTION SYSTEMS

The Nature Conservancy

encourage capital℠



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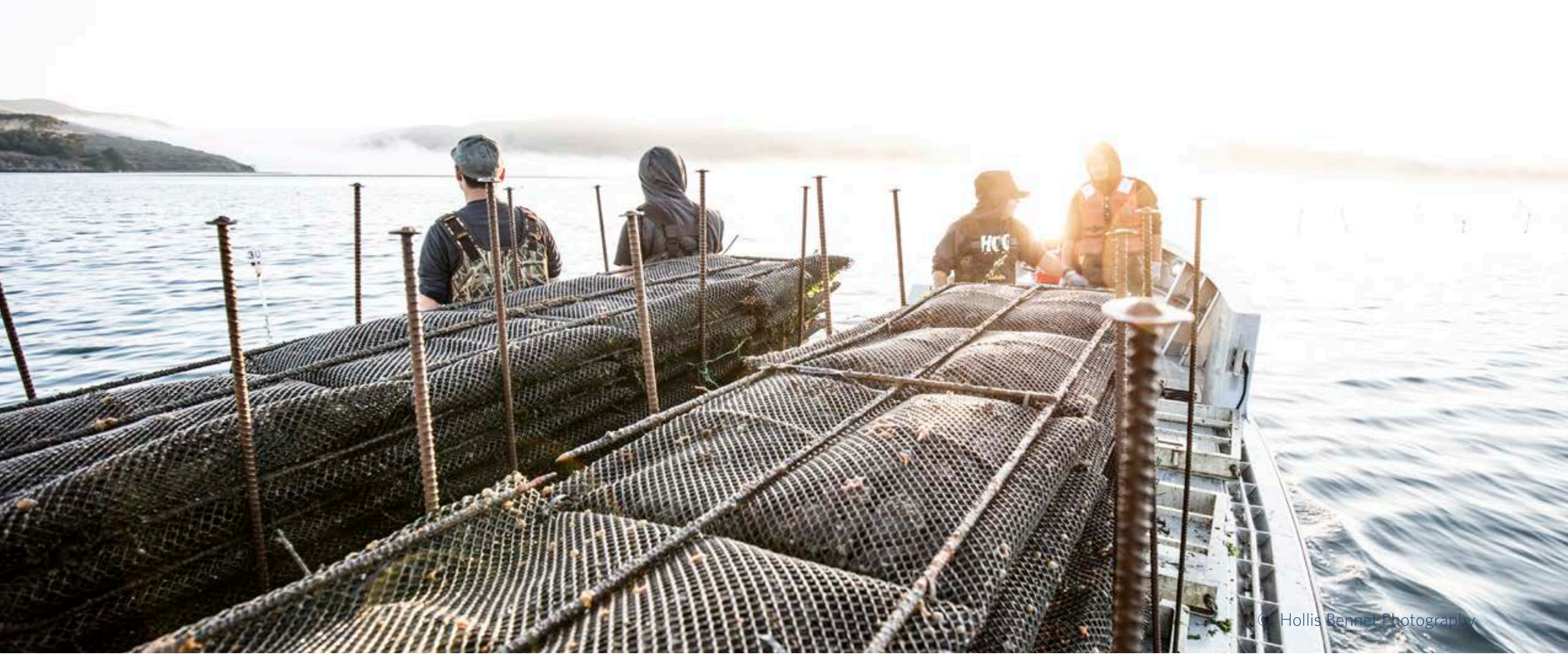
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Executive Summary

Done poorly, aquaculture can damage sensitive ecosystems, disrupt communities, and pose a threat to human health; done well, it can be a force for ecological and social good. Building on decades of science-based collaborative work, this report aims to guide investment into sustainable aquaculture production systems with the goal of transforming the sector to meet the growing demand for seafood in harmony with ocean ecosystems.

Aquaculture – the commercial production of finfish, shellfish and seaweed – is currently the fastest-growing form of food production on earth. Already a $243.5 billion industry, the rapid growth of aquaculture holds great promise to meet growing global demand for more sustainable forms of protein while protecting marine ecosystems. To date, however, conventional aquaculture production in some locations has outpaced regulation and has created significant environmental challenges in the process. Emerging aquaculture production systems have significant potential to meet growing global food security challenges and human nutritional needs with improved environmental performance.

The Nature Conservancy (TNC), a leading global conservation organization, and Encourage Capital, a New York-based impact investment firm, wrote this report to catalyze greater investment into more sustainable aquaculture, so the industry can meet its potential to deliver healthy, sustainable seafood to satisfy the rapidly growing demand. In doing so, aquaculture can create alternatives to wild caught fisheries and more resource intensive forms of land-based protein production while ensuring protection of marine ecosystems.

Towards a Blue Revolution: Catalyzing Private Investment in Sustainable Aquaculture Production Systems seeks to articulate the full scale and potential of this exciting sector to catalyze investment into aquaculture projects and companies that can deliver targeted financial returns and improved environmental performance over business-as-usual production. Conservative estimates suggest that by 2030, the aquaculture sector will require an additional $150-300 billion in capital investment to expand production infrastructure capacity to meet projected demand growth.[1] By directing large-scale, private and multilateral investment towards more sustainable production systems, we aim to drive investment into the aquaculture segments that offer the most potential for meeting growing global seafood demand in harmony with the marine ecosystems. By doing so, our aim is to unlock a true 'Blue Revolution.'

In this report, we explore investment opportunities specific to sustainable aquaculture production systems. While additional impact investment opportunities exist across the aquaculture supply chain and merit follow-on analysis, this report focuses on analysis of core production assets, which we view as a central component of a transition to a more sustainable aquaculture industry at scale. Investment in production infrastructure – with its high capital requirements and long asset life – will largely determine the sustainability paradigm followed by the industry over the coming decades, including the relative opportunities across the supply chain in areas including feed, animal welfare, services, genetics, and consumer products.

This report delves deeply into the three primary production systems that in our opinion bear the greatest potential for combined financial returns and improved environmental sustainability (See Figure ES.1, "Opportunity Set for Marine Aquaculture"):

1. On-land finfish recirculating aquaculture systems (RAS);
2. Offshore finfish aquaculture systems; and
3. Bivalve and seaweed aquaculture systems.

We chose to focus on investments in these aquaculture production systems because:

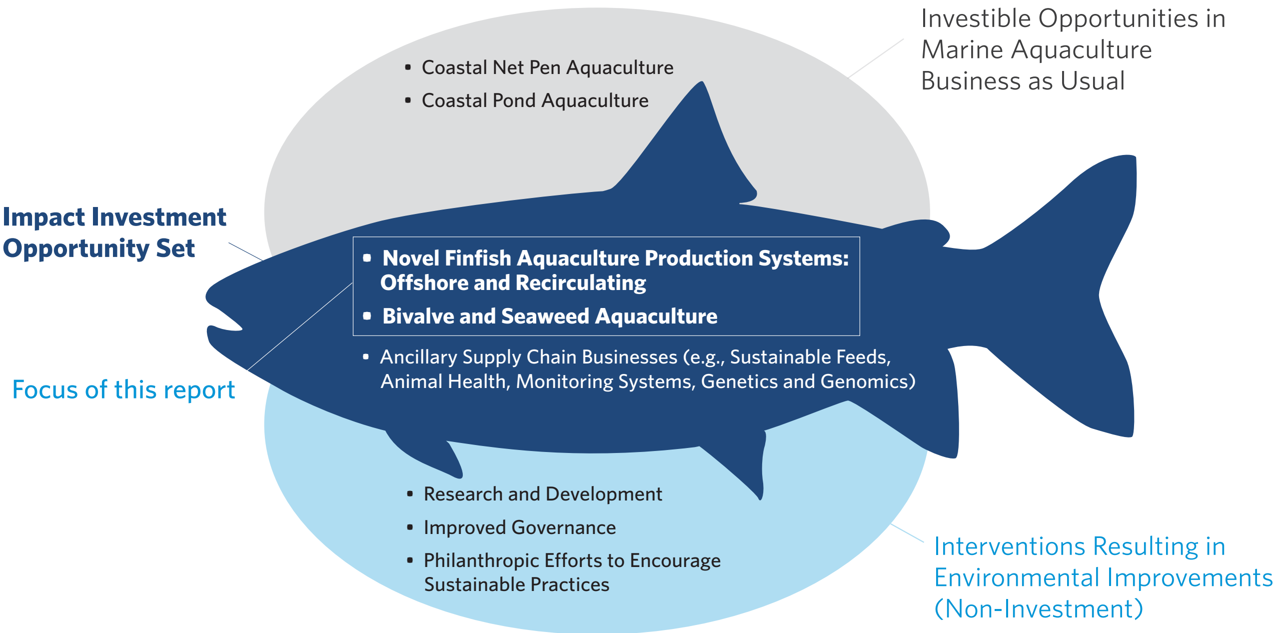
- **Evidence suggests they have improved environmental performance relative to business-as-usual production systems but have largely failed to attract private capital at a sufficient scale to reach their full commercial and impact potential.** Recirculating aquaculture systems and offshore aquaculture remain a small percentage of the aquaculture sector (Figure ES.2), while bivalve and seaweed aquaculture are falling short of their tremendous potential. ***Towards a Blue Revolution*** therefore aims to help investors better understand the operations, capital needs, industry context and potential environmental benefits of these systems in order to bring them to scale.

- **Private capital markets have historically been hesitant to finance RAS and offshore production systems because heavy capital expenditures are required, and risks have not been well understood.** While private investors of all types express growing interest in the aquaculture sector, many tend to shy away from capital-intensive investments such as RAS and offshore aquaculture, especially for technologies that are unproven at scale and for first time businesses implementing those technologies. Unlike more traditional real assets such as agriculture and forestry, or even project finance in sectors like renewable energy, investors have not been provided with an understanding of the risk-return characteristics of these relatively new aquaculture production methods. ***Towards a Blue Revolution*** provides a framework for evaluating these investments in the context of the broader aquaculture industry and offers recommendations for structuring transactions around some of the unique characteristics of these opportunities.
- **Despite the perceived risks and challenges faced when investing in aquaculture production, we believe there are ways to unlock compelling financial and impact returns by taking measures to optimize capital structures and mitigate operational risks.** After decades of prototyping and associated lessons learned, the production systems described in this report have reached a level of maturity where they are ready for investment capital at scale. These opportunities are by no means de-risked, and investors must as usual evaluate specific opportunities on their own merits, but years of operational data and experience from several geographies and species should provide sufficient guidance for investors to move into this space in a strategic and profitable way. ***Towards a Blue Revolution*** seeks to share available case studies and data, and outline lessons-learned to help better inform investors considering the sector to make investments more confidence in their ability to generate attractive financial return and positive environmental impacts.

Drying seaweed in Belize.

Photo © Randy Olson

Figure ES.1: Opportunity set for marine aquaculture



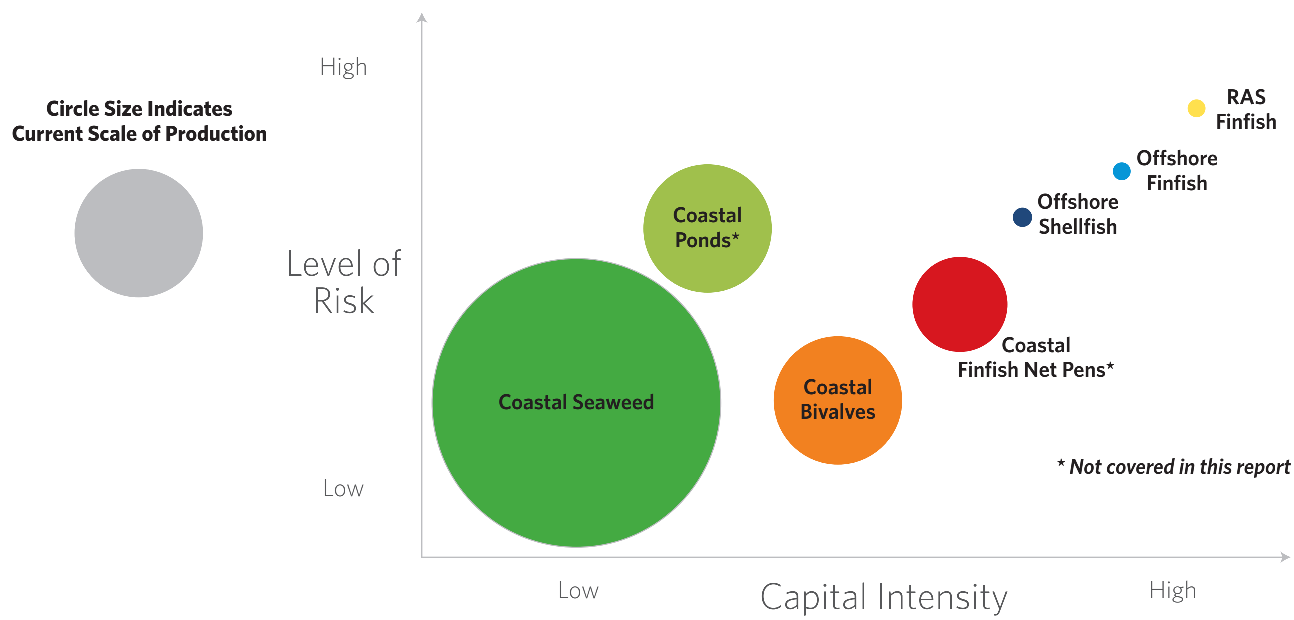
Part I of ***Towards a Blue Revolution*** identifies the major environmental challenges associated with business-as-usual production systems, describes the benefits of the focal aquaculture production systems of the report, and defines the impact thesis for sustainable aquaculture. Many of the prevailing aquaculture methods (e.g., traditional coastal net pens) can have significant negative impacts on wild fish populations, pollute the water column, and damage marine habitats when irresponsibly conducted. Investment in more sustainable systems and projects has been held back by a general lack of publicly available information, a lingering impression of outsized risks, limited consensus among industry stakeholders as to which opportunities qualify as both sustainable and commercially viable, and few widely adopted principles for sustainable investment and impact measurement. We believe that these barriers can be overcome. With ***Towards a Blue Revolution***, we endeavor to begin to remedy the outstanding issues through the following:

- Defining the sustainability, industry, and operational challenges that can be addressed through private investment in sustainable aquaculture;
- Providing commercial and conservation context on the aquaculture industry and supply chain, including risks, opportunities, challenges, and segments;
- Offering an investment thesis that identifies specific opportunities to positively impact marine ecosystems; and
- Identifying key barriers, outstanding questions, and opportunities for further analysis.

We explain the approach to this report, which evaluates the set of opportunities in aquaculture that are likely to result in attractive financial returns and improved environmental performance over business-as-usual by considering four factors: 1) Adherence to the impact thesis; 2) Environmental performance data; 3) Commercial performance data; and 4) Potential for disruptive innovation.

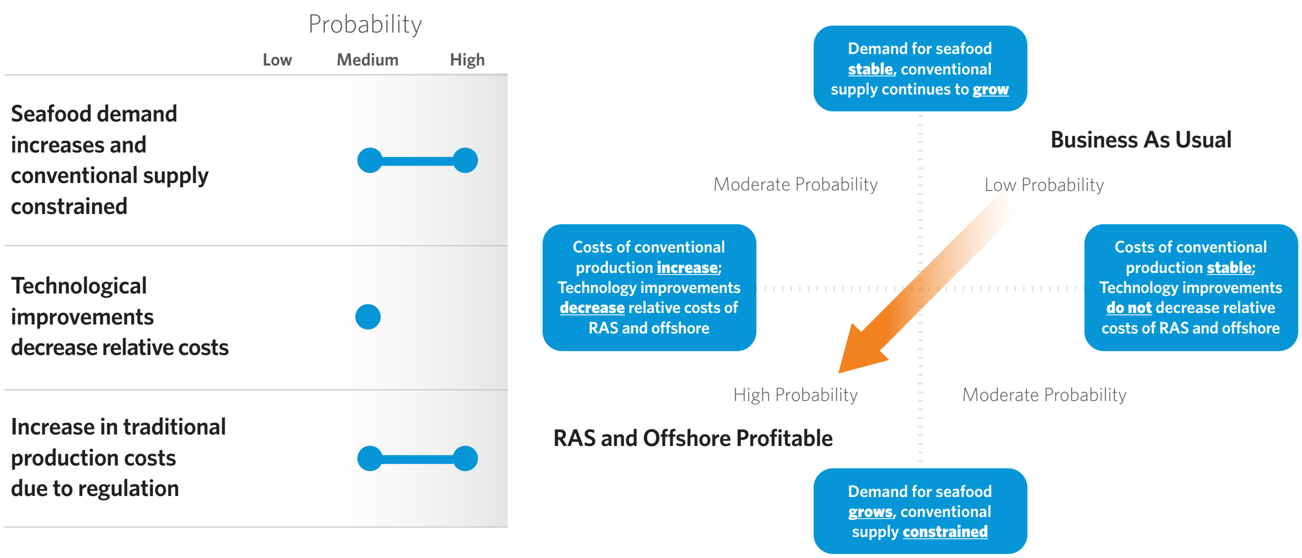
In **Part II,** we provide a market overview, which provides essential background and information on the marine aquaculture sector necessary to assess specific aquaculture investment opportunities. We provide a global seafood markets overview focused on descriptive statistics and trends associated with the aquaculture industry, explain the basics of aquaculture production system operations, and provide an overview of the firm-level economics of a typical aquaculture business.

Figure ES.2: Industry context: State of aquaculture industrialization – Risk and capital intensity



Macro-economic trends in the global seafood market generally demonstrate a favorable investment environment for aquaculture (Figure ES.3). Aquaculture is fast becoming a dominant part of global food production and a rapidly increasing share of the seafood industry by both volume and value, representing roughly half of all seafood produced for human consumption. Demand for seafood is expected to increase significantly both as the middle class expands in emerging economies and aging populations in developed economies seek to eat more seafood for health reasons. Fish prices demonstrate an upward trend and are expected to rise in nominal terms over the next 10 years. Aquaculture production predominantly occurs within Asia (nearly 90% of production), but, substantial growth is now developing in other regions, which tend to focus on higher price and quality products. We identify primary determinants of aquaculture production growth: market dynamics, strategic dynamics, marginal production drivers, biophysical variables, financing considerations, risk exposure and mitigation, and public policy and regulatory considerations, which can be used to evaluate aquaculture growth potential within a specific geography. We also identify key factors that influence demand: demographics and income growth, consumer tastes and preferences, predictability of supply, and food safety.

Figure ES.3: RAS and offshore finfish aquaculture industry profit drivers and probability of occurrence



Additionally, we provide an overview of upstream and mid-to-downstream operations for typical aquaculture operations. Key inputs affecting upstream operations include feed, labor, equipment, animal health services, distribution and logistics providers, and other ancillary support businesses. Midstream and downstream functions merge with those of the broader seafood market, including primary processing, distribution and logistics, value-added processing, and sales and marketing functions. We explain key production methods generally utilized for major species groups and identify rules of thumb for production cycle timelines in key phases including hatchery, nursery, and grow-out phases for species groups that behave similarly. We posit site selection as a key determinant of the operational and financial success or failure of aquaculture operations. Site selection is typically a complex process involving multiple interwoven factors, such as biophysical, economic, and existing use considerations. While still important, siting of land based-recirculating aquaculture systems may face fewer constraints than ocean-based facilities.

Offshore aquaculture cage.

Photo © Open Blue

We further provide an overview of firm-level microeconomics of a fish farm (Figure ES.3). Increased demand shifts, resulting in higher fish prices can facilitate higher cost farming strategies such as RAS and offshore aquaculture farms, making them more viable as they come to scale. We identify main components of an aquaculture operation's cost structure and provide information on a typical salmon farming operation. For most farming operations, feed is the most significant operational costs, at 30-50% of cost of goods sold (COGS). Cost per unit of fish production generally decreases with the scale of aquaculture businesses, but the relative share of mortality costs and animal health expenditures generally rise as production volumes increase for individual firms.

In Part III, we provide relevant strategic and investment analysis for the aquaculture sector by providing a Five Forces analysis of the aquaculture sector and an associated investment analysis. Our Five Forces analysis identifies a medium threat of new entrants, medium-to-high supplier power, high to very high buyer power, a medium to high threat of substitutes, and a medium to very high threat of competitive rivalry.

We identify 6 key operational drivers of aquaculture operations and detail their effects on revenue and costs of an aquaculture operation. These include:

1. Feed conversion ratio (finfish)
2. Growth rate
3. Stocking density
4. Normal mortality rate
5. Animal health and welfare
6. Product quality, consistency, and form

We provide publicly available financial statements on the salmon aquaculture sector, which can serve as a benchmark for comparison with RAS and offshore finfish aquaculture operations, although it should be noted these production systems have certain unique attributes. We reference unique financial accounting and performance-measure considerations necessary for analyzing aquaculture financial statements. We identify key debt financing options for farming activities: including secured and unsecured loans, project loans, and the unique challenges associated for each as they pertain to financing aquaculture projects.

We also identify several prevailing investment challenges that must be addressed to achieve greater investment in sustainable aquaculture production systems including:

- Matching risk with return and investment hold period in capital-intensive models;
- Financing early-stage R&D;
- Financing project development including addressing pilot plant risks;
- Information asymmetry and knowledge barriers in the aquaculture market; and
- Transactional friction of financing new types of assets.

Finally, we present a risk analysis matrix for new aquaculture ventures across key categories, which include project development and construction risk, technology risk, operating risks, commodity price risk, and obsolescent risk, with mitigating factors for each. A summary of these conclusions is highlighted in the following table:

Table ES.1: Aquaculture commercial risk matrix

	Mitigating Factors
Development Risk	Proper site selection, identification of high-quality management teams, and ample contingency funding
Construction Risk	Hire engineering, procurement and construction contractor with experience in aquaculture, pay for strong insurance against execution milestones
Technology Risk	Hire diligence team experienced in specific related aquaculture technology, investment in robust evaluation of pilots
Operating Risk	Management and technical expertise, emergency planning, analytics and monitoring
Commodity Price Risk	Underdeveloped: long-term supply agreements, offtake agreements, product differentiation and branding, species selection, geographic diversification, and scalable system designs
Obsolescent Risk	

Relative Negative Impact on Project Success: Low, Medium, High

According to our analysis, greenfield (early stage) project development risk and commodity price risk represent the greatest risks associated with aquaculture businesses, each with a high probability of occurrence with medium-to-high severity. We argue that early stage development risk can be mitigated through proper site selection, identification of high-quality management teams, and ample contingency funding. Operating risk can similarly be mitigated through carefully selected management teams and technical employees, well designed systems that provide contingencies in the event of emergencies, and use of real time analytics and monitoring technologies. While opportunities to mitigate commodity price risk remain underdeveloped for aquaculture, mitigating factors that can be pursued include long-term supply agreements, offtake agreements, product differentiation and branding, species selection, geographic diversification, and system designs that allow for modular scaling and optionality to cultivate multiple species as market conditions demand.

We conclude by identifying three enabling conditions needed for increased sustainable aquaculture investment:

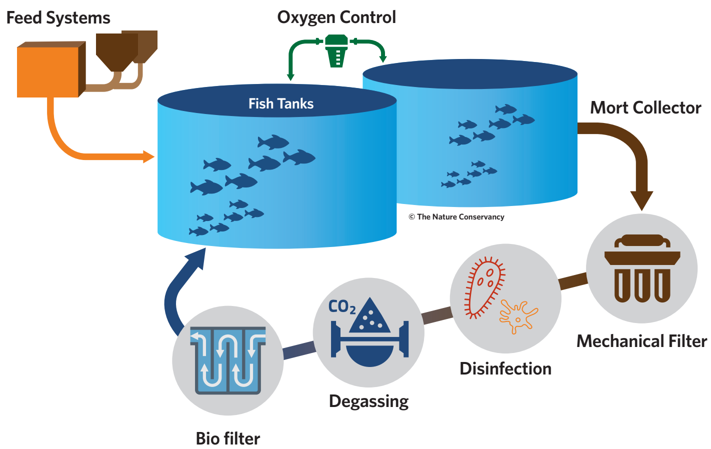
1. Defining, aligning and refining government policies;
2. Supporting sustainable innovation and pipeline cultivation; and
3. Establishing a set of commonly accepted principles for responsible marine aquaculture investment and industry benchmarking tools.

In Part IV, we provide impact opportunity profiles that show how private capital can drive a market-based transformation of the aquaculture sector through investment in these types of high-impact productions systems while delivering commercial, risk-adjusted returns. We analyze RAS, offshore finfish aquaculture, and bivalve, and seaweed marine aquaculture in depth.

For recirculating aquaculture systems (RAS) we find that:

- By decoupling fish production from the marine environment, RAS systems may offer an alternative to traditional, coastal net pen (CNP) finfish production with better environmental performance, higher production capacities per unit area, reduced mortality, and greater control over production outcomes.
- RAS systems generally offer reduced impacts to wild stocks, habitats, water pollution, and disease transfer relative to business as usual CNP production when best practices are implemented. However, RAS systems are not without environmental tradeoffs: they may result in increased energy usage, water usage, and land usage compared to CNPs.
- The large integrated salmon producers have invested heavily in developing RAS technology to raise juvenile fish to larger sizes before transferring them to net pens in nearshore environments for outgrowth.

Figure ES.4: Indicative RAS schematic



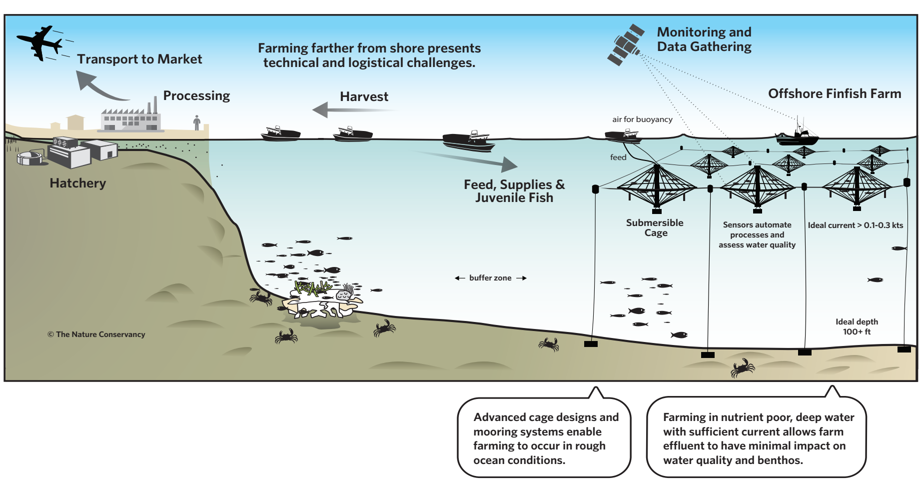
- The promise of full life-cycle, egg-to-harvest large-scale (>5,000mt) RAS production has remained elusive. A legacy of failed projects, high capital requirements, a lack of experienced operators, and unproven economics at scale has left many investors and industry players skeptical until recently.
- A new class of entrepreneurs and investors have been attracted to the RAS segment by a range of favorable trends, including regulatory challenges limiting CNP supply growth, high and growing market prices for key species like salmon, rising costs of animal health and disease prevention in CNP systems, and improvements in RAS operational knowledge and system design.
- Our view is that the sector will remain risky in the short-term, but not prohibitively so in all cases. Selective, knowledgeable investors with a higher risk tolerance may find compelling opportunities to be early movers in the space with opportunities to invest at a discount in strong projects that have highly experienced management teams.
- RAS may be most attractive in geographies with large local markets for seafood by minimizing air freight costs relative to CNPs and in regulatory environments that do not allow for expansion in CNP aquaculture.
- RAS systems for Atlantic salmon may be the closest to achieving economic viability, but other species also show potential. Appropriate engineering, systems design, and skilled management teams are essential to advancing beyond Atlantic salmon.

For offshore aquaculture systems, we find that:

- Offshore aquaculture can provide environmental performance advantages relative to traditional CNP aquaculture, including reduction of effluent and habitat impacts, and is likely to constitute an important subset of overall sector growth.
- Improvements in Feed Conversion Ratio (FCR), improved disease control, and reduced genetic interactions with certain species have in some cases been associated with offshore aquaculture, although additional studies are warranted.
- Offshore aquaculture can provide significant commercial performance advantages, including the potential for larger scale, automation of processes, and new species cultivation; improved water quality, site availability, proximity to markets, and product quality; and reduced user conflicts and unit costs.

- Most commercial-scale offshore projects have come online during the past 5 years.
- Two categories of offshore aquaculture producers have emerged: subsidiaries of large, vertically integrated, diversified incumbents from the salmon industry (predominantly in Norway); and small independent newcomers with business models dedicated to offshore technology and farming of niche species that do not compete with conventional producers.
- Large incumbent offshore leaders from the Norwegian salmon industry have accelerated technology development and validated offshore aquaculture more broadly. Such producers are backed by experienced operators that have dedicated substantial R&D resources to invest into new, mega-scale technologies. Most Norwegian producers have a salmonid focus, receive design input from offshore oil and gas sector, and are incentivized by a government program granting free development concessions.
- Independent offshore producers are relative newcomers, not diversified with conventional production, often emphasize the sustainability aspects of their production, and are generally based in Latin America. Newcomers specialize in niche species and have received private financing rather than institutional investment due to their lack of operating history and thin balance sheets.
- Concerns over limited nearshore sites, environmental sustainability, and food security have also led to new, state-sponsored development projects in China. Other countries exploring the potential for offshore aquaculture include the United States, Japan, and Indonesia, although few active operations exist.
- Due to relatively high capex requirements for offshore production, the complexity of deep-water operations, and regulatory uncertainty, early movers must be highly risk tolerant as they seek to prove commercial viability at scale.
- Promising private investment opportunities may exist for operations with phased development plans, proprietary technologies, vertical integration, or other strategic advantages. Knowledgeable private investors with long investment horizons and higher risk thresholds may find reasonably priced opportunities as early movers in a sector that remains uncrowded.

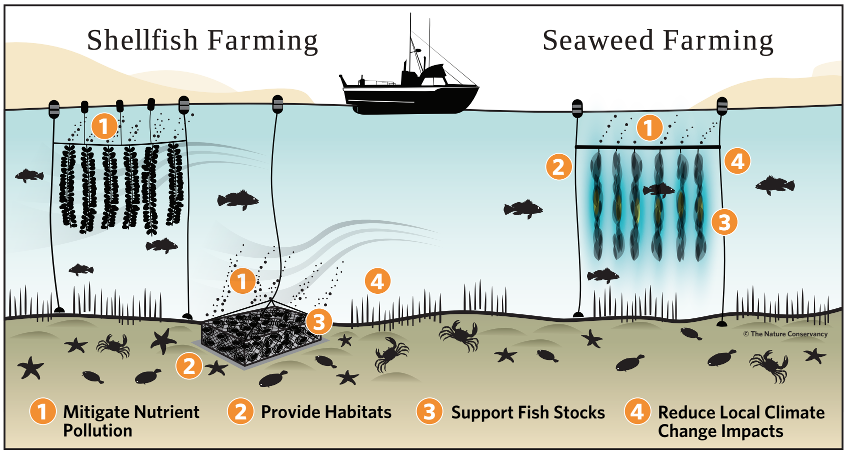
Figure ES.5: Representative offshore finfish aquaculture facility



For bivalve and seaweed production, we find that:

- Coastal bivalve production and seaweed aquaculture offers the clearest environmental value proposition, as shelled mollusks and cultured seaweed have low input requirements, and in some cases provide environmental benefits to surrounding ecosystems.

Figure ES.6: Environmental benefits of bivalve and seaweed aquaculture[2]



- Bivalves are currently predominantly produced in temperate geographies with production dominated by China, and robust industries in most other continents. There may be growth potential for development in tropical waters and potential for new species development in many regions.
- Seaweed aquaculture production is primarily limited to Asia and modest production in Africa. Significant potential may exist to extend seaweed farming to other geographies and for new species.
- China is a significant player in bivalve and seaweed industries as a producer, importer, and exporter and will continue to be a major and expanding market.
- Interest is growing for new applications of seaweed in biopolymers, cosmetics/nutraceuticals, animal feeds, and energy, which may demonstrate higher risk, but potentially higher reward investments.
- Bivalve and seaweed production remains highly fragmented and product value varies significantly across product, form, and markets; however, this presents an opportunity for investment and aggregation.
- Low inputs and low fixed costs can make the economics of both bivalve and seaweed production attractive. Strong growth and favorable market characteristics enhance the case for investment in the bivalve industry.

In Part V, the conclusion of ***Towards a Blue Revolution***, we discuss the potential for private and multilateral investment into sustainable aquaculture, and the importance of investment in aquaculture production to drive improvements in the sustainability of the sector. **We provide the following recommendations to drive more investment into the industry:**

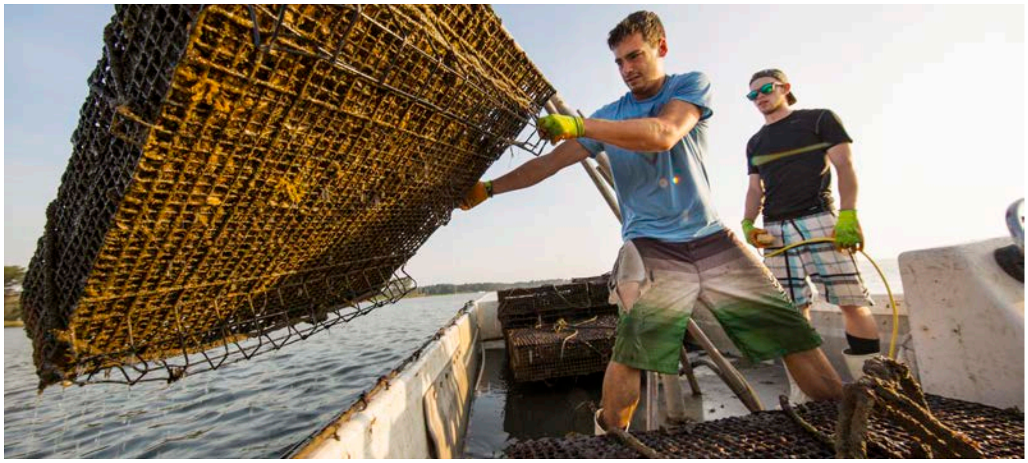
- **For Private, Commercial Investors:** We believe there is a mistaken perception among investors that novel, more sustainable production systems are riskier than they are, but in fact these models bear significant potential to deliver market-rate risk-adjusted financial returns. We argue that by framing aquaculture projects as a hybrid of a real asset and an operating company, investors can better manage their risks and returns. We recommend three strategies for investors pursuing sustainable aquaculture transactions:
    - **Seek equity upside for debt investments.** For example, private credit funds, financing companies, families or other debt providers with in-house project finance experience as well as relevant operational and industry expertise can make debt investments with equity warrants or options to capture the financial upside potential of investing in project sponsors.
    - **Secure concessionary capital alongside market rate debt sources.** For highly innovative, early stage, or proof-of-concept models, commercial investors can seek blended capital or concessionary sources (e.g., loan guarantees, credit enhancements or below market rate debt) from foundations, impact investors, mission driven families, governments and multi-lateral institutions to reduce commercial risk.
    - **Invest equity in project sponsors/operating companies alongside debt.** To maximize the financial returns for the given risks, investors can also invest in the equity of the companies operating the plants alongside providing debt. Providing relatively small equity investments alongside debt to fund the companies developing or operating the production facilities provides strong potential for financial upside and also ensures that often under-capitalized operators have the financial resources to see their projects through to profitability.

Atlantic salmon farmed in Tasmania at Queen Victoria Market, Melbourne, Australia.

Photo © Robert Jones

Young watermen at Rappahannock Oyster Company in Topping, Virginia.

Photo © Jason Houston



- **For Entrepreneurs and Companies:** Much as investors should be mindful of structuring considerations, entrepreneurs and companies can also take measures to enhance the investability of their projects and companies. For example, sustainable aquaculture projects can build in upside opportunities for companies and investors through structures that allow for capital expenditures to be paid for with debt or debt-like instruments with warrants or options attached, leaving equity available for other operational needs. We outline the following steps for companies to consider when seeking financing:
    - Finance the core capital expenditure investments needed to build prototypes, demonstration plants or full-scale operating facilities through a traditional debt-financed real asset model;
    - Build in upside for investors by offering the opportunity to invest equity in an operating company (OpCo) that represents the project developer or sponsor. This equity can be used to finance management, product development, marketing and other operating costs of the OpCo; and
    - Maintain optionality to pivot to new business models, products/species or financing strategies by raising enough capital to meet key milestones and seeking maximum operational flexibility.

- **For Impact Investors including Multilateral Institutions:** Impact investors can help to catalyze broader capital investment into sustainable aquaculture production systems by financing demonstration projects, prototypes, and R&D. Success of these pilot initiatives will eventually mobilize more risk-averse mainstream capital providers who can then replicate these efforts and take them to scale. We have seen this cycle of mission driven capital combined with concessionary sources of investment drive a transformation of the energy

In-water seaweed farming training of fishing groups from across Belize

Photo © Seleni Cruz

sector with impact investors leading the way in wind and solar, followed by more mainstream capital to follow at much greater scale. The same is now happening in biomass, energy storage and other emerging technologies. In addition, impact investors can help to define principles for sustainable aquaculture production and corresponding impact metrics. Finally, while most impact investors have to date focused on equity-investment strategies, development of specific debt or debt-like vehicles for sustainable aquaculture could provide critical additional financing to support innovative, capital intensive sustainable production systems where commercial bank financing is often challenging to secure.

- **For Philanthropists, Policymakers, and NGOs:** These groups should seek to help identify and cultivate the enabling conditions that will allow investment at scale and guide it in a more sustainable direction. Initiatives to this end should focus on the following areas:
  - Designing protective, transparent, and effective permitting processes and regulations;
  - Establishing clear property rights and resource tenure;
  - Promoting development of enabling infrastructure to support industry development;
  - Providing programs to promote sustainable innovation; and
  - Developing public financing mechanisms.

In conclusion, we believe that proper, targeted, and, in some cases, coordinated interventions between these stakeholder groups could usher in a much-needed Blue Revolution that would provide healthy protein to the world in a responsible and environmentally friendly way while generating compelling returns for investors. Transforming how we produce seafood through strategic investment in innovative, more sustainable production methods will be key in promoting a healthy, abundant, and profitable food system rather than one that degrades the environment, destroys value, and fails to meet the growing food security challenge.

Table ES.2: Impact investor considerations for RAS, offshore, bivalve, and seaweed aquaculture

	RAS	Offshore	Bivalves and Seaweed
Core Investment Thesis	• Significant cost savings (particularly with freight of fresh products) by locating production closer to demand centers • Fewer biological risks (e.g., disease/ parasite issues) relative to farming at sea • Lower environmental compliance and permitting costs relative to traditional farming at sea	• Offshore offers an opportunity to extend aquaculture production to regions where there is less competition for space and potential for conflicts • Scale advantages to help amortize higher capital and operating costs which will likely remain higher than net pens or onshore for the foreseeable future • Potential to site production closer to market	• Already profitable at smaller project sizes with significant financial upside to scaling • Proven production methods with many skilled operators and potential expansion to new species and regions • Large and diverse market opportunity for both globally
Impact Thesis (Environmental)	• Physically separating aquaculture from the marine environment and advanced water treatment technologies results in limited or no interaction with the sensitive ecosystems or species, and reduced water pollution impacts • Improved ability to control culture environment, which can improves feed conversion ratio (FCR) and reduced need for antibiotic use	• Location in deeper, higher water flow areas minimizes or negates impact on sensitive habitats and species • Cleaner offshore water can allow fish to grow more efficiently, improving FCRs. Improved gear may result in lower escapement in some cases and reduced entanglement risk • Lower water pollution impact due to better flushing by currents and farming in low nutrient environments • Potentially lower disease transfer risk both between farmed species and to wild species	• Represent the clearest environmental value proposition given they: • (a) possess the lowest input requirements of any aquaculture production model, and • (b) can provide ecological benefits to surrounding ecosystems in the form of water filtration, nitrogen removal, and habitat provision
Key risks/ challenges	• Few successful models at scale and high capital intensity • High development, construction, and operational risk due to systems complexity • Technology risks compounded by challenges of adapting to new species or significant scale-up • Higher risk of binary/catastrophic loss or mortality • Biological challenges (e.g., early maturation) associated with trying to artificially mimic natural systems • Necessity for higher stocking densities to produce competitive unit economics • Challenges with water access and waste discharge permitting • Customer perception as "unnatural" vs in-water farms or wild-capture	• Further distance from shore increases production costs and risks • Few experienced offshore operators with track record of success • Lack of suitable governance frameworks in most jurisdictions to license and regulate offshore production	• Production amounts and operation sizes have been small • Permitting and regulatory constraints for production at scale • Mortality risk from predation, disease, and temperature changes due to at-sea exposure

Table ES.2 (continued): Impact investor considerations for RAS, offshore, bivalve, and seaweed aquaculture

	RAS	Offshore	Bivalves and Seaweed
Risk mitigation	• Operational track record • Management team with deep experience with RAS production with specific culture species • Modular systems allowing for phased project development and system redundancy in case of failure • Technology validation via subscale demonstration projects • Ensure high-quality water source • Use of hedging mechanisms and long-term offtake contracts • Backing of local and national government entities • Proximity to major high-value markets	• Operational track record • Strong, experienced management team • Technology validation via subscale demonstration projects • Use of hedging mechanisms and long-term offtake contracts • Favorable regulatory jurisdiction with defined policy framework • Backing of local and national government entities • Proximity to major high-value markets	• Operational track record • Strong, experienced management team • Strategy to achieve scale • Market proximity • Vertical integration and value-added downstream operations
Unlevered IRR Hurdle[i] [3]	20-35%+ (depending on project stage and track record)	20-35%+ (depending on project stage and track record)	10-15%
Average capex/kg[ii]	**Small-Scale Projects (< 2,500mt):** $16.00 - $24.00 per kg **Large-Scale Projects (> 5,000mt):** $8.00 - $12.00 per kg	**Small-Medium Scale (< 5,000mt) Offshore Cage Farms:** $4.00 - $9.50 per kg **Large-Scale, High-Tech Norwegian Development License Farms:** $6.50 - $20.00 per kg	$20 - $60 per bushel (depending on scale, species, equipment type, and location)
Role of Concessionary capital	Subsidize technology R&D and prototyping of new species production and underwriting first plant risk	Subsidize technology R&D and underwriting first plant risk	Provide inexpensive debt for scale up of smaller production efforts
Leading Producers (current and projected)	European Union, Norway, USA, China (projected), Singapore (projected)	Mexico, Japan, Norway, Panama, China (projected), Turkey (projected)	Bivalves: China, Chile, Japan, South Korea, Peru, New Zealand, Taiwan, USA, European Union Seaweed: China, Indonesia, Phillipines, Korea, Japan
Primary species	Atlantic salmon (particularly smolt production), Yellowtail, Seabass/bream	Atlantic salmon, Cobia, Yellowtail, Snapper	Oysters, clams, mussels, scallops, and seaweed (many species of each)
Current Level of Investable Deal Flow	High	Medium	Low

[i] Based on investor interviews, market comparables, and academic research.

[ii] Compiled from estimates by DNB markets, Deloitte, Pareto Securities, interviews with investors, company materials, and reporting by IntraFish Media.

Part 1: Introduction

The global food system is reaching a critical inflection point. Despite massive gains in scale and efficiency over the past 60 years, exemplified by the Green Revolution in agriculture, food production is surpassing the ecological limits of the planet. The bill is now coming due, with spillover effects that include biodiversity loss, freshwater scarcity, polluted watersheds and coastlines, desertification, drought, and climate change. The process of feeding 7.6 billion people accounts for 70% of global freshwater consumption[4] and approximately 25% of greenhouse gas (GHG) emissions, the latter primarily from agriculture and deforestation. Most of these impacts stem from growing the animal proteins demanded by a rapidly expanding population.

Despite our unprecedented resource consumption, 800 million people—nearly 11% of the world's population—remain hungry. As many as three billion people rely on seafood as a primary source of protein.[5] Wild fisheries production peaked in the 1980s; overfishing and climate change are now leaving some fisheries dependent communities increasingly food and nutritionally insecure.[6]

To feed a projected population of 9.7 billion people in 2050, food production must increase by as much as 70%.[7] A large proportion of this increase will come from animal protein demanded by an anticipated three billion new middle-class consumers. Sustainably meeting this demand will include growing more seafood with less impact on natural systems. If the global food system is to meet this challenge without imposing untenable environmental costs, the seafood sector—and aquaculture in particular—will have a critical role to play. The time is ripe for a Blue Revolution that will expand seafood production in harmony with marine ecosystems.

The Benefits of a Blue Revolution

New research suggests that aquaculture can contribute to an environmentally and socially beneficial global food system. Below we describe several key benefits of a Blue Revolution in seafood production:

- **Resource-use efficiency:** Aquaculture can have a lower environmental footprint than most meat production in terms of freshwater use, CO_2 emissions, and land usage. For example, salmon aquaculture operations have a feed conversion ratio (FCR) close to 1.0 i.e., it takes approximately 1 pound of feed to produce 1 pound of weight gain. By contrast, chicken, pork, and beef have feed FCRs of about 2, 4, and 8, respectively.[8] Additionally, the commercial cultivation of aquatic plants and bivalve shellfish requires no external feed and can, in some cases, have beneficial effects on marine ecosystems.
- **Sustainable supply:** Over a third of wild fish stocks are fished beyond sustainable limits.[9] Aquaculture represents an alternative method of producing seafood, that potentially avoids certain ecological risks associated with wild-capture fisheries, such as bycatch.
- **Limited land use:** Land-based crops face uncertainties resulting from climate change including changing precipitation levels, rising sea levels, and higher temperatures, which may lead to increased droughts and decreased freshwater resources.[10] Marine, freshwater, and even land-based aquaculture represent food production models that can use scarce natural resources in more efficient ways.
- **Food security and nutrition:** Among animal protein sources, seafood is among the healthiest for human consumption. Seafood provides a healthy alternative to beef and pork and is a necessary source of nutrition, long-chain omega-3 fatty acids, and micronutrients.[11] These benefits may be particularly important in developing countries, for maternal health, and in early childhood development.
- **Supply chain management:** The controlled nature of aquaculture production can allow for improved traceability, logistics, inventory management, product uniformity, demand response, and product quality, compared to wild-caught seafood.[12] Innovative novel farming technologies also offer the potential to grow seafood close to end markets while limiting deleterious impacts to marine ecosystems.

Major Environmental Challenges Associated with Aquaculture

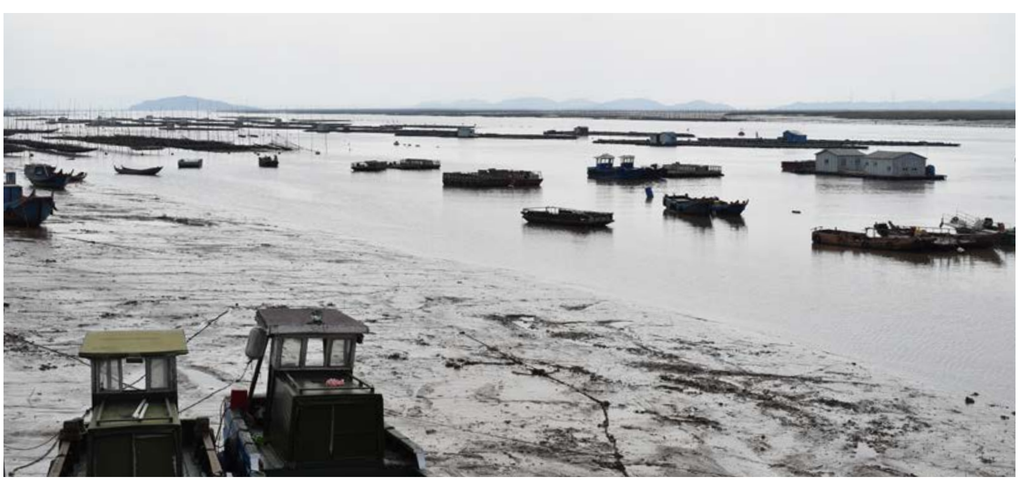
Over the past 30 years, aquaculture has grown rapidly to a $243.5 billion industry.[13] With aquaculture's rise there have been, and continue to be, major negative impacts to natural systems. In many cases, these effects have decreased over time (per unit of seafood production), but investors, producers, and other stakeholders must address the following challenges in order to realize the potential of the Blue Revolution:

Habitat impacts: Mismanaged aquaculture facilities have historically led to habitat degradation. The use of coastal ponds for shrimp aquaculture, for example, has resulted in large-scale removal of mangrove forests in some locations. Traditional aquaculture, such as coastal net pen (CNPs) and coastal pond aquaculture, can present a risk to corals, temperate reefs, or seagrasses through habitat destruction or water quality degradation if improperly sited or managed.[14] Shellfish and seaweed aquaculture can also have detrimental effects on submerged aquatic vegetation or other habitats.

Water pollution: Some aquaculture farms can create negative impacts on water quality when fish waste or undigested feed is released into surrounding areas—contributing potentially as much as 2% of anthropogenic nitrogen entering natural waterways.[15] The effect can be severe when farms are in water bodies already affected by eutrophication.

Impacts to wild stocks: Aquaculture can affect wild fishery resources negatively in several ways. If cultured species escape aquaculture facilities, they can compete with wild organisms for forage and, when reproduction is possible, impact wild stock genetics.[16] In addition, many farmed fish utilize wild fishmeal and fish oil in feed formulations, creating demand for wild fisheries resources[17] which are already under immense pressure.

Disease: Aquaculture facilities can be a vector for pathogens and affect wild populations. Sea lice, a parasite in the farmed salmon industry, for example, can negatively impact native salmon populations.[18]



Unsustainably sited farms exceeding natural carrying capacity have caused environmental damage.

Photo © Robert Jones

Impact Capital Can Help Transform Aquaculture

Aquaculture is poised to continue to grow rapidly. This expansion will either result in undue environmental and social consequences or coincide with a shift toward innovative and transformative production systems that operate in harmony with local ecosystems and communities. The outcome will depend on which production methods, practices, and species are scaled, and upon the location and intensity of the expansion. Realizing the full potential of sustainable aquaculture will require an unprecedented level of innovation, knowledge transfer, and system-level transformation.

To achieve the promise of a Blue Revolution, the right kind of investment will be critical. At the outset, concessionary capital will be needed to help catalyze and incubate innovative technologies, lower origination costs, and support new production methods as they scale. Unfortunately, the level of investment today is not commensurate with the need or the opportunity. Several factors have generally inhibited concessionary capital deployment in aquaculture:

- A general lack of publicly available information on investment opportunities or aquaculture innovations and technology;
- A lingering impression of outsized business and environmental risks resulting from well-publicized failures in the early days of the aquaculture industry;
- A lack of consensus among industry stakeholders as to which opportunities qualify as both sustainable and commercially viable;
- A lack of clarity on sustainability principles and impact metrics that can help investors quantify 'environmental returns.'

Actions can be taken now by investors, foundations, philanthropists, non-governmental organizations (NGOs), aquaculture producers, and governments to address these barriers and unlock aquaculture opportunities. These actions will affect the health of marine ecosystems, the broader environment, and the global population for decades to come.

Purpose and Audience for this Report

This report provides investors, foundations, philanthropists, the NGO community, and aquaculture producers a common understanding and logical framework for determining how private capital investment can best be deployed to accelerate sustainable systems change while achieving attractive returns.

To this end, the report aims to achieve the following:

1. Define the sustainability, business, and operational challenges that can be addressed through investment.

2. Provide context on the aquaculture industry and supply chain, including risks, opportunities, challenges, and segments, with both a commercial and conservation lens.
3. Offer an investment thesis that identifies specific opportunities that can positively impact marine ecosystems.
4. Identify key barriers, outstanding questions, and opportunities for further analysis.

This report discusses "sustainable production systems" with reference to environmental and conservation impacts and benefits. However, there also exist significant social challenges associated with aquaculture, particularly human rights abuses such as labor exploitation and trafficking.[19] Although not the focus of the report, investors and other stakeholders must work to ensure labor rights, gender equity, and safe working conditions within aquaculture supply chains.

This report is a first step in what we hope will be a continuing process of debate and consensus-building among relevant stakeholders. Our objective is to provide information that will help catalyze private capital investment in transformative, highly scalable opportunities across the aquaculture sector. Ultimately, we seek a Blue Revolution, which will result in a sustainable supply of healthy, low-impact protein, sufficient to nourish the world population through 2050 and beyond.

Greenlip mussel line with blue mussels and seaweed in Blenheim, New Zealand.

Photo © Tiffany Waters

Impact Thesis: How We Will Get There

There are two ways to achieve positive conservation outcomes for marine ecosystems through development of a sustainable aquaculture sector:

1. Reduce the negative environmental impacts of current and future aquaculture operations through innovative technologies and production systems; and
2. Increase well-managed bivalve and seaweed aquaculture production to deliver positive environmental benefits.

For investment in aquaculture to drive positive conservation outcomes, it must support operations and innovations that coincide with one or both outcomes.

Methodology

Approach

The goal of this effort is to identify the set of opportunities in aquaculture that advance marine conservation while also being commercially attractive to private capital investors. **To identify opportunities for further exploration and analysis, we considered four factors:**

1. **Adherence to the Impact Thesis:** Opportunities must employ one of the two criteria of the impact thesis identified above.
2. **Environmental performance:** We reviewed environmental performance of aquaculture production systems, species, and methods.
3. **Commercial performance:** We identified key commercial criteria that determine the attractiveness of various aquaculture opportunity areas (e.g., production methods, species) and provide case studies of existing businesses. As public data are limited within the sector, we relied upon interview and private information to inform our findings.
4. **Potential for disruptive innovation:** Recognizing the urgent need for transformation in the aquaculture industry, we prioritized production methods with the potential to substantially reduce environmental impact at scale.

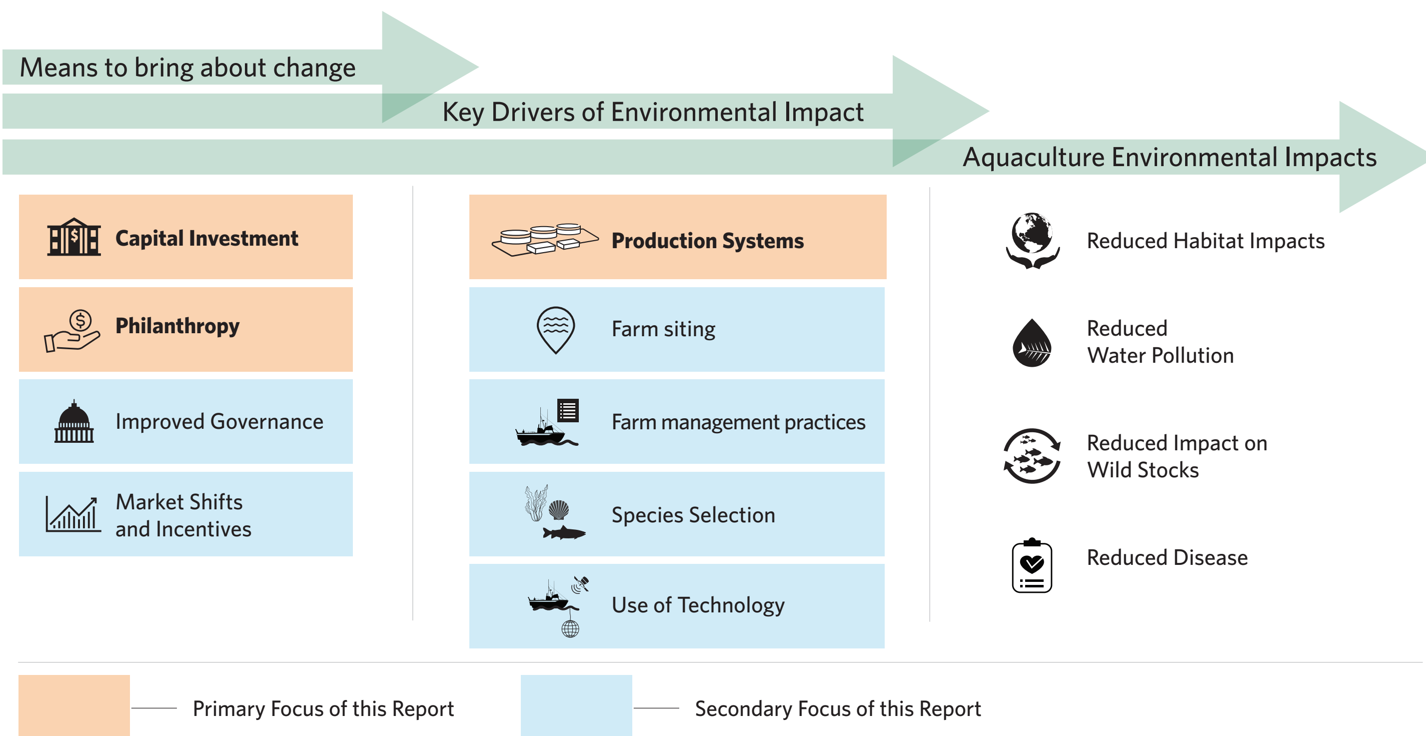
Scope

We focus on the production systems of marine, coastal, and land-based aquaculture, specifically RAS, offshore, and bivalve and seaweed aquaculture production systems. We recognize, that production systems are just one determinant of the environmental impact of an aquaculture operation, along with farm siting, farm management practices, species selection, and the use of technology. These other factors, while discussed throughout the report, are not the central focus. We also recognize that the utilization of inputs such as feed represent a significant driver of finfish aquaculture's marine ecosystem impacts, but we intend to address these other supply chain links in a separate analysis. Downstream business activities are also excluded. This report also does not presume any material changes to public policy.

We identify commercial investment opportunities that are likely suitable for a broad range of investor types, including venture capital, real asset investors, and natural resource investors. The report includes a range of concessionary investment opportunities that would appeal to impact-first investors, development finance institutions, and foundations in either a blended-capital or standalone context. Opportunities that would require long-term subsidization from concessionary capital are excluded (Figure 1.1).

While not within the scope of this report, we recognize that under certain conditions traditional production systems, such as coastal net pen (CNP) aquaculture, can be responsibly managed. The report does not investigate investment opportunities that would yield improvements in traditional aquaculture systems, although they may represent bona fide impact investment strategies. For information on current work and metrics to improve the sustainability and traceability of traditional production systems and certified aquaculture farms, reference global aquaculture certification programs (e.g., Global Aquaculture Alliance's Best Aquaculture Practices, Aquaculture Stewardship Council's farm standards).

Figure 1.1: Aquaculture impacts, drivers, and methods of influencing change



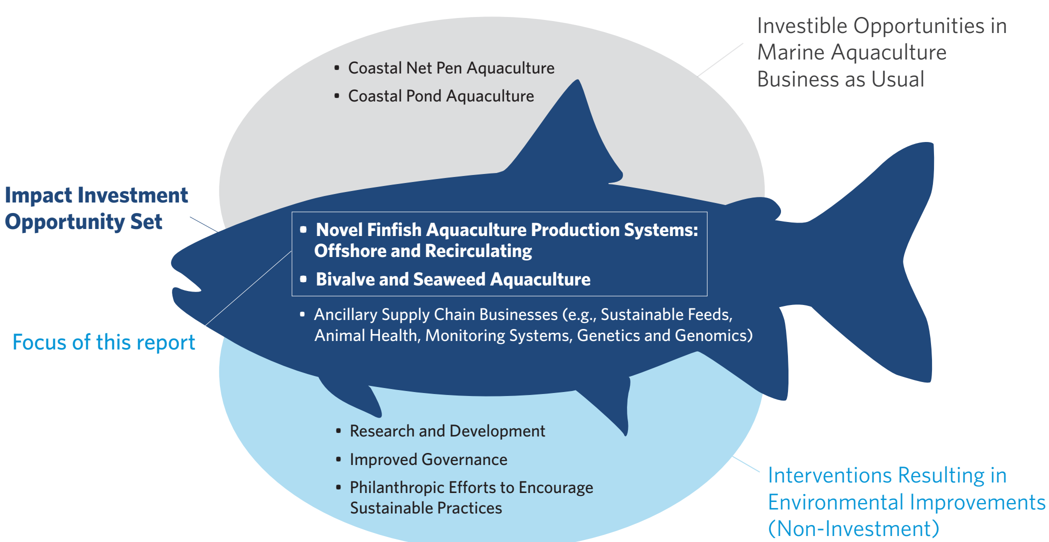
Opportunity Set Explored in This Report

The opportunity set (Figure 1.2) selected for further analysis consists of novel finfish aquaculture production systems and bivalve and seaweed aquaculture.[i] We evaluated the landscape of innovative novel farming systems with demonstrated potential for low-impact, resource-efficient production at an industrial scale. **The following opportunities are analyzed in depth in the sections that follow:**

- Land-based finfish recirculating aquaculture systems were selected because they have potential to reduce impacts to marine habitats and wild stocks, minimize water pollution and disease impacts, and reduce the likelihood of escapes through physical decoupling of the production system from the marine environment.
- Offshore finfish aquaculture systems were selected as they have potential to reduce the environmental risks to sensitive, shallow-water coastal and estuarine habitats associated with traditional coastal net pen aquaculture. Water pollution and marine habitat impacts can be reduced through location in deeper, faster moving offshore ocean waters.[20]
- Bivalves and seaweed aquaculture were selected due to their low input requirements and potential for positive impacts on the marine environment immediately surrounding production sites, such as water filtration and habitat provision.

[i] Investment into the focal production systems described within this report alone does not guarantee their sustainability. Sustainability of these systems largely depends on implementation of the factors identified and described within Part IV of this report.

Figure 1.2: Opportunity set for marine aquaculture



Part 2: Market Overview, Production Operations, and Production Economics

Section 2.1: Market Overview

Key Takeaways:

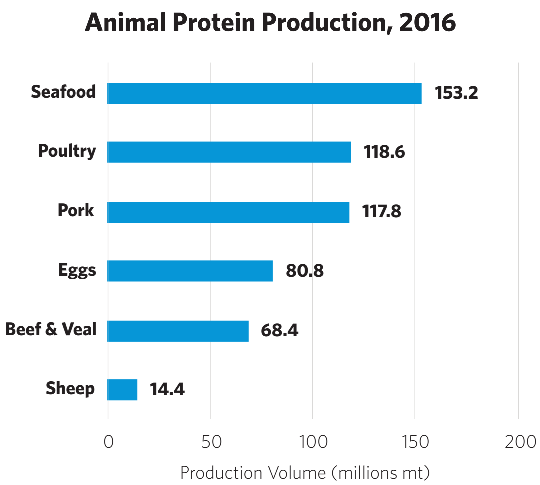
- Over the past four decades, aquaculture has been the fastest-growing global food segment, driven by robust seafood demand and supply constraints faced by traditional wild-capture sources.
- Seafood is a diverse market, segmented by production type (farmed vs. wild-capture), production environment (freshwater vs. marine), and major product category (finfish, bivalves, crustaceans, etc.).
- Farmed seafood products now represent over 50% of all seafood production by volume; Marine aquaculture is more than one third of total aquaculture production.
- Another significant farmed marine segment is aquatic plants and seaweed, considered a distinct market from seafood, which represents 30.1 million mt of annual production worth $11.7 billion.
- Demand for seafood products is increasing as middle-class populations expand in major economies throughout the globe.
- Global aquaculture prices are expected to increase in nominal terms by about 19.5% over the next 10 years.

- Aquaculture growth rates (by volume and value) vary by product types and geography, but overall growth is expected to continue in the coming decades; however, we expect growth rates to temporarily decrease in the near term due to reduced Chinese supply.

Seafood Market Overview

The global seafood market is massive. According to the Food and Agriculture Organization (FAO) of the United Nations, the total value of seafood produced for human consumption at point of first sale was $362 billion in 2016, dwarfing the $182 billion of global poultry production.[21] Seafood also represents about 28% of all animal protein consumed by volume[i] (Figure 2.1). Seafood production for human consumption of 152 million metric tons (mt) was almost 30% greater than the next highest production category, poultry, and twice that of global beef production[22] (Figure 2.1). Nearly 40% of consumed seafood is traded internationally, worth $131 billion annually.[23]

Figure 2.1: Global animal protein production by category[24]



Seafood Market Dimensions and Considerations

Although this analysis focuses on opportunities in sustainable marine aquaculture production, it is important to understand the broader seafood market, given the similar product attributes and pricing correlation of many products regardless of source. For example, farmed shrimp and wild-caught shrimp will be considered close substitutes by many buyers, with the same pricing and supply/demand dynamics affecting both production methods.

Production Method – Wild Capture vs. Aquaculture

Seafood is unique within the commercial food system in that until recently, nearly all production came from the wild capture of animals from their natural environment. Aquaculture has existed for thousands of years, but only in the past three decades has aquaculture production become a commercially significant portion of the seafood market, as wild harvests stagnated, and wild capture costs increased.

Historically, the abundance of wild fisheries deterred significant investment in the higher-cost, complex cultivation of aquatic species. But as global seafood demand has outstripped wild supply, the calculus changed, and aquaculture now accounts for just over half of seafood produced for human consumption. Looking ahead, farmed products

[i] The seafood market value is based on FAO estimates, representing 2016 farmgate prices, and includes domestic as well as international trade. Animal protein is defined as all meat, fish, poultry, eggs, and dairy products.

are expected to account for most seafood production growth, even if trends in overfishing are reversed and wild fish-stocks are restored.

Sourcing Environment – Freshwater vs. Marine

Both wild capture fisheries and aquaculture products can be sourced from freshwater, brackish, and marine environments.[ii] While the product categories and production methods are similar for freshwater and marine, there are important differences between the two, particularly regarding ecosystem impacts.

Geography

Seafood markets are highly regional, both in terms of supply and demand. This reflects several market idiosyncrasies:

- Production is geographically constrained given the requirements of specific species in each environment (e.g., a marine species like tuna cannot be produced in a landlocked country);
- Seafood is highly perishable and expensive to store;
- The seafood supply chain has numerous inefficiencies and individual relationships remain key to trading partnerships;
- Seafood products accommodate a wide range of regional tastes and preferences.

Product Diversity

Seafood is an extremely broad category. There are over 500 species produced through aquaculture with associated products.[25] This contrasts with other animal protein categories that focused on producing fewer species as production scaled, and is likely another legacy of wild capture production, where producers have historically caught what is available and economical to harvest in their region.

Seafood Supply – Status and Trends

The Rise of Aquaculture Production

Today, nearly 60% of wild fish stocks are harvested at their maximum sustainable levels, with another 33% overfished.[26] As a result, today's wild capture production directed to human consumption is 72.5 million mt, only slightly above the 25-year average of 65 million mt. During that 25-year period, aquaculture production has exploded, with volumes growing by 5.8 times.[27]

Since 1990, aquaculture has been the fastest-growing segment of food production by volume, with a compound annual growth rate (CAGR) of 8.3%.[iii] In recent years,

ii For the purposes of this analysis brackish will be considered part of the marine environment.

iii Compound annual growth rates in metric tons between 1990 and 2016.

production growth has moderated, but with a shift to higher-value products like salmon and shrimp, growth in the overall market value has continued to accelerate (11.9% CAGR between 2006 and 2016). Aquaculture production for food consumption (80 million mt) now exceeds that of wild capture (Figure 2.2). Aquaculture's market value per unit is 180% greater than that of wild-capture, reflecting aquaculture's relative focus on higher-value products (Figure 2.3). Aquaculture production is projected to continue to grow at an average rate of 2.1% per year over the next decade. The anticipated decrease in growth rate primarily results from slower growth projections in the Chinese aquaculture production.[28] Asia dominates aquaculture production, making up 89.4% of all production by volume, with China alone resposible for 61.5% (Table 2.1). Asia also leads the world market by value, albeit by a smaller margin due to the production of lower value products. Oceania produces the highest-value products, at $8.15/kg, but with the lowest production volumes (Figure 2.4).[29]

Figure 2.2a: Global aquaculture and wild capture production since 1990 and projections to 2026[28]

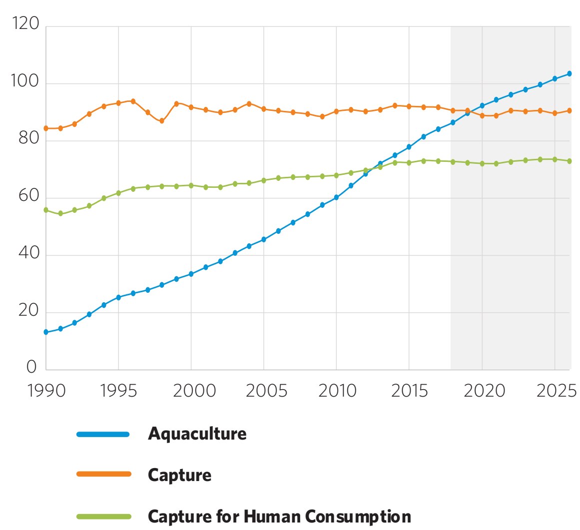


Figure 2.2b: Global aquaculture and wild capture market value since 1998 and projections to 2027[29]

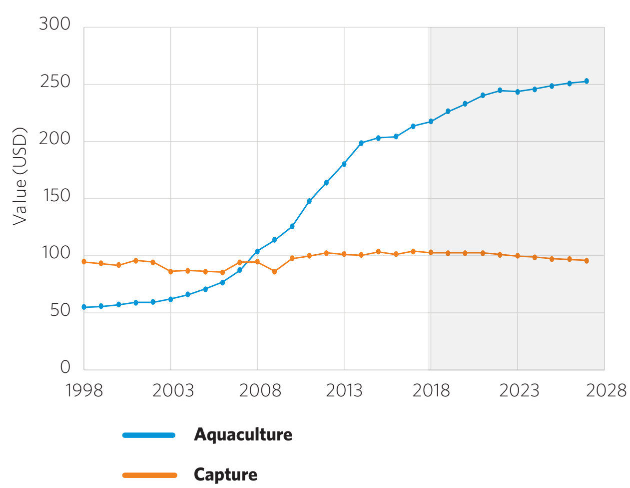


Figure 2.3: Global aquaculture and wild capture market value 1997 and projections to 2027

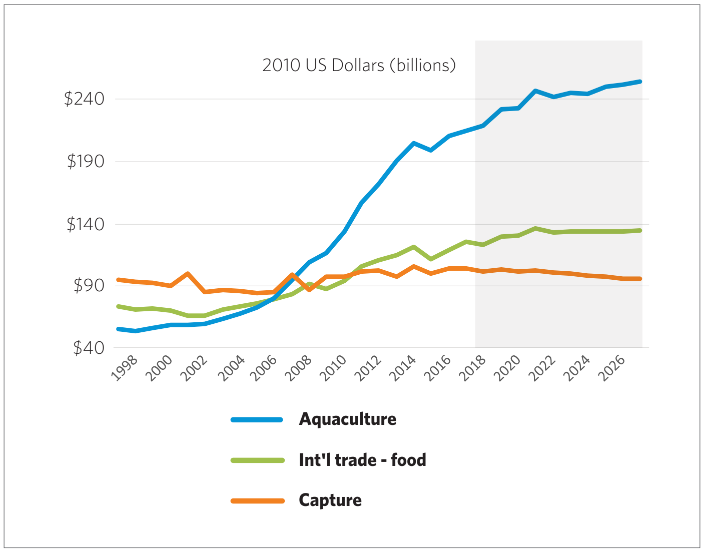
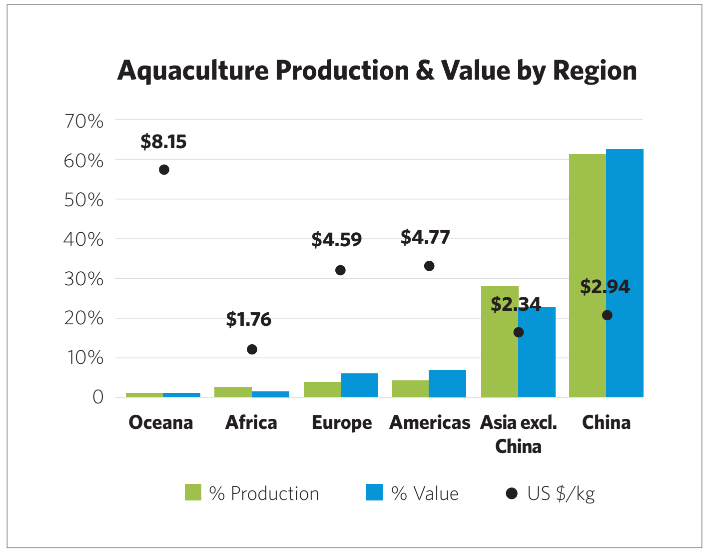


Figure 2.4: Aquaculture value and volume by region[30]



Fisherman sorts fish from fish pond in Yangon, Myanmar.

Photo © Michael Yamashita

Production Drivers

The level of marine aquaculture production is driven by several factors, including economic, policy, biological, and cultural influences. The following variables are not exhaustive but are indicative of those that may shape production and industry growth.

Table 2.1: Aquaculture production drivers

Market demand dynamics and price signals	• Global and regional commodity price expectations for products and substitutes • Secular trends (e.g., demographics, employment, and family income) • Changing tastes and preferences • Business and commodity price cycles • International trade and increased global supply chain interconnectivity
Strategic dynamics	• Level of producer market power, market consolidation, and rivalry between producers • Available production capacity and capacity utilization • Existence of supply chain ecosystem or clusters to support production
Marginal production cost drivers	• Labor • Energy • Feed (including fishmeal/fish oil price, and plant-based commodities) • Technological innovation (animal health management, genetics, production technology) • Infrastructure and market access
Biophysical variables	• Availability of suitable sites for new production • Climate change effects
Financing considerations	• Access to debt and equity capital markets • Public subsidies for research, development, and capital investment
Risk exposure and mitigation	• Prevalence of disease outbreaks and ability to manage them • Availability of price hedging, insurance, and contractual mechanisms • Subsidized backstops by state or development authorities
Public policy, regulatory, and political considerations	• Political security and conflict/crisis • Efficacy of regulatory regime/tenure/property rights • Efficacy of permitting processes • Presence of other ocean users (e.g., fishing, energy, military) • Public perception of aquaculture

Product Categories

Most seafood is harvested for human food consumption, including the vast majority of farmed product (80% in 2016).[30] The remaining volume is directed to fishmeal and fish oil production for use in animal feeds (including fish feed for aquaculture), industrial products, and human health supplements.

Marine aquaculture product categories include: marine finfish (including salmon), crustaceans (e.g., shrimp, prawns, crabs), mollusks (e.g., bivalves, snails) and other aquatic animals. Table 2.2 below illustrates marine aquaculture production by category and by continent.

Seafood can take various product forms including: whole (round), headed and gutted, filleted, or value-added. Seafood can be sold live, fresh, or frozen. Aquaculture products with a shorter shelf life that are produced far from end markets, such as shrimp, tend to be sold frozen. Products with a longer shelf life, such as Atlantic salmon, are typically sold fresh. Some aquaculture species can withstand live transport and can be sold into live markets (e.g., tilapia or olive flounder).

Table 2.2: Aquaculture production by species and continent (in thousand metric tons), 2016[31]

Aquaculture production of main groups of food fish species by continent, 2016 (in thousand tonnes, live weight)

Category	Africa	Americas	Asia	Europe	Oceania	World
Inland Aquaculture						
Finfish	1,954	1,072	43,983	502		47,511
Crustacea	0	68	2,965	0	5	3,038
Molluscs			286		0	286
Other aquatic animals		1	531			532
Subtotal	**1,954**	**1,141**	**47,765**	**502**	**5**	**51,367**
Marine and Coastal Aquaculture						
Finfish	17	906	3,739	1,830	82	6,574
Crustacea	5	727	4,091	0	6	4,829
Molluscs	6	574	15,550	613	112	16,855
Other aquatic animals	0		402	0	5	407
Subtotal	**28**	**2,207**	**23,782**	**2,443**	**205**	**28,665**
All Aquaculture						
Finfish	1,972	1978	47,722	2,332	87	54,091
Crustacea	5	795	7,055	0	7	7,862
Molluscs	6	574	15,835	613	112	17,140
Other aquatic animals	0	1	933	0	5	939
Total	**1,983**	**3,348**	**71,545**	**2,945**	**211**	**80,032**

Table 2.3: Production and value of major species in marine aquaculture, 2016

Common name	Scientific name	Production (tonnes)	*Production (%)	Value ('000 US$)	*Value (%)
Marine Molluscs		***16,772,971***	***76.28%***	***$28,544,200***	***49.01%***
Pacific oysters	*Crassostrea gigas*	4,864,393	29.00	$5,247,952	18.39
Manila clam	*Ruditapes philippinarum*	4,194,032	25.00	$6,845,970	23.98
Scallops (multiple)	*Pectinidae*	1,860,572	11.09	$4,820,938	16.89
Mussels (multiple)	*Mytilidae*	1,100,070	6.56	$556,316	1.95
Marine Crustaceans		***423,563***	***1.94%***	***$2,752,708***	***4.73%***
White leg shrimp	*Penaeus vannamei*	231,573	54.67	$1,229,053	44.65
Giant tiger prawn	*Penaeus monodon*	58,318	13.77	$570,079	20.71
Marine Finfish		***4,789,240***	***21.78%***	***$26,937,125***	***46.26%***
Atlantic salmon	*Salmo salar*	2,237,719	46.72	$14,336,639	53.22
Rainbow trout (marine only)	*Oncorhynchus mykiss*	194,101	4.05	$1,207,432	4.48
Large yellow croaker	*Larimichthys croceus*	165,496	3.46	$359,457	1.33
European seabass	*Dicentrarchus labrax*	158,337	3.31	$966,106	3.59
Gilthead seabream	*Sparus aurata*	142,684	2.98	$775,463	2.88
Japanese seabass	*Lateolabrax japonicus*	141,342	2.95	$322,628	1.20
Japanese amberjack	*Seriola quinqueradiata*	140,895	2.94	$1,108,996	4.12
Coho salmon	*Oncorhynchus kisutch*	124,012	2.59	$678,770	2.52

*Production (tonnes) and Value ('000 US$) in bold and italics represent the worldwide total amount of marine aquaculture production within each species category, and Production (%) and Value (%) in bold and italics indicate the proportion of the worldwide total amount of marine aquaculture production associated with each species category relative to each of the categories presented within this table. Production (%) and Value (%) within each species category represent the proportion of each species' contribution to total production within a species category.

Common name	Scientific name	Production (tonnes)	*Production (%)	Value ('000 US$)	*Value (%)
Marine Plants		***28,892,024***		***$11,652,635***	
Eucheuma seaweeds	*Eucheuma spp.*	10,518,771	36.45	$1,222,617	10.68
Japanese kelp	*Saccharina japonica*	8,219,210	28.48	$4,084,177	35.66
Gracilaria seaweeds	*Graciliaria spp.*	2,955,524	10.24	$1,641,870	14.34
Wakame	*Undaria pinnatifida*	2,069,682	7.17	$1,428,286	12.47
Elkhorn sea moss	*Kappaphycus alvarezii*	1,527,018	5.29	$147,865	1.29
Nori seaweeds	*Porphyra spp.*	1,352,520	4.69	$825,037	7.20

*Production (tonnes) and Value ('000 US$) in bold and italics represent the worldwide total amount of marine aquaculture production of seaweeds. Production (%) and Value (%) within each species category represent the proportion of each species' contribution to total production.

Seafood Demand – Status and Trends

With the world population expected to reach 9.7 billion by 2050, global demand for seafood is likely to grow rapidly, and aquaculture will account for most, if not all, of that growth. Seafood consumption has more than doubled, from 9.9 kg per capita in the 1960s to an average of 20.2 kg, due to the nutritional importance of fish and technological advances allowing for increased accessibility of seafood products.[33, 34]

The seafood industry remains primarily a commodity market. Demand is driven by population trends, income, regional and global tastes, and the availability and price of protein substitutes (Figure 2.5). Seafood consumption is reasonably well correlated with GDP per capita growth (Figure 2.6). As middle-class populations increase in major economies such as China, India, and Brazil, they will drive up overall global demand and may trigger greater seafood imports from other countries. Fish consumption is projected to increase in all continents (except Africa), with Latin America and Asia showing the highest growth. By 2027, modest growth in global fish consumption per capita is projected, with an annual growth rate declining from 1.8% to 0.3% over the period.[35]

Currently, geographic demand is not necessarily aligned with the geographic production. While aquaculture production is heavily concentrated in Asia, the United States and the European Union are consistently two of the top three markets for seafood consumption.[36] In the U.S., as much as 90% of seafood is imported,[37] indicating a large opportunity for domestic aquaculture expansion.

Figure 2.5: Primary demand-side drivers for seafood

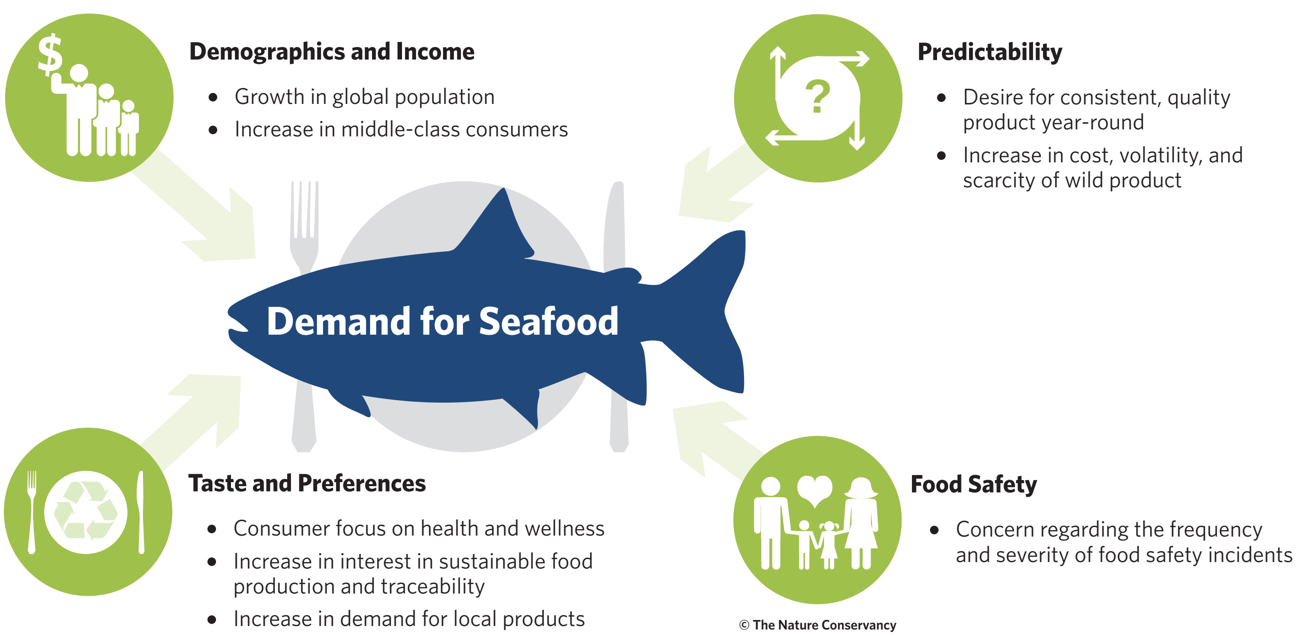
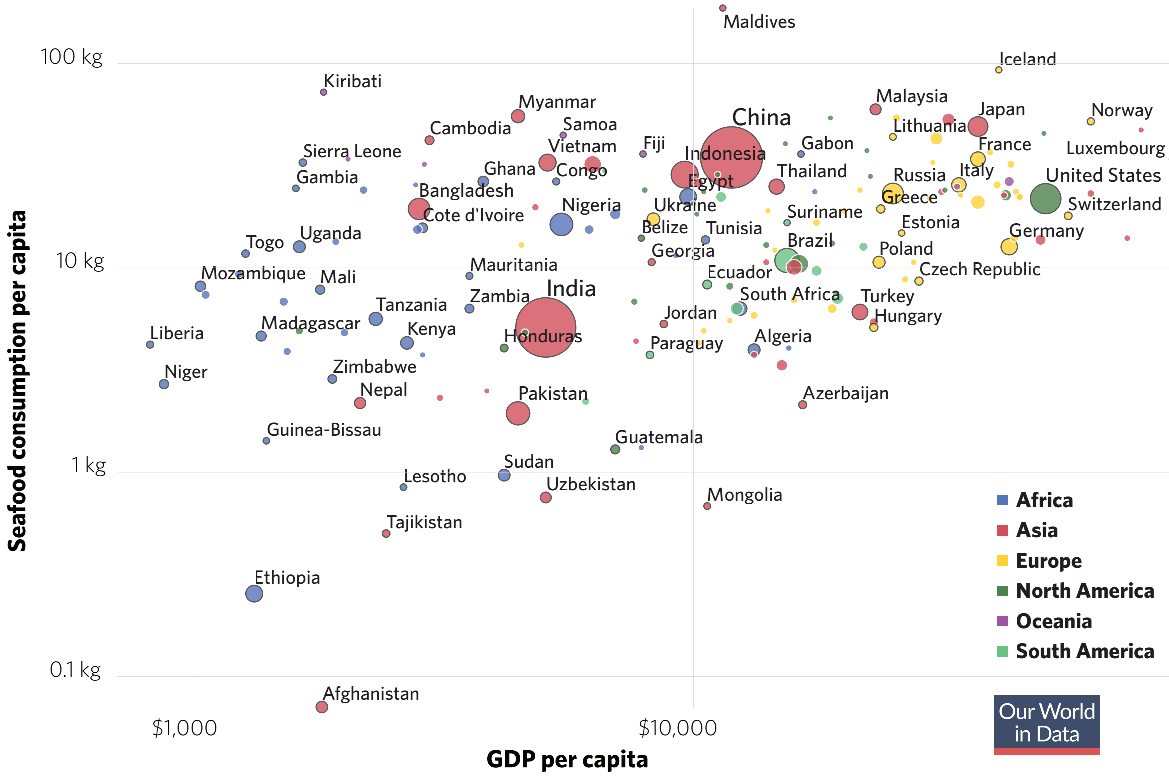


Figure 2.6: Fish and seafood consumption vs. GDP per capita, 2013 (as produced by Our World in Data)[38]

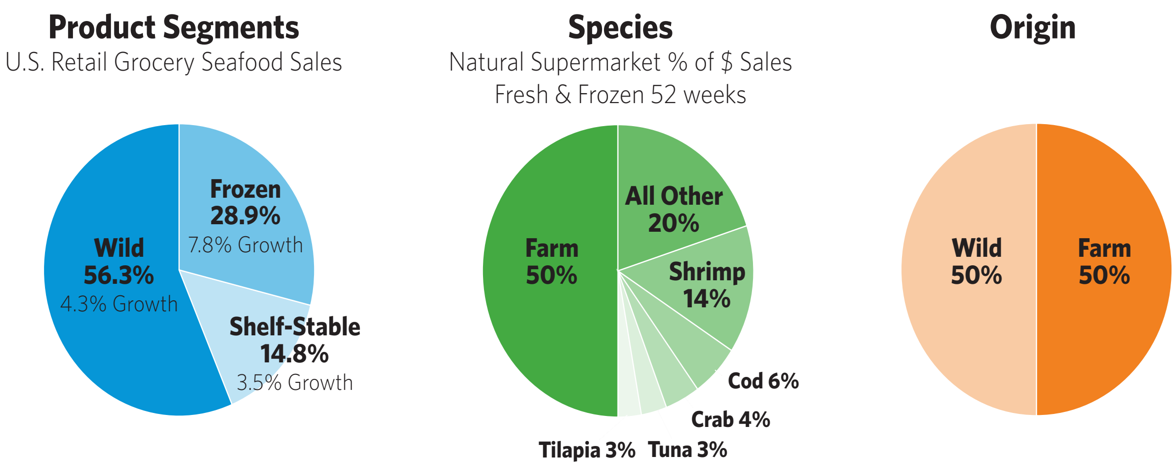
Annual average per capita consumption of fish and seafood products, measured in kilograms per person, versus gross domestic product (GDP) per capita, measured in 2011 international-$. International dollars correct for price differences across countries.



Of the top 10 seafood products Americans consume, five are primarily aquaculture products. As of 2016, the top two U.S. seafood products were salmon and shrimp, primarily produced through marine aquaculture.[39] Just over 50% of retail seafood sales in the U.S. come from fresh products, but the fastest growth is occurring in frozen and shelf stable products. Seafood products are evenly split between farmed and wild products, mirroring the global trend (Table 2.6).

Despite this growth, the U.S. National Oceanic and Atmospheric Administration (NOAA) reports that Americans are currently eating about half the recommended amount of seafood based on dietary guidelines developed by nutritionists.[40] Consumer preferences are evolving in the U.S. and other developed markets, with traceability, environmental sustainability, and social responsibility becoming increasingly important factors in food consumption decisions. The growing awareness of the benefits of Omega-3 fatty acids on neurological and cardiac health has helped drive seafood demand, while real and perceived food safety issues have offset this trend. Concerns over food safety (e.g., mercury levels, persistent organic pollutants, Coliform bacteria, misuse of antibiotics) may create demand shocks or limit long-term demand for aquaculture products.

Figure 2.7: Seafood product segments out of a $105 billion consumer category in the United States, 2013[41]



Sales and Distribution Channels

The seafood industry is especially impacted by distortions created by powerful intermediaries along the supply chain.[42] **Reasons for this include:**

- Market opacity (nearly all products aside from salmon lack trusted exchanges and price discovery mechanisms);
- Relationship-based nature of transactions;
- Importance of food service channel in dictating consumer options and setting preferences;
- Lack of end consumer awareness and education.

The key market sales channels often serve as market gatekeepers, and these buyers are in many ways more influential than end customers in price discovery and formation of consumer preferences. Consumers look to their suppliers for expert guidance in purchasing seafood (e.g., the chef at a restaurant, the fish counter at the grocer, an online meal service provider). While brands do exist, particularly for value-added product, the direct relationship with the supplier tends to be more influential on purchasing decisions of retail customers for most seafood products. The primary distribution channels are:

- Large grocery chains;
- Specialty retailers;
- Food Service providers;
- Direct to consumer (small, but growing segment that includes online sales and delivery meal kits).

Price and Dynamics:

According to the 2018 FAO-OECD Agricultural Outlook, which offers 10-year industry projections, mean aquaculture prices are expected to continue their rise from $2,896/mt to $3,439/mt over the next decade.[43]

Prices are set via spot markets, short-term forward contracts, longer-term offtake contracts, and by financial products that hedge prices. **Factors affecting seafood prices include:**

- Volatility;
- Seasonality;
- Cyclicality;
- Differentiation between product categories;
- Product quality;
- Geography.

Fishmarket in Barcelona with aquaculture and wild products.

Photo © Robert Jones

Section 2.2: Production Operations

Key Takeaways:

- Marine aquaculture production and harvest operations differ significantly by product category.
- Conventional industrial-scale methods include CNP (finfish), shoreline earthen ponds (primarily shrimp, with some finfish), suspended or floating rafts and longlines (bivalves and seaweed).
- Alternative production systems are beginning to come online though there is a lack of widespread adoption; focused on finfish grow-out, these include land-based recirculating systems, offshore production, and closed or semi-closed nearshore systems.
- The selection of production sites is a critical driver of operational and environmental performance.
- Aquaculture supply chains involve multiple steps and are globally oriented.
- The key stages of the upstream production supply chain are hatchery, nursery and grow-out, each with unique requirements.
- Primary inputs include feed (crustaceans and finfish), animal health services, labor, equipment, distribution and logistics providers, and ancillary support businesses.
- Midstream and downstream functions merge with those of the broader seafood market, and include primary processing, distribution and logistics, secondary (value-added) processing, and sales and marketing functions into the wholesale, foodservice, or retail channels.

Upstream Supply Chain

The aquaculture upstream supply chain includes the hatchery, nursery, and grow-out phases. The time spent in each phase of the production cycle can range considerably depending upon the species produced (Table 2.4), as well as biotic and abiotic factors, such as temperature.

Hatchery Production

Hatchery production of fry[iv] is a critical part of the supply chain and often is a bottleneck to industry development of new species or in new geographies. Larger, vertically integrated aquaculture farms may maintain their own hatcheries, while smaller businesses may

[iv] Also referred to as fingerlings (finfish) or seed (seaweed or shellfish).

purchase from other commercial operations. Some countries with significant aquaculture industries maintain public hatcheries to ensure a consistent and available supply of seed for smaller-scale farmers. In some cases, fry may be shipped long distances to nursery and grow-out facilities. In some aquaculture production systems, fry are collected from the wild and hatcheries are not used. Such is the case for most mussels, tropical seaweed, and some marine finfish species such as Japanese yellowtail and milkfish.

In full-cycle aquaculture production, broodstock are initially gathered from wild fisheries and selective breeding for desired traits is common practice. The hatchery portion of the supply chain typically requires a high level of technical expertise, with skilled laborers, scientists, and managers needed to achieve survivability targets.

Nursery Production

When cultured fish, shellfish, and seaweed reach an appropriate size, they are typically transferred to a nursery facility. The nursery system increases survivability and protects cultured organisms until they are large enough to move to a grow-out facility. Nurseries are typically located close to grow-out facilities, given the logistical challenges and animal welfare risks associated with transporting relatively larger animals.

For finfish systems, the nursery phase may take place within the marine environment, though industrial production has increasingly shifted to the use of land-based recirculating tank systems that allow for improved regulation of conditions. Shellfish nursery systems utilize both land-based tanks and in-water floating upweller systems.

Grow-Out and Harvest

Grow-out is the final phase of aquaculture production, and typically requires more time, cost, and capital than the earlier stages. Finfish grow-out operations generally require in-water net pens or cages, coastal ponds, land-based recirculating systems, or flow-through raceways. Shellfish aquaculture systems can vary significantly, and include longlines, rafts, floating or racked bags, and floating or bottom cages. In Asia, coastal ponds are a common grow-out system for shellfish. Seaweed aquaculture systems typically involve longlines, floating rafts, or more simplistic rope and stake systems in tropical climates.

Production Inputs

Primary inputs for aquaculture production depend on the specific production system and species group, but common elements include feed and supplements, broodstock, smolt production, production infrastructure, labor, vessels, services providers, energy (power & fuel), live-animal transport to grow-out facilities, and animal welfare inputs.

Table 2.4: Aquaculture product categories by production method[45]

Method	Marine Product Categories
Coastal Net Pen • Conventional finfish aquaculture production method, most widely adopted for industrial-scale production	**Finfish** • Gilt-head sea bream, European sea bass, various grouper species (*Epinephenalinae*) (Asia), barramundi (Asia) (*Lates calcarifer*), yellow croaker (Asia), golden pomfret (*Trachinotus blochii*) (Asia), Yellowtail (*Seriola spp.*), cobia (*Rachycentron canadum*), Atlantic salmon, coho salmon, Arctic char (*Salvelinus alpinus*), rainbow trout (steelhead), sea bream (*Sparadiae*), red drum (*Scaienops ocellatus*)
Coastal Ponds • Conventional production method for industrial scale shrimp production, some finfish production, and bi-valve production (predominately low-tech operations in Asia)	**Crustaceans** • Shrimp- black tiger prawn (*Peneaus monodon*), Pacific white (*Litopeneaus vannamei*) • Crabs (Asia) **Finfish** • Milkfish (*Chanos chanos*), sea bream, mullet (*Mugilidae*), Japanese sea bass, golden pomfret, red drum **Bivalve Mollusks** • Clams, cockles, oysters
Land-Based Recirculating Systems	**Finfish** • Sea bream, sea bass, yellowtail (*Seriola spp.*), cobia, Atlantic salmon, coho salmon, Arctic char, rainbow trout, turbot (*Scophthalmus maximus*)
Offshore Finfish Production Systems • Submersible pens, cages, pods • Floating pens, cages • Oil rig-style pens	**Finfish** • Yellowtail, cobia, totoaba (*Totoaba macdonaldi*), snapper (*Lutajanus spp.*), Atlantic salmon

Bivalve Production Methods
• On-bottom grow-out
• Rack and Bag
• Fixed or floating suspended gear
  • Taylor floats
  • Lantern nets
• Longlines
• Ponds
	Bivalve Mollusks
	• Scallops, mussels, oysters, clams

Seaweed Production Methods • Floating longlines • Floating rafts • Staked off-bottom lines • Racks	**Temperate Seaweed** • Japanese kelp (*Saccharina japonica*), Japanese nori (*Porphyra spp.*), wakame (*Undaria spp.*), *Gracilaria spp.* **Tropical Seaweed** • Elkhorn sea moss *(Kappaphycus alvarezii), Eucheuma spp., Gracilaria spp.*

Table 2.5: Typical duration of upstream supply chain phases for key species[46]

Species	Hatchery	Nursery	Grow-out
Salmon	3-4 months	6-12 months	12-24 months
Shrimp	1 month	2 months	3 months
Cobia	1 month	2 months	12-16 months
Oysters	1.5 months	1-2 months	12-36 months
Mussels	N/A	N/A	18-24 months
Tropical seaweed	N/A	N/A	1.5-2 months
Cold-water seaweed	N/A	1 month	4-6 months

Pond aquaculture of mullet in southern China.

Photo © Robert Jones

Site Selection for Aquaculture Facilities

The first and perhaps most critical decision for beginning a new aquaculture operation is site screening and selection. Site selection will have major implications for both the operation's financial success and its environmental footprint. Aquaculture operations typically involve fixed structures and rigid permits, making changes to the site difficult after operations have begun. The site selection process should include an assessment of political, regulatory, social, environmental, operational, logistical, and financial factors. There are a common set of considerations for siting that affect most types of in-water aquaculture production systems. RAS systems are generally constrained by less environmental factors than in-water production systems (Table 2.4).

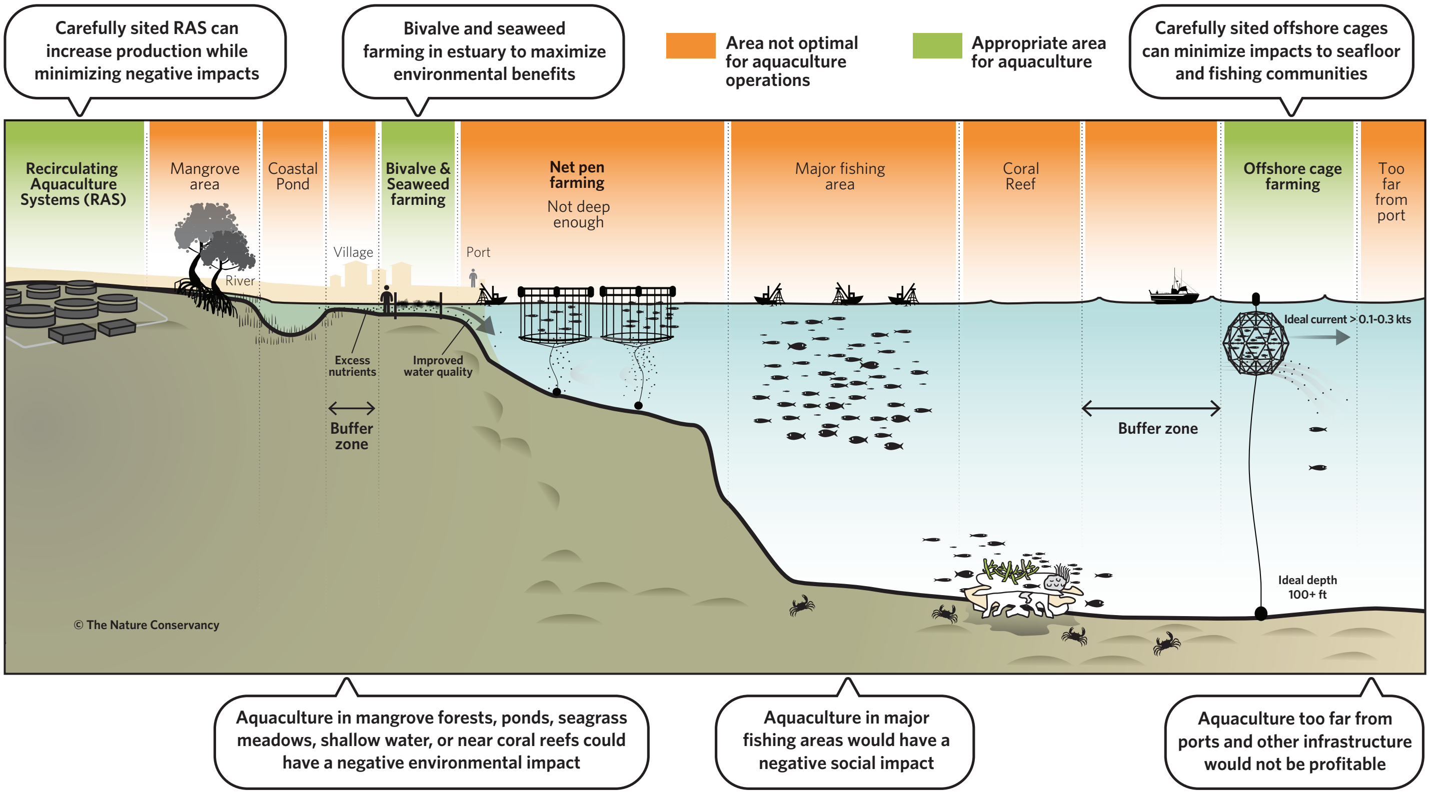
Table 2.6: Key considerations during aquaculture site selection[47]

	Traditional Coastal Ponds	Traditional Coastal Net Pen	Offshore Net Pen	Recirculating Systems	Shellfish and Seaweed
Political/Regulatory/Social-Cultural					
ease of gaining permits	•	•	•	•	•
extent of tenure rights	•	•	•	•	•
number of ocean/coastal users in vicinity	•	•	•		•
bioremediation/mitigation needs	•	•	•	•	
local public acceptance	•	•	•	•	•
Environmental					
depth profile, bathymetry		•	•		•
exposure to wind		•	•		•
incidence of storms	•	•	•		•
tides and currents	•	•	•		•
maximum wave height		•	•		•
water quality	•	•	•	•	•
seasonality	•	•	•		•
water temperature	•	•	•		•
salinity	•	•	•		•
bottom type		•	•		•
presence/absence of critical habitats	•	•	•	•	•
plankton/algae occurance distribution	•	•	•		•

Table 2.6 (continued): Key considerations during aquaculture site selection

	Traditional Coastal Ponds	Traditional Coastal Net Pen	Offshore Net Pen	Recirculating Systems	Shellfish and Seaweed
Environmental (continued)					
extent/existence of contaminants	•	•	•	•	•
red tides/plankton blooms	•	•	•		•
sedimentation/stratification		•	•		•
likelihood of impact from climate change	•	•	•		•
Operational and Logistical					
availability/cost of fingerlings/seed	•	•	•	•	•
availability/costs of appropriate feeds	•	•	•	•	
distance from shore	•	•	•		•
existence of other aquaculture farms and risk of pathogen transfer	•	•	•	•	•
farm security/threat of vandalism/theft	•	•	•	•	•
building contractors available	•	•	•	•	•
availability/cost of key service providers (engineering, veterinary)	•	•	•	•	•
availability/cost of key farm laborers	•	•	•	•	•
access to transportation (airports/shipping)	•	•	•	•	•
proximity to markets	•	•	•	•	•
proximity to processing plant	•	•	•	•	•
availability of freshwater/plumbing	•	•	•	•	•
availability of electricity/fuel	•	•	•	•	•
communications	•	•	•	•	•
access to basic services/entertainment	•	•	•	•	•
Financial					
availability of crop or disaster insurance	•	•	•	•	•
availability of loan programs financial tools	•	•	•	•	•
availability of other subsidies	•	•	•	•	•

Figure 2.8: Aquaculture siting considerations[48]

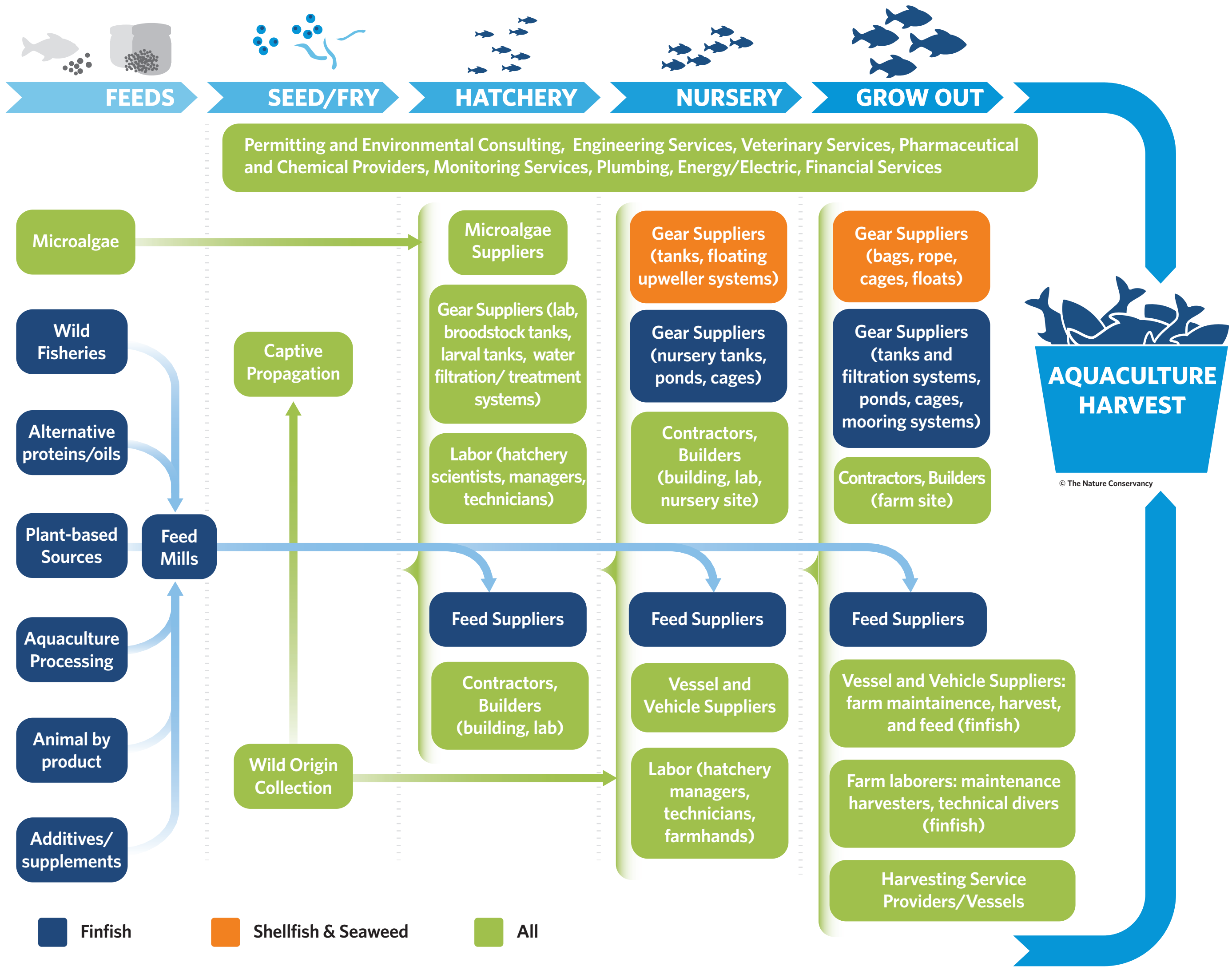


Feed

Feed is arguably the most critical variable input for finfish and crustacean operations across all production stages, and accounts for the highest share of marginal production costs. The following points summarize the role of feed inputs across the production cycle:

- In the hatchery phase, both shellfish and finfish operations require algal cultures for use in the larval-rearing process.
- During the larval phase, finfish operations typically involve cultivation of rotifers and *Artemia*. Specialized feeds are used in the hatchery and nursery phases.
- Newer candidate aquaculture species may rely upon existing commercial feeds used for other marine species.
- For the grow-out phase, marine finfish feeds may be made from fishmeal and fish oil derived from wild sources, aquaculture, animal byproduct, or plant-based products, and may include additives and supplements.
- New technologies and innovations are being developed with the goal of completely replacing the use of fishmeal and fish oil in commercial diets, but they are not yet commercially proven at scale, and adoption has been limited.
- Seaweed does not require feed at any stage of the production cycle, relying entirely upon photosynthesis, water nutrients, and CO_2.

Figure 2.9: Aquaculture upstream supply chain diagram



Animal Health and Ancillary Businesses

Mortality and growth rates are key components of operational performance, and both are directly related to maintaining animal health and welfare. Aquaculture operations generally hire veterinary services and rely on other animal health service providers (e.g., pharmaceutical companies) focusing on disease prevention, detection, and treatment. Other common ancillary businesses include permitting and legal, engineering, environmental consulting, and financial and accounting.

Downstream Supply Chain

The downstream supply chain consists of post-harvest processing, distribution, value-added processing, marketing, and wholesaling (Figure 2.9). Post-harvest processing

Sorting and packing shucked oysters at Hama Hama.

Photo © Jeff Scott Shaw

typically involves aggregating, sorting, grading, and preparing the product for market. Primary processing activities may include simple gutting or filleting, preparing frozen products (individually quick frozen or frozen blocks), and packaging. Plants are often capable of processing to multiple specifications, depending on customer demands, and can facilitate transport to downstream markets.

Value-added processing includes activities such as filleting whole fish, frozen or canned packing for branded products, and the creation of prepared food or meal kits.[v] "Last mile" marketing and wholesaling activities direct the final product through the retail sales channel. These downstream providers may be used by both wild capture and aquaculture producers. On the other hand, several of the large Atlantic salmon producers have developed their own distribution capabilities and sell directly into retail channels.

[v] Products for the foodservice channel may have no additional value-added activities.

Production Intensity:[49]

As described by the World Resources Institute, aquaculture facilities are commonly referred to by their production intensity. The range of production intensity runs from a spectrum of extensive farming (less than 1 ton per hectare) through semi intensive (2-20 tons/hectare) to intensive production (20-200+ tons per hectare per year). Input requirements generally increase with production intensity, meaning that environmental impact also increases with intensity, until a point where outputs can be controlled by the production system (e.g., RAS systems).

Extensive: Requires low levels of control, relying on natural productivity as feeds. Pond aquaculture of shrimp and fish that require no feeding or oxygenation fall into this category, as well as most bivalve or seaweed aquaculture.

Semi Intensive: Production requires fertilizers and feeds to increase production per unit area, requiring higher levels of management control.

Intensive: Requires the highest degree of management control, feeds, and aeration/oxygenation in the case of ponds and other land- based systems. Most net pen farming (coastal and offshore), raceway systems, and RAS farming fall into this category. Occasionally RAS farming may be categorized as "Super" or "Hyper"-intensive farming.

Section 2.3: Production Economics

In assessing the potential of a specific aquaculture project or segment, there are several general economic principles and drivers that will inform a broader diligence and evaluation framework. Some of these factors are discussed below, though microeconomics and risk factors of a given aquaculture project will depend on the specific conditions relevant to that operation.

Supply and Demand Analysis

When considered in isolation from the downstream supply chain, aquaculture production faces supply and demand dynamics similar to those of other commodities markets. In this case, the individual producer has no pricing power and must accept the prevailing market price as a "price taker" for the product or species. Ultimately, the economic viability of a farm will be determined by whether farming revenues exceed costs (Figure 2.13). The upward sloping market supply curve reflects the production cost per unit of each additional unit produced as supply increases (Figure 2.11). The lowest cost farms (e.g., coastal net pens) are capacity limited, reflecting the scarcity of the most economically attractive sites. Total costs of production by innovative, novel technologies with reduced environmental impact have to date exceeded those of traditional coastal production methods.[vi] However, there are three primary means by which these currently higher cost technologies can compete with and take market share from lower-cost conventional methods going forward:[50]

1. Continued demand growth and constrained conventional supply: If the demand for a given seafood product (or its substitutes) outstrips the ability of lower-cost, conventional sources to supply this demand, additional production must shift to higher cost farms and production technologies, resulting in a higher market equilibrium price. Constraints on supply from existing sources may result from factors such as disease, declining water quality, new regulations, climate change, and a lack of suitable sites for expansion. We see a medium to high probability of this scenario occurring (Figure 2.10).

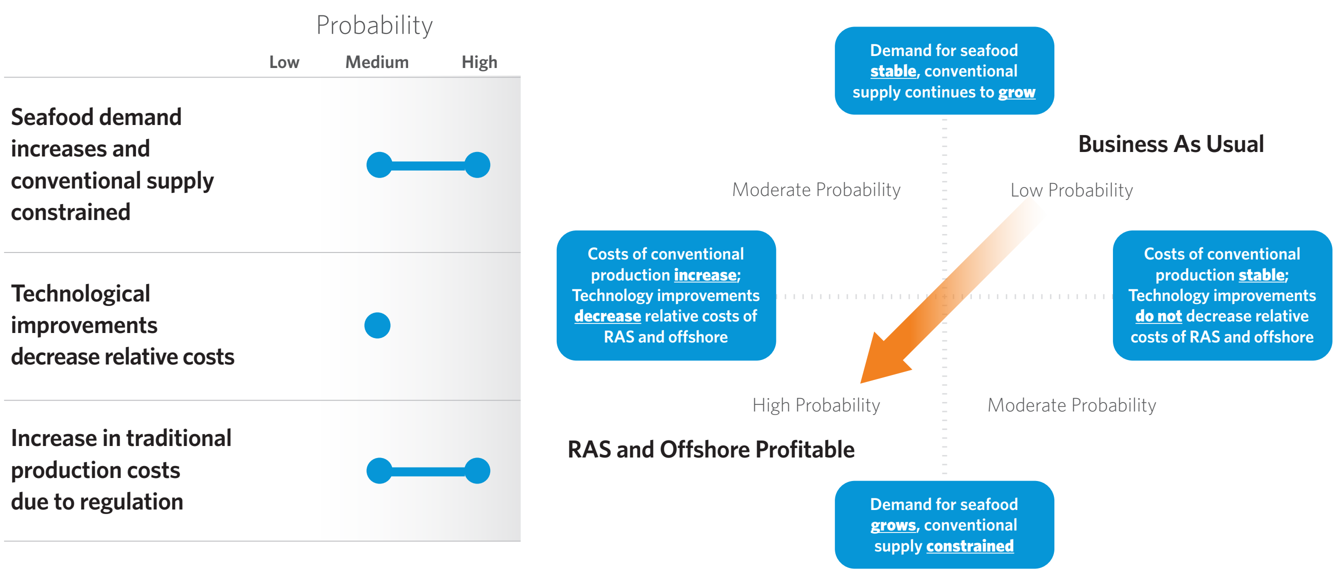
2. Reduced costs of novel alternative technologies: A reduction in production costs of innovative technologies like RAS and offshore enable them to compete with conventional systems at a given market price. Drivers could include technological advances, human capital development and management expertise, reduced cost of capital (via operational track record, technology validation,

[vi] Due primarily to amortization and cost of capital (e.g. interest on debt) of the substantially higher upfront capital requirements of these novel technologies relative to conventional coastal net pens. However, the farm's marginal production costs may be lower for the next generation systems as a result of greater production efficiencies.

hedging and insurance products, and other de-risking mechanisms), subsidies, project development and construction improvements, decreased technology-specific input costs, vertical integration, research partnerships, and streamlined regulations. We see a medium probability of this scenario occurring (Figure 2.10).

3. Increased costs of traditional production methods: Conversely, any factors that lead to increased costs from conventional coastal production methods would improve the economic viability of alternative, lower-impact production systems. These could include new regulatory burdens, increased licensing or concession fees, animal health and mortality expenses due to environmental stresses. We see a medium to high probability of this scenario occurring (Figure 2.10).

Figure 2.10: RAS and offshore finfish aquaculture industry profit drivers and probability of occurrence

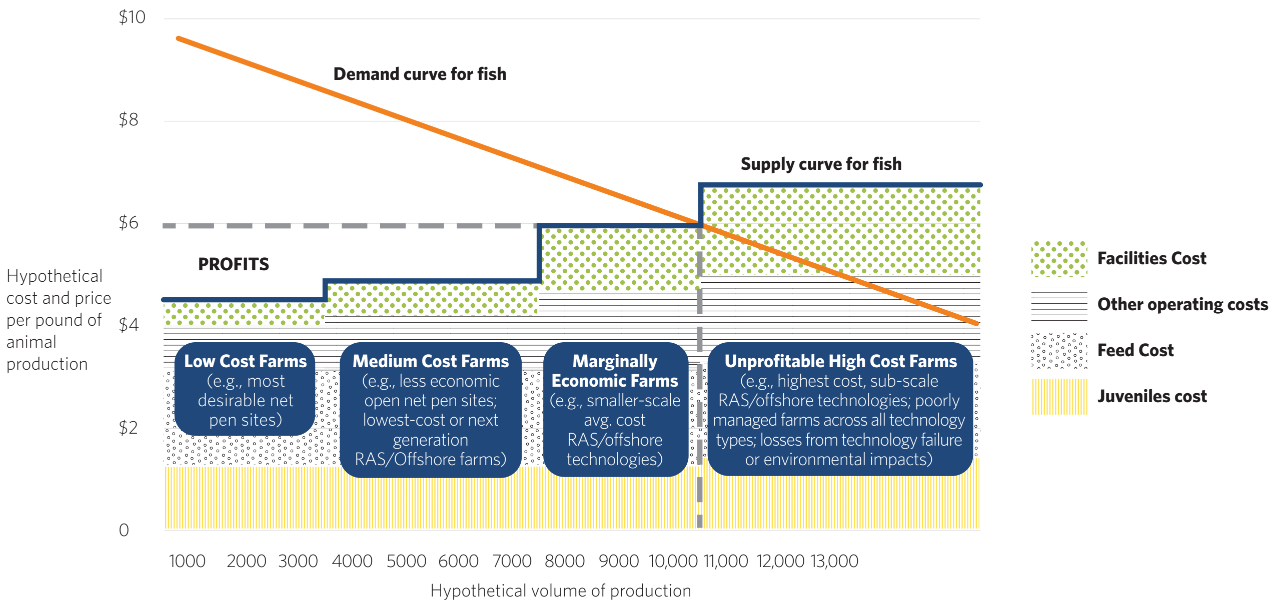


Production Cost Structure

The use of key inputs (e.g., feed, animal health interventions, electricity, and labor) per unit of production in the upstream process typically scale with production intensity yet enable higher stocking densities and production per unit of area.

Cost structure is highly variable across a range of production methods. Figure 2.12 identifies key cost components of salmon operations by geography. The following list of cost components represent the primary cost categories for most conventional marine aquaculture production:[51]

Figure 2.11. Hypothetical short-run marine aquaculture supply and demand curves for a given species/market adapted from Knapp 2008[51]



Operating Costs

Cost of Goods Sold

- **Feed:** Feed typically represents the largest component of both COGS and total operating expenses (opex) for crustaceans and finfish, representing between 30% and 50% of production costs. Feed costs per kg of fish are a function of the feed price and the feed conversion ratio.[vii] These costs are not relevant for filter feeding mollusks and aquatic plants, which feed from naturally occurring nutrients in the water column.
- **Mortality:** All production entails an expected level of mortality, which is generally capitalized and included in COGS. Species or production methods with higher expected rates of mortality will bear higher mortality costs. Unexpected or catastrophic mortality events, however, are generally excluded from COGS and booked as one-time or extraordinary charges.
- **Fry/Seed:** Producers must acquire juvenile animals or operate hatcheries/breeding operations in-house, which accounts for another critical component of COGS.
- **Animal health and welfare:** These costs relate to maximizing animal health and reducing mortality, such as protection from disease, parasites, and predators.
- **Labor:** While some functions of production can be automated (e.g., automatic feed dispensers), the majority of crustacean, finfish, mollusks, and aquatic plant rearing is reliant on direct labor. Depending on location and species reared, labor can be a significant expense.

[vii] As noted above, FCR is the ratio of the units of feed required to grow the product by one unit.

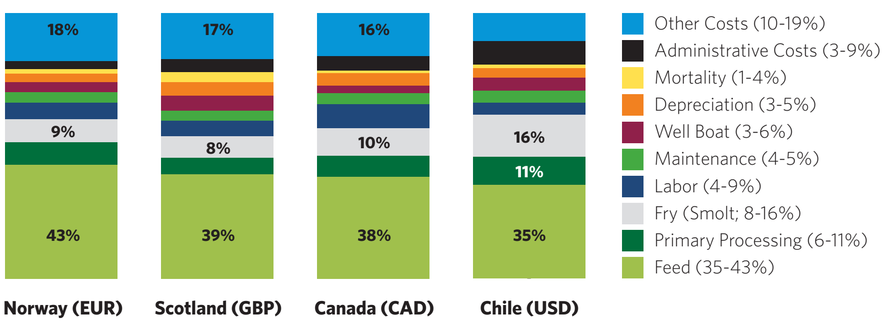
- **Other COGS:** Depending on the product category and production method, other COGS may include energy costs, variable equipment costs, miscellaneous professional services, etc.

Depreciation and amortization: Depreciation and amortization is primarily driven by facilities capex. The weight of this category is a direct reflection of the capital intensity relative to the useful life of a given production system.

Other operating expenses: Other opex includes maintenance, services, and logistics related to production not otherwise captured under COGS.

Selling, general, and administrative: SG&A is a relatively small component of "pure play" production operations (i.e., those focused strictly on grow-out and harvest activities, with no upstream or downstream supply chain integration).

Figure 2.12: Key cost components (by percentage of total cost) of the salmon industry within major producing countries[i]

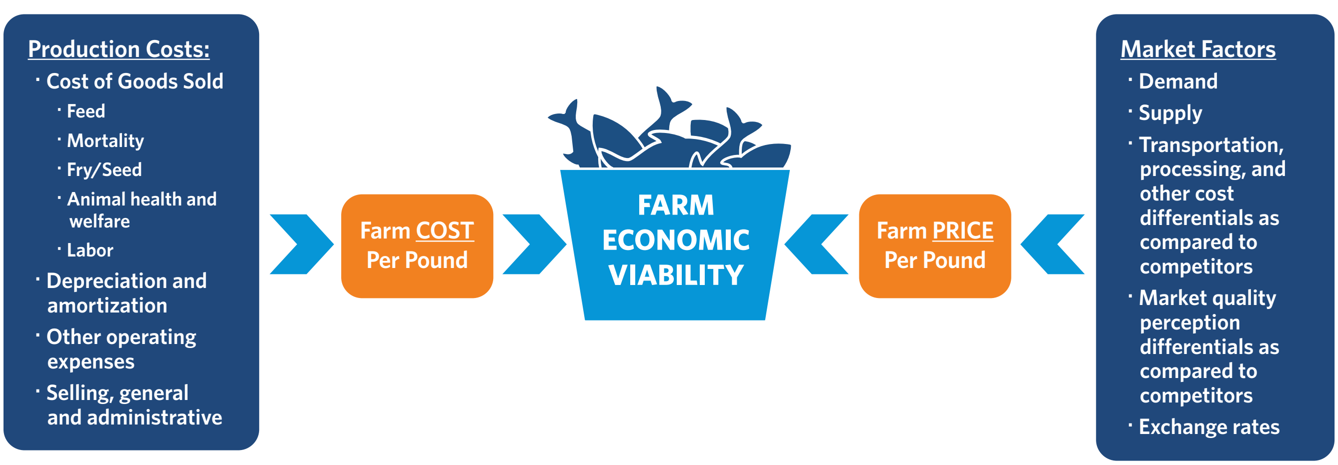


[i] Adapted from the 2018 Marine Harvest Salmon Farming Industry Handbook. Note that the Marine Harvest cost component categories listed in Figure 2.12 differ slightly from the cost component categories presented elsewhere in this report and are calculated as percentage of total operating expenditures.

Non-Operating Costs (pre-tax)

Recurring, non-operating expenses are primarily financial, and for most marine aquaculture producers represents interest expense on working capital and debt-financed portions of facilities or other capex. Industrial-scale producers also bear financial costs related to hedging and risk management.

Figure 2.13: Determinants of the economic viability of an aquaculture firm[52]



Part 3: Investment Analysis

Section 3.1: Porter's Five Forces Analysis

Key Takeaways:

- Producers in select market segments should be protected in the short- to medium-term by barriers to entry from biophysical, regulatory, economic, and financing constraints; however, in the longer-term, look for novel farming innovations to disrupt traditional production by facilitating new avenues for market entry and supply growth.
- Industrial-scale categories (e.g., salmon) pose barriers to new entrants due to supply chain complexity, high capital requirements, biophysical constraints, and regulatory frameworks; entry barriers are generally modest for lower-tech, artisanal production methods in relatively immature, fragmented, and less-regulated categories with low capital requirements (e.g., seaweed).
- Supplier power can be high for species that are challenging to cultivate, require complex production systems, or have specific feed requirements. Power of suppliers in certain areas may decline over time as the industry matures through consolidation in some segments and the entry of new suppliers in others.
- While there are exceptions (e.g., premium oyster markets in the U.S.), buyer power is generally high due to buyer consolidation and backward integration, lack of product differentiation in many seafood products, and low buyer switching cost. Consolidation of downstream sales channels suggests increasing buyer

- power over time, though channel disintermediation (e.g., direct-to-consumer platforms) may disrupt this buyer power.
- The threat of substitutes is dependent on the specific product segment (e.g., there are numerous substitutes for salmon). Many seafood products are threatened by close substitutes in the form of similar seafood options or non-seafood sources of protein.
- Levels of industry rivalry vary by product segment and geography, but to date have remained relatively low in most segments due to the fragmented and immature nature of these markets. The relatively high operating leverage required by these businesses, which will further increase from vertical integration and a shift to more costly and longer-lived novel production technologies, may lead producers to supply product at below total production cost and encourage price wars between rival firms. Undifferentiated producers that lack a competitive advantage in their region or sub-sector are likely to face challenges in cyclical downturns; this should drive further consolidation in these markets.

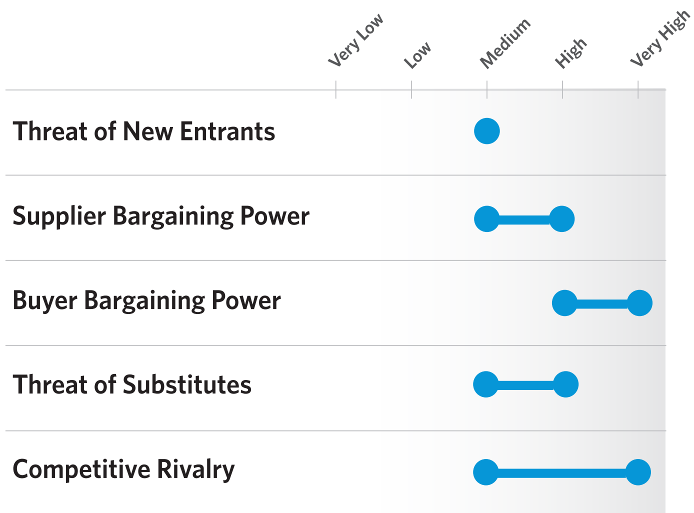
Industry Structure

According to Michael Porter's "Five Forces" framework, the attractiveness of an industry or sector—defined by the ability of firms to sustain attractive profit margins over the long-term—is driven by the fundamental industry structure. According to Porter's framework, an industry's structure is determined by the relative strength of five strategic forces that act upon all industries to pull them towards a state of what economists call "pure competition" in which firms are driven to "normal" profits (that is, the minimum level of profit required to keep them in business, but no more).[i] When these competitive forces are high, according to Porter's framework, the industry will be relatively unattractive over the long-term.

The marine aquaculture "industry" is comprised of many individual segments, each with its own competitive dynamics and market forces. It is therefore challenging to evaluate the attractiveness of all forms of marine aquaculture production within a single analysis, and prudent investors must analyze the specific market segment under consideration. In addition, the different types of producer business models and levels of vertical and horizontal integration will affect the positioning and relative attractiveness of individual firms within each segment. Nonetheless, there are certain similarities and trends

i A full discussion of perfect competition is beyond the scope of this report, but common characteristics of this hypothetical state of market equilibrium include: a) all firms sell an undifferentiated commodity product; b) firms are strictly price takers with no influence over market pricing regardless of market share; c) buyers have "perfect" information about product characteristics and full price discovery/transparency; d) resources such as labor are perfectly mobile; and e) firms can enter or exit the market with no cost.

Figure 3.1: Aquaculture five forces analysis



shared by many of these segments that bring to light several common strategic challenges and opportunities that can be summarized through five forces analysis of the sector (Figure 3.1).

In the aggregate, marine aquaculture production, like other commodity sectors, tends toward perfect competition and low margins, evincing certain characteristics of an "unattractive" industry as defined by Porter. This suggests long-term challenges for undifferentiated producers lacking strategic advantages in highly competitive markets. However, most segments of marine aquaculture production remain relatively immature, fragmented, and inefficient, indicating that significant opportunities exist for those segments or firms that can overcome the adverse effects of these strategic forces.

Threat of New Entrants

- **Medium, with exceptions**

The level of barriers to entry is among the most critical strategic considerations for commercial-scale marine aquaculture businesses, given the commodity-nature of the product and risk of capacity over-expansion when prices are high. Barriers vary significantly by product category, geography, and political jurisdiction, but tend to be higher for the larger, vertically integrated aquaculture firms. **The following list highlights several key considerations to evaluate barriers to entry in marine aquaculture:**

- **Economies of scale:** Most aquaculture businesses should benefit from some economies of scale due to high operating leverage and exploitation of production efficiencies, though there will be diminishing returns to scale beyond a certain point due to biophysical limits to production capacity for a given asset base. This deters new entry for more industrialized product categories. However, since much of the sector remains relatively immature, fragmented, and sub-scale, smaller entrants can still compete in many segments. As the industry matures and consolidates, this will likely become a more significant entry barrier, as seen in the salmon sector.
- **Vertical-integration advantages:** Like scale, the level of vertical integration may pose a barrier to the extent that vertically integrated models accrue market power and control the supply chain. While vertical integration carries its own

set of risks and challenges in a cyclical industry (namely, highly leveraged exposure to downturns), the complexity and opacity of the seafood supply chain tends to reward integrated players with outsized market power, both upstream and downstream.

- **Product differentiation:** Strong product differentiation through branding and other distinct attributes is a well-known barrier to entry in other industries. Seafood has traditionally been a price-sensitive commodity market, with a limited role for differentiation. However, within categories, differentiation can facilitate market entry by niche producers. For example, some oyster producers command a premium over bulk commodity product by marketing a distinct local flavor, or "merroir."
- **Capital requirements:** Marine aquaculture production tends to be relatively capital-intensive, with the associated cost of capital and financing challenges serving as a common barrier to entry. In addition to the investment in production infrastructure, these businesses also require significant working capital. The level of capital investment depends on the market segment and operational scale. Small-scale bivalve or seaweed operations can have lower absolute capital requirements than other segments; however, capital expenditure is typically high relative to revenue and incremental production growth requires continued on high levels of investment. A unique challenge faced by the sector is that there is generally little or no real property underlying the physical assets, which have limited value as collateral. As a result, strong industry incumbents with robust balance sheets are often best positioned to invest in new production due to their lower cost of capital, sector knowledge, and ability to mitigate project risks.
- **Access to distribution channels:** In theory, a commodity industry like seafood should provide an opportunity for lower-cost entrants to displace higher-cost incumbents. In fact, the entrenched supply chain relationships, opaque marketplace, and abundance of gatekeepers serve as a barrier to new entrants.

Offshore aquaculture cage in Panama.

Photo © Brian O'Hanlon

Strategies like direct to consumer models and community supported fisheries (CSFs) could theoretically "democratize" market entry, but this has yet to manifest throughout the sector.

- **Regulation:** In general, strict regulatory requirements around allowing new licenses/concessions, or expansion of existing sites, presents one of the most substantial barriers to entry for marine aquaculture producers, and serves as a significant cap on the expansion of entrenched incumbents (e.g., the Norwegian salmon industry). This is particularly true for production of species that can only be grown in a limited number of sites globally and cannot easily expand to a new jurisdiction in the face of regulatory constraints. Other regulatory schemes facilitate new entry by restricting consolidation and setting aside licenses for smaller businesses. Overall, regulation tends to support long-term checks on growth within a given jurisdiction and may shift production to areas with fewer constraints. However, industry development in areas with limited sector governance has historically threatened long-term business viability given potential biosecurity threats and cumulative environmental impacts, among other governance-related challenges.
- **Site availability:** Successful marine aquaculture production operations are highly dependent on the local environmental conditions at the production site, such as water temperature, quality, salinity, hydrodynamics, exposure, and proximity to other human activity. Non-biological factors like access to downstream markets, inputs, shoreline infrastructure, and existing ocean uses (e.g., shipping, commercial fishing) further constrain site availability. When site suitability is limited, barriers to entry are higher. The extent of these limits varies by product type and production method, but even land-based systems require certain environmental and logistical characteristics. However, many (if

Offshore aquaculture cage in the Bahamas

Photo © NOAA

not most) segments of the marine aquaculture market remain underdeveloped, with ample sites remaining, and the expansion of innovative production methods (such as the offshore or recirculating systems explored in the following section) will continue to increase the number of suitable sites.

Supplier Bargaining Power

- **Medium to High, with exceptions**

The market power of input providers for marine aquaculture varies significantly by production method, product type, and geography. Supplier power can be high for species that are challenging to cultivate, require complex production systems, or have specific feed requirements. The availability and quality of suppliers may also be a source of risk to producers, especially in less mature sectors. In relatively industrialized segments like the salmon industry, producers have limited supplier power by vertically integrating key activities like breeding and feed production, distribution, and value-added processing. **Additional sources of supplier power may include the following:**

- **Greenfield (new) project development inputs:** Depending on the production technology and geography, there may be a limited supply (or complete lack of) qualified project engineers/designers, equipment providers, software providers, and construction contractors.
- **Production inputs:** Producers rely on suppliers of feed, eggs/broodstock, critical specialized hardware or software, and services providers. Feed providers are relatively consolidated among a few large players with significant market power. Service provider power may decline as the industry matures and more suppliers enter the space.
- **Post-harvest:** For businesses that are not forward-integrated down the supply chain, limited access to contract processors, logistics providers, and contract distributors may serve as a key source of downstream supplier power.

Buyer Power

- **High to Very High**

While exceptions exist here as well, buyer power is generally high across most marine aquaculture market segments and geographies. The consolidation of national wholesale distribution networks and retail grocery chains in Western markets has limited producer options for reaching consumers. This is particularly true for lower-volume, pure play independent producers (i.e., those strictly focused on grow-out and harvest activities), who must sell a highly perishable commodity product to a limited number of nearby wholesalers and secondary processors.

Hama Hama's branded oyster bar co-located on the company's farm.

Photo © Jenn Repp

In marine aquaculture segments with lower volumes and differentiated products that are serving captive local or regional markets, producers may also sell through local restaurants or via direct-to-consumer channels. Several leading North American oyster producers have taken this approach, owning and operating their own branded oyster bars and e-commerce platforms. However, producers wishing to achieve meaningful scale will face increased pressure from consumers in the near-term given the common perception that seafood is an undifferentiated commodity.

Key sources of buyer power for marine aquaculture producers include:

- Buyer consolidation: Continued consolidation of key sales channels, including distribution, foodservice, and retail grocery will tend to increase buyer bargaining power.
- Threat of backward integration: Downstream supply chain players may choose to invest in upstream production to secure their own access to product with greater control over cost, sourcing, and quality.
- Lack of product differentiation: So long as buyers generally do not perceive strong differentiation between marine aquaculture products, their bargaining power will remain high.
- Low buyer switching costs: Seafood industry buyers do face switching costs, but as they diversify their supplier base and streamline sourcing strategies, these switching costs should decline, further strengthening their bargaining power.

Threat of Substitutes

- **Medium to High**

The relative fungibility of marine aquaculture products will depend on the specific market, but many end consumers remain relatively indifferent to similar seafood products. For example, a retail grocer that consistently offers a fresh salmon product may switch from farmed Atlantic salmon to wild sockeye salmon if that product is in season and the economics are favorable. A restaurant may offer a seafood dish every night but may continuously switch that product depending on market prices. "Whitefish" species, which include wild-caught cod and haddock as well as farmed species like bass and barramundi, tend to be interchangeable on menus and in seafood counters. The price of other protein sources like chicken or beef will also affect seafood prices.

Competitive Rivalry

- **Medium to Very High**

Competitive rivalry in the marine aquaculture industry varies by product segment and geography, but like other capital-intensive commodity industries, generally serves to limit the market power of any operation. This dynamic results from many similarly positioned producers who have high operating leverage, substantial perishable inventory, and high product storage costs. The effects of rivalry typically manifest as periodic "boom/bust" cycles, with producers over-investing during periods of high prices. This results in excess supply and corresponding price crashes. This rivalry is exacerbated when the relevant producer segment is highly leveraged and vertically integrated.

The following drivers of competitive rivalry are common to many marine aquaculture segments:

- Numerous competitors within the same market segment;
- High fixed cost structure;
- High storage costs;
- Perishable goods;
- Large volumes of inventory and pre-harvest biological assets;
- Low inventory turnover;
- High barriers to exit;
- High switching costs;
- Large incremental capacity additions.

Despite these challenges, the rivalry among many marine aquaculture market segments is moderated by several influences:

- Many segments of the seafood market are experiencing strong secular demand growth and strict supply constraints, which has tended to support prices even during market downturns;
- Low financial leverage due to difficulty obtaining debt financing; investments in production have not typically been financed by non-recourse project debt;
- Many marine aquaculture segments remain undercapitalized and sub-scale;
- Marine aquaculture production continues to make up a minority share of production for marine finfish, other than salmonids, limiting the influence of farmed production on market prices;
- Many marine aquaculture market segments remain regional in nature, which tends to isolate rivalry effects.

Section 3.2: Business Models and Operational Drivers

Key Takeaways:

- There are three typical business models that describe the global aquaculture industry: "pure play" grow-out producers, semi-integrated producers, and fully integrated producers;
- Aquaculture operations, regardless of the level of integration, are not generally diversified across product type because of the differences in complexity and skillsets of different species and production systems and differences in downstream supply chains; the notable exception may be China, in which poly-culture is more commonly practiced;
- There are generally three phases of aquaculture project development: greenfield, established operations, and growth. Each phase may be attractive to different private capital debt and equity investor profiles;
- The six key operational drivers for the aquaculture industry are: feed conversion ratio, stocking density, growth rate, normal mortality rate, animal health and welfare, and product quality consistency and form.

Business Models

As described in Part I, this report focuses on marine aquaculture production systems and the role of investment to transform the environmental and natural resource footprint of these activities. While ancillary businesses along the supply chain will have an important role to play in the aggregate, production operations are key to the overall industry's resource intensity and environmental impact. Investors and stakeholders should understand the conventional production business models and current approaches to value creation, so that they may effectively evaluate strategies for investments in disruptive, sustainable, and restorative aquaculture production systems.

Conventional marine aquaculture production models tend to fall along two axes based on the levels of **vertical integration** and **product diversification.**

Vertical Integration

Vertical integration categories include the following three general groupings:

1. **"Pure play" grow-out producers** focus strictly on grow-out and harvest activities, with no upstream or downstream supply chain integration. The "pure play" segment tends to be highly fragmented and common in less mature segments. These producers are analogous to smaller, family-run crop or livestock operations

that are generally too small to make upstream or downstream investments. However, such operations may rely on cooperative arrangements or other "synthetic" means of vertical integration to achieve limited economies of scale.

2. **Semi-integrated producers** have exclusive control of production assets and capabilities one step beyond "pure play" grow-out and harvest activities. Additional elements of these businesses commonly include in-house hatchery or broodstock operations, primary processing, and/or basic cold-chain logistics. These producers may have direct ownership or utilize joint-ventures and long-term contractual arrangements. They are often former "pure-play" producers that have grown production capacity enough to justify limited investment in key supply chain components.

3. **Fully integrated producers** maintain exclusive control of production assets and all critical inputs and downstream value-added activities, including branded product distribution and occasionally retail sales.[ii] They are typically governed by a single (often publicly traded) holding company with a series of wholly owned or controlled subsidiaries managing each set of operations. The fully integrated model remains relatively uncommon as a proportion of all marine aquaculture producers but has come to dominate global production in more mature sectors (e.g., salmon) and is becoming more common at the regional level for bivalve production. For most fully integrated producers, farming remains the core business driver, accounting for 60-75% of revenues and 75-90% of operating EBIDTA at the holding company level.[53]

Diversification

For any given level of integration, production companies may seek to diversify across product categories. While the level of diversification theoretically falls on a continuum, most producers are either single product (species) producers or diversified within a product category or production method.

The level of diversification does not necessarily correlate to production scale or level of integration; most of the largest salmon producers, for example, produce Atlantic salmon exclusively, while there are relatively small, regional bivalve producers who grow mussels, oysters, and scallops. The majority of marine aquaculture producers globally are undiversified, growing either a single product or a few related products using similar methods and specialization. Some large salmon producers will grow other salmonids, such as rainbow trout, Arctic char, and Coho salmon, but the other species account for a small fraction of their total production volumes. The notable exception may be in China,

ii There are instances of retailers, branded wholesale, or branded products companies buying production assets, but this type of backward integration is less typical than for producers expanding downstream.

where marine pond aquaculture operations typically include some degree of poly-culture (e.g., crabs, shrimp and/or fish in a single system).

This general lack of diversification results from two primary factors: 1) the complexity and specificity of skillsets involved in producing distinct species in different environments; and 2) differences in downstream supply chains, marketing, and distribution assets across marine aquaculture products. Some of these differences stem from technical capabilities, such as processing or cold-chain requirements, while others stem from traditional barriers formed by relationships and geography.

Case Study: The Oslo Stock Exchange

The Oslo Stock Exchange (or Oslo Børs; referred to here as the OSE) was traditionally dominated by Norway's global leaders in shipping, logistics, and offshore oil exploration and production, with some small seafood listings. In the early 2000's the Norwegian Government and private sector leaders began to look beyond oil and gas for new national economic growth drivers. The search coincided with a boom in domestic salmon production, driven by acquisitive consolidation by Mowi (formerly Marine Harvest), Greig, Leroy, SalMar, and others. In an apt parallel to its evolving view of the oil and gas sector, Norway had realized decades earlier that its traditional wild capture fishing industries were not scalable and invested strategically to become the world's leader in salmon farming.

Today, the OSE is the premier global exchange for publicly traded seafood companies, and the center of banking and finance for seafood and aquaculture capital markets. Aquaculture is now among the most important sectors for the OSE, with the 14 listed seafood companies now representing 10% of the market capitalization of the entire Exchange. Norway is also now the largest supplier of Atlantic salmon by a considerable margin. Mowi projects 2018 Norwegian production at ~1.25 million mt (~2x the amount expected from Chile, the second largest producer).

Salmon farm in Norway.

Photo © Andrey Armyagov / 123RF

Turning from its Nordic roots, the OSE has been promoting itself internationally to institutionalize, professionalize, and bring transparency to next-generation seafood production. On October 16th, 2018, the OSE executed a formal agreement with Chile's Santiago Stock Exchange to pursue dual listings across both exchanges. By improving liquidity, transparency, price discovery, and trust built on the foundations of the OSE, this partnership should make the marine aquaculture sector more attractive to mainstream investors, not only for salmon, but for a range of species, products, and farming methods.

Life-Cycle

Investment considerations must also be calibrated according to project phase and operational activities. There are typically three categories of investment, each with sub-stages that may be attractive to different private capital debt and equity investor profiles:

1. **New greenfield production facilities** include pre-development, development, and pre-construction opportunities.
2. **Established production operations** may or may not be part of an operating company, but may serve as a platform for additional growth, with established track record and management credibility and validated business models.
3. **Growth operations** are characterized by organic investment in additional production facilities or upstream/downstream integration, as well as inorganic growth via M&A targeting strategic horizontal or vertical assets.

Operational Drivers

Company growth, in absolute terms and on a per unit (kg) basis, results from cost reduction and revenue maximization, which are in turn driven by six key operational factors:

1. Feed conversion ratio (FCR) refers to the ratio of the units of feed required to grow a product by one unit. A low FCR value implies a reduced feed input requirement per unit production.
2. Growth rate describes the rate of animal growth, which is needed to understand the length of time required to grow fry to a market size.
3. Stocking density refers to the number of individuals stocked with an aquaculture production system (e.g., salmonid RAS projects typically stock at 55-65 kg/m^3), which affects expected maximum production volumes.
4. Normal mortality rate describes the expected rate of animal deaths during grow-out and production, also essential for understanding expected maximum production.
5. Animal health & welfare refers to considerations that improve the living conditions and reduce the likelihood of mortality due to disease, parasites, or predators.
6. Product quality, consistency, and form inform product marketability; improvements in these areas can result in higher prices and more effective branding.

Table 3.1: Relationship between key operational factors and the financial performance of the business

Primary Operational[a] Drivers of Production-Level Harvest Volumes, Costs and Revenues[b]

Drivers	Relevant Metric(s)	Effects of Operational Drivers on Farm-Level Performance: Total Harvest Volume	Total Revenue	Revenue/kg	Total Production Cost	Production Cost/kg	Secondary Effects
Growth Rate Definition: Rate of biomass increase over the growout period Influences/Constraints: - Species type and characteristics - Water quality - Stocking density - Growout method/technology type - Animal health & Welfare - Management experience and ability - Mortality rate - Feed Conversion Efficiency - Feeding schedule and volume - Harvest size/maturity (growth slows past a certain size)	**Δ Biomass / Day / Cohort (avg.)** - Avg. weight of harvested fish and avg. weight of smolt stocked for a given cohort ÷ number of production days for a given cohort	**Positive ↑** - Incr. production vol. per period	**Positive ↑** - Increased production vol. / pd. = increased revenue	**N/A** - No direct effect	**Positive ↑/ Neutral ↔** - Likely increased total costs per period due to increased turnover; depends on what is driving increased growth rate and associated costs	**Negative ↓** - Higher capacity utilization of fixed production assets & inputs/ unit prod.	Feed Efficiency (increased ↑) Mortality rate (potentially decreased ↓)
Feed Conversion Efficiency Definition: Biomass increase over growout period for a given volume of feed - Key measure of input efficiency Influences/Constraints: - Species type and characteristics - Water quality - Stocking density - Growout method/technology type - Animal health & Welfare - Management experience and ability - Harvest size/maturity (FCR slows past a certain size) - Feeding methods, technology - Feed formulation - Wasted food - Feeding schedule and quantity - Monitoring systems	**Feed Conversion Ratio (FCR)[c]** - Ratio of the weight of feed required to produce a single unit of fish - FCR is inversely correlated with feed conversion efficiency; i.e. a lower FCR indicates greater feed conversion efficiency. - The inverse of the FCR is also called the Feed Efficiency Ratio	**N/A** - No Direct Effect - FCR improvements alone will be neutral to harvest volumes assuming constant growth rates	**N/A** - No Direct Effect - FCR improvements alone will be neutral to total revenues assuming constant growth rates	**N/A** - No direct effect	**Negative ↓** - Decreased feed inputs should drive absolute cost reductions (assuming constant growth rates)	**Negative ↓** - Reduced feed input per unit production	Growth Rate: - While feed conversion efficiency is positively influenced by improved by may be both a determinant of growth rates; assuming all other growth inputs remain constant, an exogenous improvement in feed conversion (e.g. an improved feed formulation) should increase the growth rate.
Initial Stocking Volume[d] Definition: The total number of juveniles stocked across the business at the start of the growout cycle for a given cohort. - Primary driver of operational scale, future harvest volumes, capital planning, capacity utilization, working capital, and profit potential. - In practice, stocking volumes tend to drive stocking density since increased volumes will required higher density in the absence of capacity expansion Influences/Constraints: - Existing capacity of growout infrastructure at target stocking density - Species type - Licensing/permitting constraints - Growout method/technology type - Management experience and ability - Working capital constraints - Management view of market forecasts - Strategic considerations (ability to capture new markets, - Biophysical carrying capacity of local environment (water circulation, oxygen content, depth, etc.)	**# Juveniles Stocked** - Total # of individuals stocked at the farm or business unit-level at the start of the growout cycle for a given cohort	**Positive ↑** - Increases in stocking volume drives corresponding growth in harvest volumes	**Positive ↑** - Increased stocking volume drives overall revenue growth due to corresponding harvest volume expansion	**N/A** -Production volumes do not tend to influences revenue/ kg	**Positive ↑** - Increased total costs due to larger production volume	**Negative ↓/ Neutral ↔** - If economies of scale exist, cost/kg will decline with volume, otherwise the effect will likely be neutral	Stocking Density: - Will tend to increase stocking densities in practice in the absence of excess capacity

Table 3.1 (continued): Relationship between key operational factors and the financial performance of the business

Drivers	Relevant Metric(s)	Effects of Operational Drivers on Farm-Level Performance: Total Harvest Volume	Total Revenue	Revenue/kg	Total Production Cost	Production Cost/kg	Secondary Effects
Stocking Density Definition: Measurement of production intensity; how crowded growing conditions are Influences/Constraints: - Existing capacity/volume of growout enclosures - Species type - Licensing/permitting constraints - Management's stocking plan and volume - Growout method/technology type - Management experience and ability - Bioeconomic optimization strategy - Biophysical carrying capacity of growing environment - Threats to animal health & welfare	**# fish per m³** **Max. biomass (kg per m³ growout facilities)**	**N/A** - Density alone has no influence on harvest volume - will only influence volume via increased stocking volumes	**N/A** - Stocking density in isolation will not affect overall revenue except when driven by higher stocking volumes	**N/A** - Stocking density in isolation will not affect revenue/kg	**Negative ↓** - Impact of stocking density on total cost will generally be negative as constant volumes can be produced at lower cost due to efficiencies, better capacity utilization, and amortization of fixed costs across larger volumes.	**Negative ↓** - Likely to see decreased cost/kg due to higher capacity utilization of fixed production assets & inputs / unit produced	• Reduced growth rates • Impaired animal health • Increase mortality rates • Reduced prod. quality
Mortality Rate Definition: Rate of individuals lost during growout period from initial stocking to harvest due to mortality or escapes - Determined of "normal", or expected losses from mortality and escapes during the normal course of operation, and unpredicted "incident based" mortality or escape events Influences/Constraints: - Species type and characteristics - Predation - Structural integrity of infrastructure - Water quality - Stocking density - Growout method/technology type - Animal health & Welfare - Management experience and ability - Harvest size/maturity	**Mortality Rate** = (1 - # individuals harvested / # individuals stocked) * 100	**Negative ↓** - Reduced harvest volumes per cohort	**Negative ↓** - Reduced production volumes per period = decreased revenue	**N/A** - No direct impact	**Negative ↓** - Decreased production volumes and variable input costs	**Positive ↑** - Reduced capacity utilization of fixed production assets & inputs per unit produced	Mortality rate inversely affects stocking density over time
Animal Health & Welfare Definition: Protection from threats like parasites (e.g. sea lice), disease, stress, and environmental factors (algal blooms, pollution, water temperature, oxygen) that are not ultimately lethal but negatively affect production quality, efficiency, and cost. Influences/Constraints: - Biophysical carrying capacity of growing environment (water circulation, oxygen content, depth, etc.) - Species type and vulnerabilities - Management's planned stocking density and total volume - Growout method/technology type - Management experience and ability - Prevalence of exogenous health & welfare threats (parasites, bacteria, viruses, climate threats, other environmental stressors)	**No single metric** - Considerations include reduced growth rates, stress behavior, disease rates, parasite threats, health treatment costs	**Positive ↑/ Neutral ↔** - Health & welfare improvements may directly increase revenues through improved harvest volumes (due to reduced interruptions to production) and improved product quality grades; otherwise effects will likely be neutral - Indirectl effects to revenue from improved animal health may result from increased growth rates, improved feed conversion efficiency, and reduced mortality	**Positive ↑/ Neutral ↔** - Health & welfare improvements may directly increase revenue/ kg through improved product quality grades; otherwise effects will likely be neutral	**Positive ↑/ Neutral ↔** - Likely increased total costs per period due to increased turnover; depends on what is	**Negative ↓** - Decreased health-related production inputs should drive absolute cost reductions	**Positive ↑** - Reduced input costs (meds, treatment, mitigation, etc.) per unit produced - Improved capacity utilization from reduced production disruptions	• Increased growth rates • Improved feed conversion Reduced normal mortality rates • Improved product quality

Table 3.1 (continued): Relationship between key operational factors and the financial performance of the business

Drivers	Relevant Metric(s)	Effects of Operational Drivers on Farm-Level Performance					Secondary Effects
		Total Harvest Volume	Total Revenue	Revenue/kg	Total Production Cost	Production Cost/kg	
Average Harvest Weight (LWE) Definition: Average weight of harvested individuals within a given cohort - Driven by a) growth rate and b) time to harvest Influences/Constraints: - Growth rate - Species type and characteristics - Growout method/technology type - Market factors - Marginal growth vs. marginal cost - Extent of price premium for larger sized individuals	**Avg. Total kg Harvested / # fish harvested** - Harvest volumes in kg based on Live Weight Equivalent (LWE)	**Positive ↑** - Harvest volumes should increase assuming marginal growth exceeds losses from mortality and escapes	**Positive ↑** - Revenue will increase proportional to harvest volumes and due to higher per unit prices achieved by larger individuals	**Positive ↑** - Revenue/kg will generally increase due to higher prices commanded by larger individual fish	**Positive ↑** - Increased total costs due to longer time to harvest, additional inputs, labor, and depreciation	**Neutral ↔** - Undetermined - will depend on growth rates vs cost structure (increasing or decreasing marginal cost trend)	• Mortality decline as fish grow larger • Growth rate slows beyond a certain point • FCR increases with slowing growth rate
Product Quality and Differentiation Definition: Ability of specific product to command a premium over the commodity reference price for that product due to some real or perceived benefit Influences/Constraints: - Harvest weight - Growout method/technology type - Sustainability credentials - Water quality - Feed formulation - Health and welfare - Farm siting	**Quality grade** **Price premium** (over benchmark reference price)	**N/A** - No direct effect on harvest volume due to product differentiation	**Positive ↑** - Revenue increase due to price premia	**Positive ↑** - Revenue / kg increase due to price premia	**Neutral ↔** - Undetermined - may be higher due to product enhancement, but this depends on source of product differentiation and any additional costs associated with differentiation.	**Neutral ↔** - Undetermined - may be higher due to product enhancement, but this depends on source of product differentiation and any additional costs associated with differentiation.	**N/A**

[a] Farm-level operational variables only, independent of exogenous market factors; assumes constant product and input prices.

[b] This analysis considers the notional implication of each driver assuming that all other variables are held constant; in reality, the interdependence and indirect influences between several variables likely means that the reality will be more dynamic and complex in nature.

[c] Two commonly used FCR variants are Economic FCR (eFCR) and Biological FCR (bFCR):

1. Biological FCR = Total weight of feed provided to the target cohort during the measurement period (typically the growout phase) ÷ [Total live weight of the cohort segment harvested for sale at end of period + Sum of live weight (as of the loss) of the cohort segment lost to early mortality during period - Total live weight of cohort juveniles stocked at beginning of period]
   - bFCR eliminates the effect of mortality on FCR calculations by including the biomass of pre-harvest losses; by doing so, bFCR provides a relatively more "pure" measure of the feed conversion efficiency from biological processes alone.
2. Economic FCR = Total weight of feed provided to the target cohort during the measurement period (typically the growout phase) ÷ [Total live weight of cohort segment harvested for sale at end of period - Total live weight of cohort juveniles stocked at beginning of period].
   - Because the denominator excludes the volume of pre-harvest mortality during the growout period, Economic FCR reflects mortality rates in addition to purely biological feed conversion; this may skewed eFCR values when evaluating operations with unusually high or low mortality rates.
   - Since mortality effects reduce feed conversion efficiency at the cohort-level, eFCR will always be higher than bFCR for a given cohort.

[d] While the operational implications of the number of cohort juveniles stocked for grow-out overlap in many ways with stocking density, this analysis assumes that stocking volume is evaluated independently from stocking density in order to isolate the direct effects of each driver.

Section 3.3 Financial Accounting and Metrics

Industry-Specific Accounting Considerations

Investors are likely to encounter unfamiliar or unintuitive concepts in financial reports prepared by even the largest listed salmon producers using accepted International Financial Reporting Standards (IFRS) methods. This challenge may be more acute for private seafood companies, which may have incomplete or inconsistent statements, and no prior experience raising capital from professional investors. Some unique aspects of marine aquaculture financial reporting are described below.

Biomass: Biomass, or biological assets, is defined as "the fish in the sea" during the grow-out cycle for a given species (while differences exist between bivalves, crustaceans, and finfish, the concept remains the same). Unlike inventory, which is typically not expensed until revenue is recognized,[iii] standard accounting requires that living, growing biological assets are "re-valued" on the balance sheet for each reporting period using fair value adjustments.[iv]

Even during periods of "normal" activity, the capitalized value of biomass can swing wildly up (booked as income for the period) and down (booked as a loss for the period) due to changes in market prices and average age, even though the animals may still be many months from harvest. Upon harvest, these valuation discrepancies may be reversed through line items such as "Fair value uplift on harvested fish."

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iii By way of simplification, this ignores inventory write-offs due to obsolescence, shrink, or other pre-sale inventory valuation adjustments.

iv For readers looking to better understand the fair value accounting of biological assets and implications for standard accounting metrics, please refer to the Marine Harvest 2018 Annual Report, 2018 Salmon Industry Handbook, and Q2 2018 Non-IFRS-Financial Measures Appendix.

Atlantic salmon broodstock, USA.

Photo © NOAA

Mortality: During production at commercial scale, like any farming activity, some expected level of mortality will occur. Mortality typically is highest during the hatchery and nursery phases, and the immediate period after juveniles are introduced to seawater cages or grow-out systems. Following this initial acclimation, the mortality rate should fall over time. Mortality later in the production cycle usually results from disease, parasites (e.g., salmonid sea lice), cannibalism, and predation.

There is no official accounting standard for how to treat mortality, and even leading public companies differ in this respect. **Three common approaches are to:**

1. Charge all mortality as an immediate expense when observed.
2. Capitalize mortality, which effectively shifts the costs to the surviving individuals upon harvest (a "blended" or average-cost approach).
3. Distinguish between "run-rate" mortality and "catastrophic" events, and immediately expense the incremental value of catastrophic mortality (less the expected value) as a one-time charge, while capitalizing the expected level of mortality.

By capitalizing the expected mortality for a given species and production system, harvest costs will more accurately adhere to the conservatism principle of accounting. In cases of one-time, catastrophic losses, an argument can be made to use the third approach above but given the relatively common occurrences of catastrophic losses observed within the industry, the second approach may be suitable for most operations. Whichever approach is taken, investors should be aware of the implications on operational and financial metrics for the reporting period.

Industry-Specific Alternative Performance Metrics

To address distortions deriving from the idiosyncrasies mentioned above, publicly traded salmon producers and bankers have pushed for a set of non-IFRS, non-GAAP "Alternative Performance Measures" (APMs). Investors should be aware that these APMs may differ between companies and marine aquaculture segments, often requiring additional adjustments on the part of the investor to ensure a consistent methodology and set of comparisons across companies.[54]

Common APMs include the following:

- Operational EBIT/EBITDA
- Operational EBIT/EBITDA Margin
- Operational Revenues
- Net Interest-Bearing Debt
- Return on Capital Employed (ROCE)
- Underlying Earnings Per Share (EPS)
- Adjusted Equity Ratio

Benchmarking the Salmon Sector

Because most marine aquaculture producers are closely held private companies, or relatively small, opaque subsidiaries of large public conglomerates, operational and valuation benchmarks are limited. This presents a barrier to institutional investment, due to limited price discovery options and asset valuation uncertainty. For investors with deep sector knowledge, however, this also serves as an opportunity to discover hidden sources of value that have been mispriced due to illiquidity and opacity.

The salmon industry presents a major exception to this trend, having received considerable public and private institutional investment. Although these companies are conventional, industrial-scale producers with mixed sustainability track records, the Norwegian salmon industry, in particular, has invested heavily in R&D efforts to improve environmental performance. These efforts have focused on resource-efficient production methods like land-based RAS and offshore, open-ocean production, both of which are detailed in Part IV, below.

Public Trading Comparables from the Salmon Sector

While the salmon sector is an imperfect benchmark for other finfish aquaculture production investments in new species or (non-salmon) RAS and offshore, it does have many large, public companies, broad research coverage, and available data regarding valuation and operational metrics.

Table 3.2: Comparables data for publicly traded salmon producers[55]

Integrated Salmon Producers - Public Trading Comparables Analysis

($ in thousands, except per share)

Company Name	Share Price 8/25/2018	% off 52-week High	Equity Value	Net Debt	Enterprise Value	Dividend Yield	Last 12 months (LTM) EV / Revenue	EV / EBIT	EV / EBITDA	Price / Earnings
Mowi ASA	$21.16	6.3%	$10,371.1	$1,246.0	$11,619.2	5.9%	2.8x	14.8x	12.1x	16.6x
Multiexport Foods S.A.	0.50	7.8%	707.6	3.5	779.5	4.1%	1.5x	8.1x	6.9x	7.2x
AquaChile, S.A.	0.71	0.9%	817.8	155.0	979.3	–	1.6x	10.1x	7.5x	14.6x
Tassal Group, LTD	3.30	2.8%	574.9	59.0	627.7	3.5%	1.7x	9.0x	7.2x	20.0x
Leroy Seafood ASA	7.42	5.6%	4,418.3	361.6	4,780.2	2.4%	2.1x	11.1x	9.5x	12.8x
Grieg Seafood ASA	10.97	10.9%	1,224.4	259.5	1,485.6	4.4%	1.7x	13.7x	11.0x	15.2x
SalMar ASA	47.90	10.6%	5,426.6	302.0	5,616.2	4.8%	4.3x	15.4x	13.4x	18.0x
Bakkafrost	56.53	9.3%	2,749.7	68.6	2,806.0	2.9%	5.2x	14.4x	12.5x	17.4x
Median		**7.0%**	**1,987.0**	**207.3**	**2,145.8**	**3.8%**	**1.9x**	**12.4x**	**10.3x**	**15.9x**
Mean		**6.8%**	**3,286.3**	**306.9**	**3,586.7**	**3.5%**	**2.6x**	**12.1x**	**10.0x**	**15.2x**
High		10.9%	10,371.1	1,246.0	11,619.2	5.9%	5.2x	15.4x	13.4x	20.0x
Low		0.9%	574.9	3.5	627.7	0.0%	1.5x	8.1x	6.9x	7.2x

Table 3.3: Operating metrics for publicly traded salmon producers[55]

Integrated Salmon Producers - Standardized Operating Metrics

	Last 12 months (LTM)									
Company Name	**Production Vol. (HOG)**	**Sales / kg**	**Gross Profit / kg**	**COGS / kg**	**SG&A / kg**	**EBIT / kg**	**D&A / kg**	**EBITDA/ kg**	**Interest/ kg**	**N.I. / kg**
Mowi ASA	367,524mt	$11.38	$5.41	$5.96	$4.63	$2.14	$0.47	$2.61	$0.15	$1.70
Multiexport Foods S.A.	66,013mt	7.63	5.85	1.78	0.28	1.45	0.27	1.72	0.03	1.50
AquaChile, S.A.	68,255mt	9.08	7.22	1.86	0.44	1.42	0.48	1.90	0.23	0.82
Tassal Group, LTD	24,548mt	14.66	9.11	5.55	2.64	2.85	0.70	3.55	0.23	1.17
Leroy Seafood ASA	137,408mt	16.58	8.62	7.96	4.87	3.12	0.53	3.65	0.16	2.52
Grieg Seafood ASA	69,543mt	12.70	6.60	6.09	4.24	1.56	0.38	1.94	0.10	1.15
SalMar ASA	139,800mt	9.33	4.07	5.26	2.37	2.61	0.40	3.00	0.09	2.15
Bakkafrost	49,264mt	11.04	3.02	8.02	5.24	3.95	0.60	4.55	0.06	3.21
Median	**68,899mt**	**$ 11.21**	**$ 6.23**	**$ 5.76**	**$ 3.44**	**$ 2.38**	**$ 0.48**	**$ 2.81**	**$ 0.12**	**$ 1.60**
Mean	**115,294mt**	**$ 11.55**	**$ 6.24**	**$ 5.31**	**$ 3.09**	**$ 2.39**	**$ 0.48**	**$ 2.87**	**$ 0.13**	**$ 1.78**
High	367,524mt	$ 16.58	$ 9.11	$ 8.02	$ 5.24	$ 3.95	$ 0.70	$ 4.55	$ 0.23	$ 3.21
Low	24,548mt	$ 7.63	$ 3.02	$ 1.78	$ 0.28	$ 1.42	$ 0.27	$ 1.72	$ 0.03	$ 0.82

Table 3.4: Cost structure and margins for publicly traded salmon producers[55]

Integrated Salmon Producers - Cost Structure and Margin Analysis

	Cost Structure (LTM)				LTM			
Company Name	**% COGS**	**% SG&A**	**% D&A**	**% Interest**	**Gross Margin**	**EBIT Margin**	**EBITDA Margin**	**Net Margin**
Mowi ASA	50.8%	43.4%	4.4%	1.4%	52.4%	18.8%	23.0%	15.0%
Multiexport Foods S.A.	91.1%	4.3%	4.2%	0.4%	23.3%	19.0%	22.5%	19.6%
AquaChile, S.A.	86.2%	5.2%	5.8%	2.8%	20.5%	15.6%	21.0%	9.0%
Tassal Group, LTD	71.9%	20.8%	5.5%	1.8%	37.8%	19.5%	24.2%	8.0%
Leroy Seafood ASA	60.8%	34.4%	3.7%	1.1%	48.0%	18.8%	22.0%	15.2%
Grieg Seafood ASA	58.3%	37.4%	3.3%	0.9%	48.0%	12.3%	15.3%	9.1%
SalMar ASA	58.8%	34.2%	5.7%	1.2%	56.4%	27.9%	32.2%	23.1%
Bakkafrost	33.8%	58.7%	6.7%	0.7%	72.7%	35.8%	41.2%	29.0%
Median	**59.8%**	**34.3%**	**5.0%**	**1.2%**	**48.0%**	**18.9%**	**22.7%**	**15.1%**
Mean	**64.0%**	**29.8%**	**4.9%**	**1.3%**	**44.9%**	**21.0%**	**25.2%**	**16.0%**
High	91.1%	58.7%	6.7%	2.8%	72.7%	35.8%	41.2%	29.0%
Low	33.8%	4.3%	3.3%	0.4%	20.5%	12.3%	15.3%	8.0%

* EBIT & EBITDA numbers calculated on adjusted operational basis; may differ from company statements due to adjustments for non-recurring or other items in order to ensure methodological consistency across companies.

Financing Production as a Capital-Intensive Asset Class

Investors primarily focused on financial return that are seeking investments in capital-intensive assets typically will need low-cost secured debt in order to bid against strategic investors pursuing synergistic acquisitions.[v] Bank loans for capex in capital intensive assets/businesses are typically made on either a secured or project basis, with unsecured loans a secondary source of debt for qualifying borrowers. **We identify here the debt financing options for production assets:**

- **Secured loans:** These loans are backed by physical assets as collateral and can be repossessed in the case of default. Secured loans work well for true real assets such as real estate. They are relatively fungible, with many potential buyers, price discovery, valuation comps, mark-to-market accounting, optionality, and operational flexibility. Financial investors in marine aquaculture without deep industry knowledge or operational knowledge may be reluctant to risk putting themselves in the position of repossessing collateral like a RAS facility that they cannot operate and may not be able to sell for fair value.
- **Project loans:** Project financing typically is backed by the forecasted expected cash flows of a given project, structured as a special purpose vehicle, with recourse limited to the project assets. This financing option works well for projects with long-term contracted cash flows provided by offtake agreements with credit-worthy counterparties. However, most marine aquaculture projects today do not have such fixed-price offtake agreements.
- **Unsecured loans:** Unsecured loans are backed not by a specific asset, but by the firm's credit history and current/forecasted cash flows. For a financial investor, these loans are difficult to achieve unless buying a fully operating company with an established operating history and credit rating. Most early-stage projects will not qualify for this type of debt, requiring equity investors to finance startup costs and working capital. Unsecured loans are more commonly used as a secondary source of capex financing if needed.

v Corporate strategic investors, depending on size and strength of their balance sheets and access to public markets, may be able to raise equity at a lower cost of capital, layer on low-cost debt backed by other company assets, and may be able to justify a higher bid price due to real or perceived synergies gained through the transaction.

Section 3.4 Investment Challenges and Risk Analysis

Investment Challenges

Marine aquaculture production is usually capital intensive, particularly for innovative, low-impact technologies. Based on production forecasts to 2030, capex required for the infrastructure to meet these growing needs range from $150-300 billion ($12.5-25 billion annually), which does not include required upstream and downstream supply chain investments.[56] Private capital investment can drive the market-based transformation of the aquaculture sector, and it can do so while making commercial-level risk-adjusted returns. However, several challenges must be addressed in order to achieve the investment expansion with resource-efficient production models.

Challenge #1: Matching risk with return and duration in capital-intensive models

The risk-return expectations of aquaculture production fit a yield-based, real asset profile, as opposed to a capital appreciation model (in fact, projects will generally experience capital depreciation in the absence of favorable commodity cycles). However, because of the lack of hedging products, long-term contracts, and other risk management tools, projects face higher expected volatility than the more established agriculture and forestry sectors. Aquaculture also faces higher binary and catastrophic risk, especially for novel technologies and new entrants.

Upside returns and scale are capped by capital requirements; a given project is limited to its installed production capacity without additional equity investment. Asset value drivers are also limited. Revenue growth is capped–generally the only way to grow revenue in the absence of additional investment is through favorable commodity price trends, which are highly cyclical and out of an individual producer's control. Margin expansion may be possible through increased operational efficiencies and cost advantages achieved through economies of scale and scope; however, producers have limited control over primary input costs for feed, labor, and energy.

Capital intensity requires levered equity returns, but individual projects are generally not bankable. Without long-term offtake contracts, project financing is either prohibitively costly or unavailable. And unlike traditional agriculture, there is generally no real property associated with the producing assets. The only value derives from uncertain future cash flows, which advantages large incumbents who can obtain debt-financing using corporate balance sheets.

Challenge #2: Financing early-stage R&D

There has been limited private R&D investment given an unclear upside and potential difficulties establishing intellectual property ownership (apart from specific equipment, software, or services). Investors are thus wary of taking on technology risk unless it supports an already-sound investment proposition, which is why large incumbents have driven most R&D to date.

In North America, there has been limited public or foundational support for R&D. Norway has supported salmon industry research, and China now appears to be taking steps in this direction as well. This situation parallels the earliest days of renewables development before the industry was scaled through substantial public investment and tax incentives. Aquaculture therefore needs additional public incentives for innovation, and/or additional risk-tolerant investors who believe in the long-term environmental and financial benefits.

Challenge #3: Financing project development

Greenfield projects are inherently risky, given their likely reliance on unproven technologies and processes, new management teams, and contractors without established track records. The lack of maturity in some sectors also makes it difficult to hedge against risks of non-performance through equipment insurance or success-based contracts. As with R&D financing, the project development situation parallels the early days of renewables and unconventional oil and gas production.

Project development is also more difficult to finance than for other real asset classes, where underlying assets have inherent value and clear property rights. **Other real assets also benefit from:**

- Readily available service providers
- Legal and regulatory precedents
- Revenue and cost visibility through long-term offtake contracts, forward contracts, and pre-construction leasing
- Opportunities for pre-construction or asset-based debt financing

Challenge #4: Information asymmetry and knowledge barriers

A dearth of publicly available information makes it difficult for investors to fully understand the sector. This makes it time-consuming and costly to evaluate deals or develop investment strategies. The lack of data results from inherent industry structure and a lack of maturity (especially in North America). This report begins to address this challenge.

Challenge #5: Transactional friction

The private equity market has limited experience with aquaculture entrepreneurs (and vice-versa). Despite certain geographic exceptions, these cultural differences and expectations will need to harmonize before significant private equity investment can occur.

Risk Analysis and Mitigating Measures

Investing in the aquaculture industry presents a unique set of risks, summarized in Table 3.5.

Table 3.5: Aquaculture commercial risk matrix

Risk	Probability	Magnitude	Risk Mitigation
Greenfield Project Development Phase (pre-financial close) For new projects in the pre-construction phase, there are several risks assumed before the project becomes "shovel ready." The degree of risk will depend on the stage of development, from concept stage to the start of construction: • Regulatory & Permitting Risk • Financing Risk • Cost Overruns • Delays • Design Risk	High	Medium to High	• Well-vetted site selection, with support from key regulators and policymakers, ideally within a jurisdiction that has experience with the project type • Qualified, trusted management team with project development track record and/or deep knowledge of engineering and project execution needs • Ample contingency funding for the development phase, with management incentives linked to performance targets (as well as favorable terms for investors if targets are missed) • Use of proven technologies, contractors, designers • Budgeting based on precedent projects • Early involvement by equipment providers and contractors
Construction Risk Following financial close, early-stage development risks are mitigated, but construction risks become critical – these risks include: • Delays • Cost overruns • Contractor Solvency • Ability of contractor to deliver • System integration risks	Medium	Medium	• Strong management team with successful track records • Turnkey construction arrangements with equipment providers; outsourced construction processes • Fixed price contracts, milestone-based payments, and other risk-sharing arrangements with contractors • Vendor financing from equipment suppliers
Technology Risk Risk that the equipment, system design, or another key input does not perform as expected.	Medium	Medium	• Select equipment providers with successful track records with similar systems and species • Ensure integrated, turnkey construction so that all components work together as designed • Long-term performance guarantees from turnkey provider
Operating Risk Normal risks related to day-to-day management and operation of the facility. These risks will be highest in the early stages of production, as inevitable adjustments will need to be made to maximize production efficiency and product quality; these risks should fall over time as operating teams gain experience: • Production Efficiency & Cost Management • Mortality Risk (disease, contamination, power outages) • Product Quality Risks (e.g., off-flavoring, early maturation)	High	Medium to High	• Strong management team with track record of operations, familiarity with relevant technology and species • Well-designed system contingencies in the event of power outages, contamination, etc. • Modular units to prevent systemic issues and limit binary mortality events • Real-time analytics and protocols to ensure animal health and provide early warnings for potential issues

Table 3.5 (continued): Aquaculture commercial risk matrix

Risk	Probability	Magnitude	Risk Mitigation
Commodity Price Risk Volatile prices are inherent in this industry and can dramatically affect the economic viability of an operation. Commodity prices can affect the economics of the operation in two ways: • Input costs: commodity cycles can cause swings in prices of key inputs such as feed and eggs/roe • Output prices: product prices are affected by exogenous market factors such as the availability of substitutes, demand, and supply	High	Medium to High	Opportunities for commodity risk hedging remain underdeveloped in this sector; however, the following mitigants should be pursued: • Long-term supply agreements with fixed or collared prices • Long-term offtake agreements with fixed or collared prices • Product differentiation via branding, marketing, quality, or reputation, which can buffer against price fluctuations • Thoughtful selection of species type and key inputs with a focus on minimizing price volatility and maintaining options for sourcing and product sales • System flexibility to adapt production for different species
Obsolescence Risk As technology continues to improve and costs decline, existing assets may be unable to compete with newer projects, effectively becoming "stranded," potentially resulting in: • Write-downs of asset book value • Valuation implications for investment exits	High	Low to Medium	• Forward contracting of product or long-term, fixed-price or collared offtake agreements • Build a diversified portfolio of assets across project vintage years • Budget for and invest in systems that can be retrofitted and upgraded, and allow for low-cost substitution of components

Recirculating aquaculture facility under construction in Guangdong province, China.

Photo © Robert Jones

Section 3.5: Building the Enabling Conditions for Sustainable Aquaculture Investment

Early mover investors, concessionary and blended capital providers, philanthropists, policymakers, NGOs, and the broader private sector have an opportunity to cultivate the enabling conditions that can attract investment at scale and help resource-efficient, low-impact aquaculture operations to succeed. These groups must collectively support the following objectives:

1. Defining, aligning, and refining government policies and supporting innovation
2. Establishing sustainability principles for marine aquaculture
3. Establishing benchmarking tools to assess operational and environmental performance

Defining, Aligning, and Refining Government Policy

A stable, predictable policy framework based around sound property rights, frictionless transactions, enforceable contracts, and fair arbitration is necessary (though not alone sufficient) for any efficient market. Clear, well-enforced policy and regulations must be established by national and sub-national entities to foster greater aquaculture adoption and shape future growth.

The political-regulatory scenario varies widely by region and jurisdiction. In some cases, creating an investable environment requires increased regulation and stability. In other locations, convoluted, restrictive regulatory and permitting processes have impeded growth. **A policy environment conducive to the Blue Revolution should include the following:**

1. **Protective, transparent, and effective permitting processes and regulations** to ensure that:
    a. Governments do not issue permits to operators or allow other operators to continue practices that degrade ecosystems or undermine businesses (e.g., protective biosecurity measures against the spread of disease or overstocking aquaculture facilities).
    b. Enforcement entities can protect assets from theft or vandalism and uphold environmental standards.
    c. Developers can obtain a permit within a reasonable amount of time.
2. **Clear property rights and resource tenure** are essential for project developers and asset buyers. Because most aquaculture production occurs in the legally ambiguous ocean setting, often considered a "common resource," regulators

must provide a strong framework to select, allocate, limit, and regulate production site concessions.

3. **Enabling infrastructure** is required to support sector development, such as transportation, storage, sanitation, energy, and water. A lack of suitable infrastructure can be a major constraint for capital-intensive, innovative business models such as offshore aquaculture.
4. **Special programs to promote sustainable innovation** can help address the unique set of challenges faced by aquaculture producers. Governments should explore ways to engage industry in "moonshot" undertakings by structuring proper incentives, using the Norwegian Development License program as an example (see box below). While there may be a selection process, governments should not pick winners, but rather establish the broad objectives and allow the marketplace of ideas to develop novel solutions to overcome scaling challenges. The Norwegian Development License program is still in its early days and should be closely observed for lessons on encouraging private sector investment, innovation, and risk-taking towards a more sustainable production system.
5. **Public financing mechanisms:** Low-interest loan programs and crop/disaster insurance programs can be used to build up key industries or de-risk sustainable practices. In the U.S., MARBIDCO low-interest loan programs in Maryland have been used to jumpstart oyster farming, and USDA Crop Disaster Insurance helps subsidize farming operations through disaster events.

Norwegian Salmon Sector Leadership in Sustainable Innovation

Conventional salmon producers have invested in potentially transformative marine aquaculture technologies such as RAS and offshore aquaculture. Sustainability-oriented investors should understand the dynamics and incentives that drove this investment and monitor a trend that may transform the broader sector.

Alternative production investment by the salmon sector has been driven primarily by four related trends, which all stem from natural resource constraints:

1. The imposition of strict environmental and siting standards by the Norwegian government in recognition of physical, biological, and environmental limits to production expansion, especially due to the growing threat of sea lice and disease. This reduction in new site availability placed a high value on new and existing conventional licenses, driving consolidation through M&A, which favored integrated incumbents.
2. Increased production costs due to the threats of sea lice and disease, which has created an incentive for salmon companies to limit coastal net pen production and focus on new growth via acquisition and innovation.
3. Norwegian licensing policies that incentivized large R&D investments targeting previously inaccessible offshore sites.
4. The development of onshore RAS to support juvenile growth during a longer portion of the growth cycle, which can maximize net pen biomass capacity and reduce mortality and animal health issues associated with sea lice and disease.

Establishing Sustainability Principles for Marine Aquaculture Investment

One clear and consistent message from investors interested in making a sustainability-oriented investment in the space is: *"What does sustainability mean when it comes to aquaculture?"*

Their concern is two-fold. First, as investors, they are concerned about reputational risk associated with making sustainability claims. Second, from a product-market fit perspective, they are concerned that consumers, wary of "farmed" fish, will be reluctant to adopt the product or that it will sell at a discount to wild alternatives. For established farmed species with broad market adoption, like salmon, this second concern may be alleviated, but for the introduction of farmed species traditionally known as wild, this is a very real risk. That stated, farmed salmon is not immune to reputational backlash, and consumers remain generally undereducated about the seafood they consume.

Some environmental NGOs have led significant campaigns against aquaculture in response to a legitimate set of concerns, especially in the early days of industrial-scale fish farming, and an entire generation of consumers in developed countries learned to avoid buying farmed seafood. These campaigns have created uncertainty for impact-oriented investors looking to improve the food system, who may be concerned about reactions from non-profit partners and other stakeholders.

Photo © Jez O'Hare

While standard-setting bodies like the Aquaculture Stewardship Council (ASC), Global Aquaculture Alliance Best Aqua-culture Practices, and the Global Seafood Sustainability Index (GSSI) are developing metrics and benchmarking, investors lack a clear set of sustainable aquaculture investment principles backed by a consensus of public, private, and NGO leaders. Addressing this issue would help eliminate confusion around the sustainability merits or considerations of a particular investment and reduce due diligence costs.

Establishing Benchmarking Tools to Assess Operational and Environmental Performance

To accurately assess impact investment aquaculture deals, reliable information on industry standards are also needed. Consistent information on considerations like feed prices, fish prices, feed conversion ratios, growth and mortality rates, energy usage, and discharge levels are critical in this regard. While this data is largely available for salmon production, it is difficult to obtain for other marine aquaculture species.

Enterprise budgets are commonly available for various land-based agriculture segments but are not readily available for most aquaculture species and production methods. Part of the challenge is that aquaculture businesses, especially those working with new production methods and species, have incentives to protect this information from potential competitors. Ironically, this lack of transparent and consistent information stymies capital from entering the space at-large. The potential new application of inexpensive monitoring technologies and data platforms offers a new opportunity to accurately gather and aggregate such information. If participation by farmers can be incentivized, it is possible that such improved information products can be developed and made broadly available through a fee-based system.

Diver swimming below offshore aquaculture cage.

Photo © Open Blue

Part 4: Impact Opportunity Profiles

Section 4.1: Land-Based Recirculating Aquaculture Systems

Key Takeaways:

- By decoupling fish production from the marine environment, RAS systems may offer an alternative to traditional, coastal net pen (CNP) finfish production with better environmental performance, higher production capacities per unit area, reduced mortality, and greater control over production outcomes.
- RAS systems generally offer reduced impacts to wild stocks, habitats, water pollution, and disease transfer relative to business as usual CNP production when best practices are implemented. However, RAS systems are not without environmental tradeoffs: they may result in increased energy usage, water usage, and land usage compared to CNPs.
- The large integrated salmon producers have invested heavily in developing RAS technology to raise juvenile fish to larger sizes before transferring them to net pens in nearshore environments for outgrowth.
- The promise of full life-cycle, egg-to-harvest large-scale (>5,000mt) RAS production has remained elusive. A legacy of failed projects, high capital requirements, a lack of experienced operators, and unproven economics at scale has left many investors and industry players skeptical until recently.

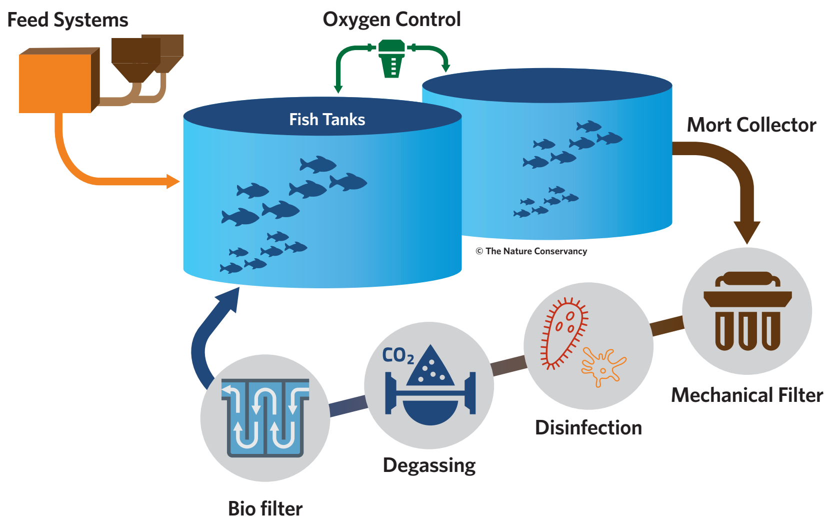
- A new class of entrepreneurs and investors have been attracted to the RAS segment by a range of favorable trends, including regulatory challenges limiting CNP supply growth, high and growing market prices for key species like salmon, rising costs of animal health and disease prevention in CNP systems, and improvements in RAS operational knowledge and system design.
- Our view is that the sector will remain risky in the short-term, but not prohibitively so in all cases. Selective, knowledgeable investors with a higher risk tolerance may find compelling opportunities to be early movers in the space with opportunities to invest at a discount in strong projects that have highly experienced management teams.
- RAS may be most attractive in geographies with large local markets for seafood by minimizing air freight costs relative to CNPs and in regulatory environments that do not allow for expansion in CNP aquaculture.
- RAS systems for Atlantic salmon may be the closest to achieving economic viability, but other species also show potential. Appropriate engineering, systems design, and skilled management teams are essential to advancing beyond Atlantic salmon.
- Geographies that are likely to lead the RAS space, both in terms of production and technology development, are the European Union, Norway, the United States, and China.
- Assuming the next generation of RAS projects currently in development are able to show sustained success after coming online over the next five years, these assets and ancillary business models will likely become targets for a range of mainstream private capital pools, including real asset, yield-focused investment, venture capital, and private debt.

Background and Market Landscape

A growing number of innovators are looking to RAS due to mounting challenges in conventional CNP supply growth, including: siting and permitting constraints on new CNP production, growing animal health and disease mitigation costs, and environmental impact concerns.[57] While CNP facilities are exposed to the variability of the natural marine environment, RAS facilities rely on enclosed, land-based tank systems to grow animals from egg to harvest in a controlled environment. RAS systems make use of sophisticated engineering equipment, including water heaters and chillers, mechanical, biological, and UV-filters, and ozonation, and advanced monitoring systems. Some systems may recycle over 90% of the water used for production (Figure 4.1).

Modern RAS technology was first developed in the 1970s for broodstock cultivation in the salmon industry and was first attempted for full-life cycle commercial production of eel in Europe during the 1980s and early '90s.[58] Many engineering designs and principles have been adapted over time from wastewater treatment facilities.

Figure 4.1: Indicative RAS schematic[i]



i For those unfamiliar with the RAS segment, the FAO's "A Guide to Recirculating Aquaculture" (2015) provides a helpful primer, found here: http://www.fao.org/3/a-i4626e.pdf.

Unfortunately, commercial development of RAS faced a series of setbacks over the past 30 years with a number of costly, well-documented failures, resulting from inexperienced management teams, excessive leverage, trial and error, inferior or inappropriate technology, undercapitalization, and a lack of R&D support and incubation.[59] Over the past decade, however, the technology and operational capabilities have matured rapidly, with reported reductions in water requirements and 3-4x increases in water recycling efficiency since 2008.[60]

In North America alone, RAS demonstration projects have successfully shown the technical feasibility of cultivating a range of freshwater and marine species such as tilapia (*Oreochromus spp.*), striped bass, cobia, barramundi, salmonids, European sea bass, and marine shrimp.[61] However, many early projects have struggled to be commercially viable. Salmonids are the most commonly cultured species and are closest to commercial viability at scale—a result of the salmon sector's deep research and experience with RAS.

RAS began as a fragmented cottage industry, but with the increasing reliance of land-based systems in the salmon industry over the past three decades, equipment providers have become consolidated among a few large players. The primary competing systems are produced by Billund, Veolia, and Pentair. A number of smaller companies, independent consultants, and universities offer services in systems engineering and design. Norway, the United States, and the European Union, are the primary technology developers and producers. Due to new regulatory changes for in-water production in China, we anticipate that China may also emerge as a significant technology developer and producer.

Some RAS projects currently in operation tend to be sub-scale pilot or 'phase I' facilities producing 100 to 1,000mt annually, with significant financing of capital expenditures and/or R&D coming from government or grant funding.[62] Due to the economies of scale inherent in RAS production, some industry analysts estimate the minimum viable scale of production for a single farm to be between 2,500mt and 5,000mt. This scale would allow the operation to achieve long-term profitability and cover capital costs on a fully unsubsidized basis, with better economic projections for larger projects (greater than 10,000mt). However, the dearth of operational projects with established track records at this scale means that investors and analysts can only speculate on the ultimate viability.[63] Other analysts indicate that a disaggregated model of several smaller farms (<2500mt), linked through a shared upstream and downstream supply chain, may also be a viable business model.

Table 4.1: Selected RAS projects that are no longer in operation (1990 to 2016)[64]

Project Name	Year	Location	Species	Planned Capacity	Cause of Failure[i]
Fish & Dakota	n/a	North Dakota, U.S.	Tilapia	No Data	Power Outage; System Design Flaw; Human Error
Magnolia Shrimp	2008	Kentucky, U.S.	Shrimp	23 mt	Human Error; Management Challenges; Fungal Outbreak
Bell Farms	2015	Indiana, U.S.	Yellow Perch; Rainbow Trout	1,000 mt	Project Economics; Financing Challenges
Fingerlakes Aquaculture	2009	New York, U.S.	Tilapia	545 mt	No Data
Blue Ridge Fisheries	1991	Virginia, U.S.	Catfish; Cobia	454 mt	Project Economics
Virginia Cobia Farm	2013	Virginia, U.S.	Cobia	No Data	No Data
Continental Organics	2015	New York, U.S.	Tilapia	No Data	No Data
Vero Blue	2014	Iowa, U.S.	Barramundi	4,500 mt	Management Challenges

i As reported by Timmons & Ebeling (2013) and interviews with investors and consultants familiar with these projects.

The salmon industry, with the most extensive RAS production and R&D investments, remains divided on the potential for RAS to achieve meaningful scale, with some leading associations and producers arguing that RAS's higher capex requirements, water and electricity costs, and operational risks will outweigh the benefits in most cases.[65] Other experts suggest that this skepticism is biased by entrenched conventional interests resisting technological disruption, or investing in competing modes of production. Still others envision a salmon industry that relies on RAS for a greater portion of the production cycle without abandoning CNP production; in this scenario, salmon juveniles are grown to an increasingly large size in recirculating systems before being moved to net pens. While an industry consensus remains elusive, 2017 and 2018 ushered in an accelerating commitment to RAS by leading equipment providers, project developers, and large investors.[66]

In early 2017, Norway's largest investment bank, DNB Markets, released an influential report entitled "Deep Dive Into Land-Based Farming" that highlighted the potential for RAS in the salmon industry. **The report identified four key drivers that would favor RAS production growth:**

1. A continuation of low growth from traditional CNP farming due to project siting and licensing limits;
2. A long-term secular trend of sustained high salmon prices driven by a continued strong and growing global demand;
3. Convergence of marginal production costs between land-based and traditional CNP farming, driven by RAS technology improvements and escalating animal health costs for CNP producers;[i] and
4. Price inflation for new CNP salmon farming licenses in Norway, which currently accounts for 80% to 90% of the total capex for new CNP development and has brought upfront investment requirements in line with RAS.[ii]

In an updated analysis from Q2 2017, DNB identified a new project pipeline representing 225,000mt of planned capacity across 18 RAS projects with plans to come online by 2023, compared to an estimated 4,000mt of capacity at the end of 2018. Some portion of these announced projects will likely fail to navigate the development and construction process and DNB identified several projects from a previous survey that had failed to obtain regulatory approvals and/or financing.[iii] In many cases, management teams lacked experience with RAS and underestimated the development challenges. Many were located far from high-growth end markets like the U.S., eliminating one key cost advantage enjoyed by RAS (the ability to co-locate with high-value end markets). However, the authors note that estimated average project sizes are also increasing from 364mt in 2018 to 12,500mt by 2023, with multiple mega-projects of over 30,000mt (Table 4.2).[67]

Pareto Securities, a Norwegian investment bank covering the seafood sector, is more cautious, projecting realized production of 54,500mt by 2022, suggesting a lag in the scale and speed of RAS expansion. However, Pareto acknowledges continued growth potential to 2025, especially if CNP supply constraints persist.[iv]

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i DNB Markets estimates production costs of about $4.42/kg for a 3-5mt land-based operation, compared to marginal ONP production costs of about $4.30/kg.

ii While the capex requirements of ONP may be approaching RAS, the risk profile of a license is generally more favorable to an investor or creditor because it is a fungible, scarce asset assigned in perpetuity, compared to the 20-year useful life and limited liquidity of RAS assets.

iii Failed or delayed projects are not included in DNB's current estimates.

iv Pareto's analysis does not provide estimates through 2025, but if several of the mega-projects it has identified do come online after 2022, capacity under Pareto's assumptions would increase substantially.

Table 4.2: Land-based RAS projects identified as of April 2018[68]

#	Category	Location	Production	2018E (mt)	2020E (mt)	Total Planned Capacity (mt)
1	Small Commercial - Europe	Denmark	Y	500	2,750	2,750
2	Small Commercial - Europe	Poland	Y	150	150	2,000
3	Small Commercial - Europe	Denmark	Y	900	n.a.	2,000
4	R&D - North America	Canada	Y	400	400	1,500
5	Small Commercial - North America	Canada	Y	200	500	500
6	R&D - North America	U.S.	Y	200	200	200
7	Small Commercial - Europe	Switzerland	Y	400	600	1,500
8	Small Commercial - Asia	China	Y	200	200	1,000
9	Small Commercial - North America	U.S.	Y	30	60	60
10	Small Commercial - Europe	Iceland	Y	1,000	1,000	1,000
11	Small Commercial - North America	Multiple	Y	25	1,475	1,475
12	Small Commercial - Europe	Norway	N	–	6,000	6,000
13	Large Commercial - North America	U.S. (Florida)	N	–	5,000	90,000
14	Small Commercial - Europe	Norway	N	–	–	10,000
15	Small Commercial - Europe	Norway	N	–	–	2,500
16	Large Commercial - North America	U.S. (Maine)	N	–	–	50,000
17	Large Commercial - North America	U.S. (Maine)	N	–	–	33,000
18	Large Commercial - North America	U.S.	N	–	–	10,000
19	Partly In-Sea - Europe	Norway	N	–	–	–
	Total			**4,005**	**18,335**	**215,485**

Environmental and Commercial Value Proposition

Environmental Value Proposition

Proponents of RAS point to a range of environmental benefits of closed systems. By using a closed system, RAS reduces or eliminates the negative environmental impacts from traditional CNP on coastal and marine ecosystems, including reduced impacts to wild stocks, reduction of habitat impacts, reduced water pollution impacts, and reduction of disease transfer. However, RAS systems can be accompanied by higher energy usage, increased freshwater usage, and an increased land footprint compared to traditional systems such as CNPs. The environmental impact of RAS facilities, especially in the area of waste management and water usage is expected to improve as new technologies are refined.[69] Table 4.3 provides a comparison of the expected conservation benefits and challenges between RAS and business as usual, conventional CNP production technologies. Figure 4.3 shows average sustainability rankings of CNP and RAS aquaculture by the Monterey Bay Aquarium Seafood Watch Program. While sustainability categories differ, Monterey Bay Aquarium results generally align with the expected sustainability benefits in Table 4.3.

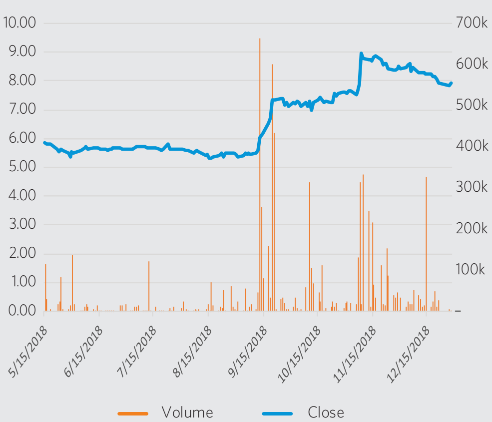
Is Bigger Better? Atlantic Sapphire as a Test Case of the Viability of Large-Scale RAS Systems:

Atlantic Sapphire, a RAS project developer looking to build the world's first land-based mega-project near Miami, FL, has emerged as the highest profile RAS project to date given its ambitious size, U.S. presence, and unconventional (for salmon) tropical location. In April 2018, the company raised NOK600 ($75 million) from institutional investors and leading northern European family offices. The successful raise came on top of NOK805 ($100 million) already raised to date since the company launched with a Danish demonstration project in 2010. The raise was "many times" oversubscribed, and share prices have continued to rise since then.

This suggests a positive outlook for RAS that will continue if these projects are able to fulfill their promises. Investors included global institutional investors (e.g., the University of Michigan Endowment and Statoil Pension Fund) and several large Scandinavian private equity funds and family offices. The project looks to scale to 90,000mt in annual capacity by 2025 across three phases of development. The Phase 1 capacity is targeted at 5,000mt, reaching a first harvest by 2020. As of Q4 2018, fresh water smolt production had begun and construction is underway, with full Phase 1 commercial operations and post-smolt grow-out expected to come online in Q3 2019. The Atlantic Sapphire project has captured the attention of mainstream investors and banks, and is seen by many analysts as a key test case for the viability of large-scale RAS projects. The net proceeds from the Private Placement will be used to continue development and finalize construction of the Atlantic Sapphire group's Denmark production facility expansion (phase 2) and the Miami production facility site (phase 1), as well as for general corporate purposes.

Figure 4.2: Atlantic Sapphire shareholders and stock price performance following the April 2018 private placement[71]

ASAME:NO
Atlantic Sapphire AS
$7.92
Daily closing share price (USD) and volumes as of 12/31/2018



DNB equity research, Atlantic Sapphire
December 5th, 2018
($USD in millions, except per share data)

Summary	
Recommendation	BUY
Share price (USD)	$8.58
52-week high / low	$8.99 / $5.30
% of 52-week high	95.5%
Analyst 52-week target price (USD)	$13.88
Upside potential (%)	61.6%
Tickers	ASA-ME; ASAME.NO
CAPITAL STRUCTURE	
No. of shares fully diluted (m)	62.5
Market cap. (USDm)	$536.6
NIBD[a] adj. end-2018e (USDm)	($40.9)
Enterprise value adj. (USDm)	$495.7
Net Debt / EBITDA adj.	5.8x

Source: Company Filings; DNB Markets.
[a]NIBD = Net Interest Bearing Debt

Atlantic Sapphire Shareholders
(as of December 31st, 2018)

Name	Country	Account Type	Holding	%
Alsco AS	Norway	Ordinary	9,459,671	15.1%
Skagen Kon-Tiki	Norway	Ordinary	5,844,306	9.4%
Vatne Equity AS	Norway	Ordinary	2,832,893	4.5%
Danske Bank AS	Denmark	Nominee	2,369,430	3.8%
Evermore Global Value Fund	Belgium	Ordinary	2,299,859	3.7%
Louise Mohn	Norway	Ordinary	1,775,280	2.8%
Sundt AS	Norway	Ordinary	1,632,953	2.6%
Blue Future Holdings AS	Norway	Ordinary	1,621,621	2.6%
Norron Sicav - Target	Luxembourg	Ordinary	1,425,830	2.3%
Citibank, N.A.	United States	Nominee	1,375,490	2.2%
Hortulan AS	Norway	Ordinary	1,367,756	2.2%
Joh Johannson Eiendom AS	Norway	Ordinary	1,214,595	1.9%
Jea Invest AS	Norway	Ordinary	1,102,630	1.8%
Norron Sicav - Active	Luxembourg	Ordinary	1,092,665	1.7%
Verdipapirfondet DNB SMB	Norway	Ordinary	1,067,855	1.7%
Nordea Bank AB	Sweden	Nominee	1,006,363	1.6%
Lani Invest AS	Norway	Ordinary	970,484	1.6%
Canica AS	Norway	Ordinary	964,010	1.5%
Statoil Pension	Norway	Ordinary	943,000	1.5%
Taconic AS	Norway	Ordinary	850,000	1.4%
Eika Norge	Norway	Ordinary	810,237	1.3%
Norsk Landbrukskjemi AS	Norway	Ordinary	744,284	1.2%
Borgano AS	Norway	Ordinary	714,244	1.1%
Skøien AS	Norway	Ordinary	700,000	1.1%
Regents of the Univ. of Michigan	United States	Ordinary	689,400	1.1%
Top 25			**44,874,856**	**71.8%**
Other			17,627,860	28.2%
TOTAL			**62,502,716**	**100.0%**

Source: Atlantic Sapphire

Commercial Value Proposition

The ability to control variables in a closed system allows for a range of production efficiencies and other advantages. RAS advocates point to several trends driving its commercial viability and potential for widespread adoption in the coming years.

RAS are declining rapidly, and by some estimates, nearing the levelized costs for new CNP projects. Ironically, these developments have been driven by RAS smolt (feed) production for net-pen producers in Norway, with many conventional salmon farmers opting to keep the fish on land for a longer duration before transfer to CNPs. The drivers of cost reduction include: a) increased stocking density; b) improved animal health and survival rates; c) more efficient feed conversion and growth rates; d) increased scale of new projects; e) lower costs for specialized equipment; and f) streamlined project development costs due to greater experience and shared knowledge resources. Though it is unlikely that RAS production costs will ever fall below those currently achieved

v Total lifetime costs of production, including fixed and capital costs, divided by the anticipated production volume over the life of the asset.

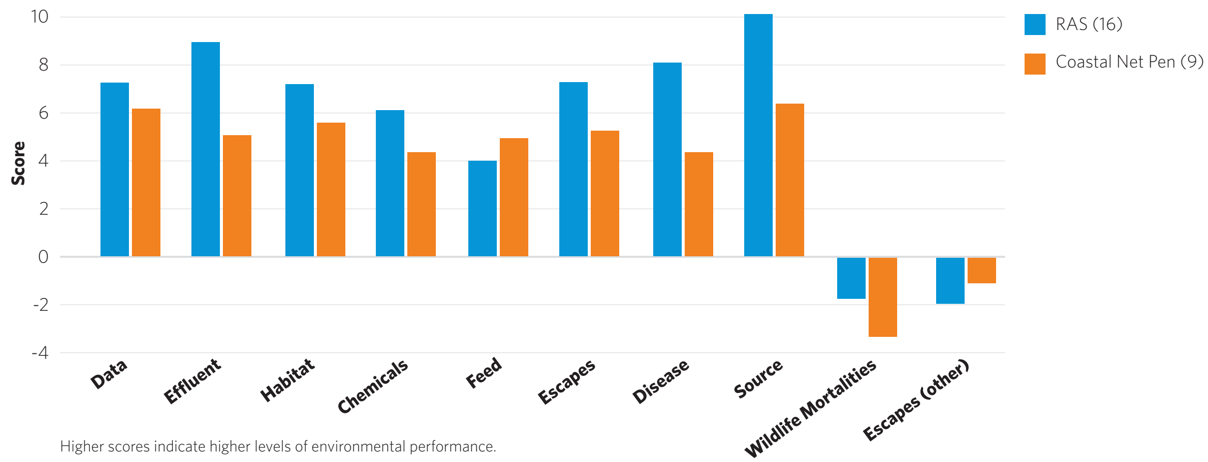
Table 4.3: Comparison of environmental impacts of RAS aquaculture to business-as-usual CNP aquaculture[72]

Environmental Factor		Expected Impacts Relative to Coastal Net Pen Farming *(other things equal)*	Rationale
Impacts to Wild Stocks	Source of Fry	Neutral	The use of RAS systems has no effect on sourcing of seed. Fry are ideally produced from a closed system hatchery from broodstock rather than collected from the wild.
	Escapes/ Genetic Interactions	Improved	Carefully and appropriately designed closed systems make escapes highly unlikely from RAS systems, minimizing or eliminating potential genetic impacts. In some limited or unusual circumstances (e.g., a natural disaster, flooding), it may be possible for cultured organisms to escape and survive in the surrounding environment. Beyond fish themselves, it may be possible that genetic material may escape the facility.
	Marine/coastal Macro-faunal interactions	Improved	RAS facilities generally have minimal direct impact on marine macrofauna, reducing or eliminating harmful interactions with sea birds, mammals, turtles, and other marine species.
	Feeds	Neutral to Improved	Some RAS producers have reported feed conversion ratios up to 15% more efficient than net pens for the salmon industry, and in commercial pilots with other species, resulting in greater resource and less fishmeal/fish oil utilization per unit of production.
Habitat Impacts		Improved	Most RAS facilities have no direct physical interaction with marine habitats. While ecological impacts on terrestrial habitats are possible with construction of physical infrastructure associated with RAS, harmful impacts can be avoided by locating on previously developed sites and avoiding sensitive habitat.

Table 4.3 (continued): Comparison of land-based RAS to business as usual CNP

Environmental Factor	Expected Impacts Relative to Coastal Net Pen Farming *(other things equal)*	Rationale
Water Pollution	Improved	RAS facilities are anticipated as having a reduced impact on the marine environment, assuming any effluent has been appropriately treated, sludge and solid waste is properly disposed, and farms are appropriately sited. Even though RAS facilities may recirculate up to 90% of water per day, large farms may still discharge significant quantities of water – millions of gallons of water per day in the case of large farms. For reduced environmental impacts to be realized, sludge and solid waste must be properly stored and disposed.
Disease	Improved	Closed RAS systems enable control over system inputs and utilize advanced water treatment technologies such as ozonation and UV irradiation, potentially reducing the need for antibiotics or other chemicals. While pathogen transfer is still possible to natural systems if effluent is not treated properly, closed system RAS reduces the transfer of pathogens to wild animals.
Freshwater Usage	Neutral to Worsened	While RAS facilities can recycle more than 90% of the water taken from the environment, these systems do require large volumes of clean water. Marine or brackish water can be used, but in some circumstances, freshwater sources may be utilized for marine aquaculture. Water usage could have adverse environmental consequences on marine, coastal, or freshwater resources in locations without sufficient groundwater or where the facility is drawing from already depleted aquifers. Compared to flow through land-based systems, however, water usage of RAS systems is drastically improved.
Land Usage	Worsened	Given the need for land for RAS facilities, the physical footprint for a land-based farm generally exceed that of CNPs on a levelized per unit basis. However, compared to coastal pond aquaculture or flow through systems, land usage for RAS can be significantly less.
Energy Usage	Worsened to Neutral	RAS production requires constant water pumping, filtration, and temperature control to maintain a healthy growing environment. Electricity consumption is thus up to two times higher than traditional production methods such as CNP systems and can be a significant drawback. However, optimized farm siting near end markets and use of renewable energy are possible. As such, high energy usage can be mitigated and may in some cases even result in fewer greenhouse gas emissions relative to CNP when considering impacts beyond the farm-gate.

Figure 4.3: Average sustainability rankings of RAS vs CNP aquaculture by the Monterey Bay Aquarium Seafood Watch Program[73]



Higher scores indicate higher levels of environmental performance.

by the most efficient CNP producers, that gap will continue to close. Indeed, new CNP production costs could potentially increase at some point due to competition over fewer licenses, and the growing impact of negative environmental variables such as climate change, effluent pollution, micro-plastics, and disease.

Optimized project siting: CNP production is limited to locations with specific environmental attributes, so these facilities are often located far from end markets, adding significant freight costs accounting for up to one third of total production costs per kilogram.[74] By co-locating production facilities in proximity to major markets, such as urban corridors in the U.S., Europe, and China, RAS facilities can offer substantial savings on shipping.

Product uniformity and quality: Because the closed-nature of RAS production allows for greater control over production variables, it is conceivable that production can be fine-tuned to more closely match the demands of the market in terms of product size, quality, and form. These attributes may ultimately allow RAS products to achieve a differentiated, premium status within the market, which may allow the industry to negotiate better terms with customers and potentially obtain a price premium over conventional products.[vi]

Controlled climate: Conventional production is subject to seasonal influences on growth rates from variables like water temperature. Land-based production allows for optimal growing conditions during the entire year, ensuring efficiency and consistency of production.

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vi Price premium assumptions are speculative given that these are commodity markets, and any competitive advantage may prove fleeting as other players enter the market.

Competitive Disadvantages and Risks

Competitive Disadvantages

Cost and scale challenges: Despite decades of interest and research dedicated to RAS, and the theoretical advantages over conventional models, RAS technology has struggled to achieve large-scale commercial adoption. Skeptics point to the significant capital requirements, long project development timelines, additional risk (technology and operational), and higher production costs relative to conventional production. The high fixed costs and operating leverage necessitate facilities with larger capacity projects and higher stocking densities relative to conventional farms to amortize these fixed costs. The minimum viable scale for a given facility will depend on a range of factors, including the species produced, stocking densities achieved, survival rates, equipment provider, land costs, power costs, and location.[vii] Substantial operational, technological, and executional challenges remain, and there will almost certainly be failures.

Systems complexity and lack of skilled operators: RAS systems are complex, requiring specialized equipment and skilled operators.[75] This complexity grows with project scale. There is a very small group of experts (perhaps less than 100) with the requisite knowledge to design, build, maintain, and operate a successful RAS project.[76] While institutional knowledge will expand as the commercial opportunity becomes more attractive, the scarcity of human capital is a near-term constraint.

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vii Location is particularly important as it relates to the distance and associated transportation costs to get products to end markets and source key inputs, such as feed, from suppliers. Other considerations such as local property and income taxes, permitting, and water treatment/discharge costs will also be determined by site location.

AQQUUA Recirculating aquaculture farm in Thailand.

Photo © Robert Jones

Large and uncertain capex requirements, high cost of capital: Although the economic case has become more compelling, estimated capex requirements ranging from $11 to $24 per kg of installed capacity for next generation RAS projects suggests that investments at the minimum viable project scale will be upwards of $50 million for the physical plant alone. Since there is very little precedent for these commercial scale projects, capital markets may be reluctant to finance them even if the business looks compelling on paper. On the debt side, the uncertainty around asset performance may deter banks and other institutional asset-backed lenders, for whom the collateral value of the asset is difficult to assess. These lenders would also have difficulty operating or selling a RAS facility in the event of a default and repossession. The resulting high cost of capital may burden early projects with unfavorable terms relative to other capital-intensive infrastructure and real assets and create a first-mover disadvantage.

Risk Analysis

RAS production faces many of the same systematic risks and drivers discussed previously in the Investment Analysis (Part III). These considerations include price risk, exchange rate risk when producing for international sale, regulatory and political risks, execution risk, animal welfare concerns, and operational capability. Additional RAS-specific risks are described below.

RAS-Specific Project Development & Construction Risks

For greenfield projects, or those requiring phased expansion over time, development risk will be high at the outset of a project and negatively correlated to the stage of development. While a similar pattern of risk exists for conventional aquaculture projects, the quantum of risk for alternative production models like RAS is currently much higher, both because the technology and operations are less proven, and because conventional operations are relatively low-tech, with less systems and operational complexity.

These risks will be substantially mitigated for operational projects that are looking to expand production by phased development on an existing footprint and will be irrelevant for the acquisition of projects that are already fully constructed and operating.

RAS-Specific Technology Risks

Since RAS technology is relatively new, these systems will inevitably encounter unforeseen design and engineering challenges and require ongoing adjustment. As many of these systems have been designed for salmonids, this is particularly a challenge for other cultured species. This will require specific alterations to meet the life cycle and physiological requirements of other species.

RAS-Specific Operating Risks

Due to the complexity of RAS systems and lack of operational track record, the short- and medium-term operational risks are higher than those for conventional production. These risks will be compounded with new species, or at very large scale. Over time, RAS operations may ultimately prove to be less risky than conventional production due to the greater control over system variables that a closed-system allows, including reduced risk of losses from large storm events. Mortality and losses from day-to-day operations should be lower for RAS than CNP, due to higher water quality controls, protection from predators, elimination of escapes, and disease and parasite exclusion. Catastrophic losses from exogenous environmental factors that affect CNP production are reduced, but RAS facilities have their own risks. The lower mortality rates within RAS require high water quality standards and adequate protection of biosecurity (i.e., ensuring no contamination from feed, or workers).

RAS-Specific Obsolescence Risks

As the technology improves over time, RAS assets also will become obsolete and less competitive, necessitating capital improvements and potentially costly upgrades to existing operations.

Impact Investment Considerations

Environmental

Even though RAS systems may systematically offer sustainability benefits compared to conventional production, such as CNP, these benefits are not guaranteed. Environmental benefits will accrue only if farms implement sound siting, farm management practices, monitoring, and application of appropriate new technologies. Environmental due diligence procedures will vary significantly depending on the phase of project development, (e.g. greenfield versus farm expansion). Table 4.4 provides a beginning set of principles, mitigating measures, and metrics that can enable responsible investing in RAS (though this list is not exhaustive). For more guidance on appropriate targets for the principles, mitigating measures, and metrics identified, refer to certification standards (e.g., Aquaculture Stewardship Council, Global Aquaculture Alliance Best Aquaculture Practices) and seafood rating guides (e.g., Monterey Bay Aquarium Seafood Watch).

Commercial

Despite the adoption challenges of the past, a structural shift may be in store for RAS economics. Studies by DNB Markets and Deloitte make the case that scarce CNP licenses and recent technological advances in salmonid production are driving RAS levelized production costs close to greenfield CNP development.[78] Capacity-adjusted capex needs for a large-scale RAS project, estimated at between $11-12/kg, are moving

Table 4.4: RAS environmental impact considerations[79]

Environmental Factor and Guiding Principle		Mitigating Measures	Metrics
Impacts to Wild Stocks	**Source of Fry** *Eliminate or minimize reliance on wild resources*	• Broodstock are not sourced from wild resources, except in the cases where necessary to ensure genetic health/sustainability of farming operations	• Documented proof of fry supply/source
	Escapes/ Genetic Interactions *Eliminate or minimize escapes and genetic interactions*	• Farm siting: farm is located in a place which makes farm escapes and the probability of survival less likely • Species selection/genetic makeup can be addressed through several possible strategies including (but are not limited to): species which cannot survive in surrounding environment should escape events occur, genetic makeup of fish matches or is not likely to impact wild populations, and/or utilization of sterile fish • Farm design: include appropriate barriers and screens to limit escapes/genetic material • Farm management and maintenance practices, protocols, and plans are in place to prevent escapes and to respond to escape emergencies	• Number of escape events • Type of species and genetic make-up documented (when applicable)
	Feeds *Minimize feed impact to wild fishery resources; Maximize feed efficiency/ resource utilization*	• Develop appropriate, high quality feeds, and specialized diets for cultured species • Ensure and monitor for efficient feeding practices • Utilize feeds with lowest fishmeal inclusion/ fish oil rates as appropriate for species • When sourcing feeds from wild fisheries, ensure sources are from sustainably managed fish stocks • Ensure sustainable sourcing of other feed ingredients (e.g., plant-based products, such as soy)	• Feed Conversion Ratio (context: under current technologies generally approaches 1:1 in the case of salmon; often 2:1 for other carnivorous marine finfish) • Fish In–Fish Out Ratio: amount of wild fish required to produce farmed fish • Fishmeal/Fish Oil Inclusion Rate
Habitat Impacts *Eliminate or minimize habitat impacts from farms*		• Use of spatial siting analysis tools to site farms away from areas of critical habitat, especially for protected/endangered species; including assessment of cumulative impacts of surrounding operations and indirect effects of habitat impacts, such as impact of water usage on surrounding habitat	• Presence, extent of protected/ endangered species, habitats, and other wildlife in area • Acreage/extent area of habitat displaced by type • Extent of development within vicinity of system

Table 4.4 (continued): RAS environmental impact considerations

Environmental Factor and Guiding Principle	Mitigating Measures	Metrics
Water Pollution *Eliminate or minimize water pollution impacts*	• Ensure appropriate design and equipment's ability to treat water to local water quality thresholds • Ensure routine water quality monitoring and testing • Ensure sound maintenance of outgoing wastewater treatment facilities • Utilization of integrated farming (e.g. wetlands, aquatic plants, algal systems) to recycle nutrients • Ensure effective solids storage (e.g. holding tanks and ponds), treatment and disposal methods (e.g. filter cleaning procedures, composting, fertilizer, and lagoons) • Deploy recent innovations to improve waste treatment (e.g. denitrifying technology, sludge technology, and ozone treatments) • Assess cumulative impacts of surrounding operations	• Discharge amount/flow • Routine water quality measurements, at least weekly or in some cases continuously, including: total suspended solids, water temperature, oxygen, salinity, nitrogens (ammonia, nitrate, nitrite), phosphorus, silicates, chlorophyll, pH, etc. • Residual chemicals, antibiotics, hormones
Disease *Minimize or eliminate any potential disease/pathogen for cultured animals and transfer to wild resources*	• Ensure appropriate biosecurity protocols • Development and implementation of animal health plans, including veterinary services • Appropriate stocking densities to minimize disease potential • Minimize chemicals and antibiotics, and use only legally approved animal drugs • Deployment of appropriate mortality removal and disposal practices	• Frequency, type, and extent of antibiotic and chemical use are in accordance with animal health standards and food and drug regulations • Appropriate stocking densities • Mortality extent and frequency
Freshwater Usage *Minimize water usage and ensure sources of water do not impact local ecology and aquifers*	• Farm siting to ensure appropriate sources of water are available and do not alter water flows • Farms are designed to efficiently utilize water	• Freshwater water use per day and per unit of production • Percent of water turnover/ reuse per day • Water use relative to aquafer and coastal system • Assess cumulative impacts of surrounding operations
Land Usage *Ensure efficient farm design and areal footprint*	• Farm design effectively minimizes land footprint	• Land/water area used per unit of production
Energy Usage *Minimize carbon footprint*	• Locate farms within proximity of major markets to avoid air freight • Utilize renewable sources of energy to mitigate energy usage • Measures to ensure feed efficiency	• KW hrs per day • KW hrs per unit of production • Average distance traveled to market

closer to estimated capex and licensing costs for a new CNP project.[viii, 80] While capex for RAS is unlikely to achieve parity with CNP capex in the near future, the 3-6x runup in CNP license costs over the past decade, combined with falling RAS costs, have narrowed the RAS capex/kg premium from nearly 400% a decade ago to just 15-50% today.

Table 4.5 provides a comparison of these figures for capex and levelized production costs for different profiles of CNP versus RAS production. On a levelized cost basis, considering total expenses related to capex depreciation, interest, and production costs, the gap has narrowed even further. CNP operating expenses have increased due to disease and sea lice issues, and the need to shift new production to higher-cost locations. According to estimates from analysts, levelized costs per kg for new CNP capacity are between 0% and 15% below those of RAS (Table 4.5).[81]

Table 4.5: Investment and production cost data of RAS vs. CNP salmon production* [82]

Production Profile	Capex ($/kg)	Levelized Cost ($/kg)	Levelized Cost w/ Transport** ($/kg)	Pre-Tax Margin @ $7.50/kg HOG***
Low capacity RAS, U.S. < 2,500mt	16.00 – 19.00	6.00 – 6.50	[6.00 – 7.50]	[0.00 – 1.50]
High capacity RAS, U.S. >2,500mt	8.00 - 12.00****	4.50 – 5.50	4.50 – 5.50	2.00 – 3.00
Low-cost legacy Norwegian CNP producers	$4.00	3.45 – 3.60	5.37 – 5.52	1.98 - 2.13
Estimates for new Norwegian CNP projects	$8.00 - $9.50	3.85 – 4.50	5.77 – 6.42	1.08 - 1.73

* Assumes average installed equipment costs of $1.92/kg, and license costs at the original issue price of $2.05/kg; however, license costs have since increased due to a moratorium on new licenses and high salmon prices, with estimates currently between $6.78 and $12.28/kg.

** Assumes $1.75 transport cost from Norway to the US.

*** On a levelized cost basis at the retail gate, including air-freight.

**** Based on DNB Markets' estimates for systems with capacity greater than 1,000 mt.

The most significant RAS cost advantage, however, derives from co-locating production close to major end markets, with corresponding air-freight savings for fresh product. For salmon, these savings amount to about $1.92/kg, which should offset any levelized cost advantages from even the lowest-cost Norwegian CNP producers. Table 4.6 provides a comparison of the detailed cost structure of RAS production using DNB Markets' estimate and projections from an actual project, as well as average numbers from CNP over the past several years.

viii While avg. ONP capex/kg is ~$1.92/kg for installed equipment, new ONP license costs have increased from $2.05/kg in 2010, to $6.78/kg as of the most recent sale in 2016. Given the Norwegian government's restrictions on new licenses, it is unclear what the value of a new license would be, but DNB Markets estimates that under an acquisition scenario this could be high as $12.25/kg (Norwegian salmon production is used as the benchmark because Norway is the largest, most cost-efficient supplier of high-quality salmon from conventional production).

Table 4.6: Comparative operational and levelized costs of RAS vs. CNP production in the salmon industry, based on a 2,500mt facility, adapted from DNB Markets, 2017[83]

Cost estimate for land-based and coastal net pen (USD/kg)

	Land-Based	Land-Based	Norway		
Cost per kg LWE	**(DNB est.)**	**(Project X)**	**CNP 2012**	**CNP 2015**	**CNP 2016**
Feed	1.54	1.54	1.30	1.57	1.75
Smolt	0.24	–	0.24	0.36	0.36
Salaries	0.36	0.36	0.24	0.24	0.24
Other Operating Costs	0.71	0.83	0.39	0.74	0.81
Depreciation	0.36	0.36	0.12	0.18	0.23
Total Production Cost	**3.20**	**3.08**	**2.28**	**3.08**	**3.38**
Net Finance	0.30	0.18	–	–	–
Insurance	–	–	–	–	–
Harvesting Cost	0.36	0.36	0.36	0.36	0.36
Production Cost (WFE)	**3.85**	**3.62**	**2.64**	**3.44**	**3.74**
Production Cost (HOG)	**4.28**	**4.02**	**2.93**	**3.82**	**4.15**
Air Freight Packaging	–	–	0.09	0.09	0.09
Inland Freight	0.12	0.12	0.12	0.12	0.12
Export Levy	–	–	–	–	–
FOB Norwegian Border	**4.40**	**4.14**	**3.15**	**4.03**	**4.36**
Estimated Freight Cost (Asia / U.S.)	–	–	1.66	1.66	1.66
Import Duties	–	–	–	–	–
Estimated Total Cost to Asia / U.S.	**4.40**	**4.14**	**4.81**	**5.69**	**6.02**

Assumption: NOK:USD = 8.4327

Operational

As identified in section 3.2, the six key operational drivers for the aquaculture industry are: (1) feed conversion ratio, (2) stocking density, (3) growth rate, (4) normal mortality rate, (5) animal health and welfare, and (6) product quality consistency and form. Here we discuss specific considerations for RAS production systems.

Overall, we find that the operational success of a project will depend critically on the system design and suitability for a given location, species, and production volume, as well as a strong management team with a track record of success operating the system in question. These factors will affect nearly all the key operational variables mentioned above.

The system supplier contract will also be an important consideration, with some suppliers offering turnkey delivery and set-up, maintenance and repair consultations, and 3-5 year systems performance guarantees. While multiple providers sell "off the shelf" RAS systems for Atlantic salmon aquaculture, appropriate and proven systems for other marine finfish species are much more limited. Particular scrutiny must be given to engineering designs and systems for new species.

Feed Conversion:

The ability to control the water temperature, quality, and feeding within a closed system should reduce waste, improve survival, and improve growth rates relative to CNP production. Because of the unique RAS environment, feed formulations must be customized, and the amount and timing of feeding is critical to optimize production and avoid detrimental health effects.

Stocking Density

The production unit economics for a given system generally improve with increasing stocking density up to the point that density begins to stress the animals, leading to health problems, reduced growth, and increased mortality. Salmon industry studies indicate that densities of up to 75-80 kg/m^3 can be achieved without significantly stressing the animals, though in practice salmonid RAS projects stock at lower densities 55-65 kg/m^3. This is a significant value driver for RAS production over CNP, where densities range from 15-30 kg/m^3.[84] Improved water quality controls (e.g., oxygenation, flushing, and pathogen exclusion) are a major driver of increased RAS stocking densities.

Growth rates:

Fish growth rates are strongly tied to optimal water temperature and water quality conditions.[85] In a RAS system where these factors can be controlled, increased growth rates over CNP production could be expected.

Mortality Rate/ Animal Health and Welfare:

With improved control over growing conditions, mortality rates and the incidence of disease events can potentially be mitigated. However, should such a disease event occur, the possibility of impact to the entire crop or system can remain quite significant.

Product Quality, Consistency, and Form:

Off-flavoring can result from marine salmon absorbing elements from the surrounding water that bioaccumulate in their fat cells. Additionally, salmon and other species may absorb coastal contaminants, which are eliminated within RAS production. That stated, it is possible for off-flavoring to occur in RAS production if production is too high-density and water reuse is not handled correctly. Specialized feeds, proper water treatment techniques, and farm practices (e.g., purging the fish for prescribed periods of time) can alleviate off-flavor issues. Additional R&D may further improve production efficiency and quality.

Early maturation, a phenomenon unique to salmonids, leads to lower-quality flesh, and in turn affects price and customer acceptance. Variables such as salinity, temperature, lighting, and stocking density can affect maturation, and must be carefully managed. A benefit for RAS producers is the ability to control and modify these factors, which (aside from stocking density) CNP producers cannot control. However, an operational challenge for RAS producers is that several of the same variables that maximize growth rates, such as a slightly warmer water temperature, also lead to early maturation.[86] Improvements in managing these variables has reduced rates of early maturation from 35% to 5%.

Conclusions

RAS technology has long been challenged by economic and technological disadvantages, but progress has accelerated markedly in recent years. The environmental conservation advantages of RAS offer a compelling story from an impact perspective, and the flexibility of a controlled, closed system has the potential to be commercially superior as well.

In the short term, our view is that the sector will remain risky, but knowledgeable investors with a higher risk threshold may find compelling opportunities at a discount. The risk-return profile of RAS projects in the near term will likely pose a challenge for real-asset investors seeking long-duration, capital-intensive, low-risk, yield-based assets available in traditional infrastructure, real estate, and agriculture. For investors with a higher development-stage risk tolerance, a thesis around capital appreciation, and higher return hurdles, the profile of these investments may be more attractive. However, these investors may be less comfortable with the asset characteristics (capital intensity, long life, cash generating, project-based, low-growth). Therefore, we foresee the most suitable investors at this stage to be those with flexible capital sources, a broad mandate, and long investment time horizons, such as family offices and high-net worth individuals. Impact funds or mission-related components of foundation endowments, with a mandate to catalyze positive social and environmental change using patient capital, are also appropriate investors at this stage.

We believe that it is only a matter of time before RAS production assets and ancillary business models become targets for a range of mainstream private capital pools, including real asset and yield-focused investment, venture capital, and private debt. Once there are multiple next generation RAS projects online with multi-year operating histories, the sector will offer significant opportunities for mainstream institutional capital.

Section 4.2: Offshore Finfish Aquaculture Systems

Key Takeaways

- Offshore finfish aquaculture has the potential to provide a sustainable and scalable alternative to traditional coastal net pen (CNP) aquaculture and is likely to constitute an important subset of overall sector growth.
- Offshore aquaculture can provide environmental performance advantages relative to traditional CNP aquaculture, including reduction of effluent and habitat impacts, improvements in Feed Conversion Ratio (FCR), improved disease control, and reduced genetic interactions with certain species in some cases, although additional studies are warranted.
- Offshore aquaculture can provide significant commercial performance advantages, including the potential for larger scale, automation of processes, and new species cultivation; improved water quality, site availability, proximity to markets, and product quality; and reduced user conflicts and unit costs.
- Most commercial-scale offshore projects have come online during the past five years.
- Two categories of offshore aquaculture producers have emerged: subsidiaries of large, vertically integrated, diversified incumbents from the salmon industry (predominantly in Norway); and small independent newcomers with business models dedicated to offshore technology and farming of niche species that do not compete with conventional producers.
- Large incumbent offshore leaders from the Norwegian salmon industry have accelerated technology development and validated offshore aquaculture more broadly. Such producers are backed by experienced operators that have dedicated substantial R&D resources to invest into new, mega-scale technologies. Most Norwegian producers have a salmonid focus, receive design input from offshore oil and gas sector, and are incentivized by a government program granting free development concessions.
- Independent offshore producers are relative newcomers, not diversified with conventional production, often emphasize the sustainability aspects of their production, and are generally based in Latin America. Newcomers specialize in niche species and have received private financing rather than institutional investment due to their lack of operating history and thin balance sheets.
- Concerns over limited nearshore sites, environmental sustainability, and food security have also led to new, state-sponsored development projects in China.

Other countries exploring the potential for offshore aquaculture include the United States, Japan, and Indonesia, although few active operations exist.

- Due to relatively high capex requirements for offshore production, the complexity of deep-water operations, and regulatory uncertainty, early movers must be highly risk tolerant as they seek to prove commercial viability at scale.
- Promising private investment opportunities may exist for operations with phased development plans, proprietary technologies, vertical integration, or other strategic advantages. Knowledgeable private investors with long investment horizons and higher risk thresholds may find reasonably priced opportunities as early movers in a sector that remains uncrowded.

Background and Market Landscape

As with RAS, offshore production provides a model of aquaculture that avoids many of the environmental and economic downsides of conventional production. A growing number of proponents suggest that these open-ocean systems, located far from sensitive shoreline habitat and competing interests, offer the potential to scale production in a more resource-efficient, environmentally friendly manner.[87] Futher, recent research suggests that most coastal countries have sufficient suitable ocean area to fulfill their entire domestic seafood supply through offshore aquaculture.

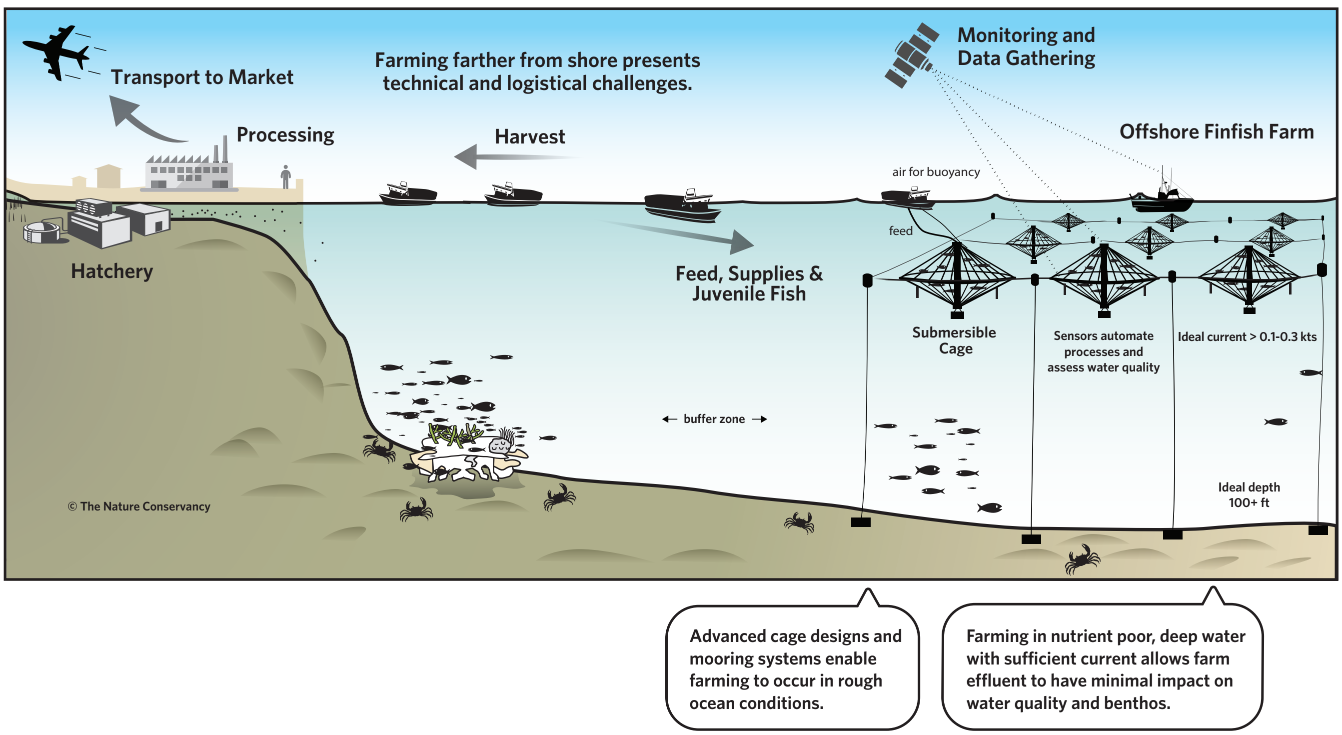
Offshore, or "open-ocean" aquaculture encompasses a broad range of production systems located within deep water marine environments. These operations are fully exposed to open-ocean elements such as wind, waves, storms, and currents. Offshore aquaculture is primarily defined by a high level of exposure and lack of protection from land masses, rather than a predetermined distance from shore. Countries generally have different definitions of what constitutes offshore aquaculture. The Norwegian government classifies offshore production sites according to a series of five site classes, which correspond to degree of open-ocean exposure (small to extreme) and significant wave heights (<0.5m to >3.0m).[88] Offshore production sites could theoretically extend to the 200-mile national Exclusive Economic Zone (EEZ), or even the High Seas beyond that. However, observation of existing offshore aquaculture operations suggests that the practical boundaries are limited to about 30 miles from shore.[89]

History & Context

While the idea of farming seafood in the open ocean has been around for decades, early efforts were hindered by a lack of suitable cage designs and equipment needed for extreme conditions. Serious efforts to design specialized systems began in the early 1990s, but project development was generally limited to small pilots. This was largely due to prohibitively high capex and operating costs, uncertainty around technological performance at scale, an abundance of lower-cost conventional nearshore sites, and a lack of regulatory frameworks for offshore concessions.

Offshore marine finfish aquaculture began with net pens like those used in coastal waters; however, a broad range of production technologies have been developed, some of which bear little resemblance to simple net pens. Exposure to the elements of the open ocean environment has required new engineering approaches to address system fragility and capitalize on the greater size and scale afforded by abundant offshore space. This has led to the development of large systems, that can withstand large storms by utilizing sophisticated cage designs, some of which are submersible and utilize advanced mooring systems (see Figures 4.4 and 4.5).

Figure 4.4: Representative offshore finfish aquaculture facility



During the past 10 years, however, regulatory constraints on conventional site expansion have intensified the interest in offshore production among industry heavyweights.[ix] Most commercial-scale offshore projects have come online during the past five years. While these operations represent only a small fraction of overall production, as the infrastructure and supporting technologies improve and costs fall, the commercial attractiveness and scale of production should increase. The interest from the Norwegian salmon industry has also accelerated technological development and validated offshore

ix The competition for conventional sites results from growing demand and escalating prices for salmon.

more broadly. While many of the largest offshore salmon technologies remain in either concept or demonstration stage, smaller cage technologies employed by the independent offshore producers have operational track records of a decade or more.

Market Landscape

Offshore aquaculture producers tend to fall into two categories, each with a distinctive business profile and strategic justification for entering the sector. The first category consists of subsidiaries of large, vertically integrated, diversified incumbents from the salmon industry. Their activity is spurred by a Norwegian Government program to grant free medium-term concessions for the development of innovative offshore production technologies. The second group consists of small, independent newcomers with business models fully dedicated to offshore technology. These independent producers tend to harvest niche species that do not compete directly with large, conventional producers. These categories are profiled below.

Integrated Incumbents (Salmon Industry)

The largest offshore producers tend to be subsidiaries of the largest, publicly traded salmon-industry incumbents, and projects often include joint ventures with companies having deep water oil and gas exploration expertise. They view offshore production as a future growth engine, given the limits to CNP expansion, and are generally financed via cash-rich balance sheets of the parent companies.

The technology employed in these operations is similar in size and scale to offshore oil rigs and is designed to be deployed in depths of up to 1,000 feet and beyond five miles into the open ocean. The facilities are able to withstand waves of over 50 feet and hurricane-force winds.

Within the salmon industry, large-scale offshore projects are being deployed at the demonstration phase by large integrated majors with long operating histories and extensive conventional CNP grow-out operations. Primarily based in Norway, these companies are publicly traded on the OSE and manage multi-national operations across the supply chain. They are among the largest companies in the seafood industry, with annual revenues of $250 million or more.[x]

The Norwegian government has a stated goal to increase salmon production from 1 million to 5 million mt by 2050. To incentivize development of the offshore sector, the Norwegian Directorate of Fisheries launched a new Development Licensing Program (DLP) in November 2015 that will grant free development concessions for up to 15 years to approved offshore projects. The projects must be large-scale, backed by established teams with operational and development expertise in aquaculture and

x Mowi, the largest company by annual revenues, posted sales of $4.25 billion in 2017 with a market capitalization of nearly $10.3 billion, according to the Marine Harvest 2017 Annual Report and Oslo Stock Exchange data.

offshore infrastructure (including deep-water oil and gas), and offer commercially viable technologies to address environmental and health challenges. Successful projects will be able to convert the concessions into ordinary commercial licenses at the end of the concession period, at a cost of $1.25 million (well below the $6.5-7.5 million needed for conventional coastal licenses). A single license allows for up to 780mt maximum allowable biomass on a live weight basis.[xi]

xi Approximately 655.2mt on a HOG basis, assuming a live to gutted weight conversion rate of 0.84.

Table 4.7: Major salmon industry players leading offshore finfish aquaculture development

($ in millions, except per share)	BAKKAFROST	Grieg Seafood	LERØY	marineharvest	NORWAY ROYAL SALMON	SALMAR
CEO / Headquarters	Regin Jacobsen	Andreas Kvame	Henning Kolbjørn Beltestad	Alf-Helge Aarskog	Charles Høstlund	Olav-Andreas Ervik
	Bergen, Norway	Bergen, Norway	Bergen, Norway	Bergen, Norway	Trondheim, Norway	Bergen, Norway
# Employees	1,072	780	4,298	13,233	172	1,195
LTM Production	43,826mt	69,609mt	154,906mt	367,524mt	31,238mt	142,000mt
Share Price as of 02/01/2019	$51.65	$12.71	$7.95	$22.07	$23.67	$50.99
Market Capitalization	$2,523.3	$1,403.6	$4,731.2	$11,024.4	$1,031.3	$5,777.4
Enterprise Value	$2,551.6	$1,715.7	$5,103.7	$12,641.7	$1,040.9	$6,177.0
<u>Financial Projections:</u>						
Revenues						
2018e	$505.7	$912.2	$2,431.3	$4,368.8	$608.8	$ 1,330.8
2019e	$592.6	$1,003.8	$2,621.6	$5,182.2	$688.4	$1,409.9
2020e	630.0	$1,198.9	$2,748.1	$5,580.3	$740.9	$1,536.4
EBIT (adj.)						
2018e	$200.0	$170.2	$498.8	$930.4	$90.7	$342.1
2019e	$260.7	$222.9	$575.4	$1,310.2	$139.7	$395.7
2020e	$295.6	$282.8	$644.8	$1,441.0	$154.0	$443.4
EPS (adj.)						
2018e	$3.07	$0.90	$0.63	$1.45	$1.56	$2.85
2019e	$4.00	$1.43	$0.72	$1.94	$2.41	$3.50
2020e	$4.61	$1.85	$0.82	$2.16	$2.70	$3.91

Table 4.8: Offshore development licenses awarded and preliminarily granted by the Norwegian Directorate of Fisheries as of 10/31/2018[90]

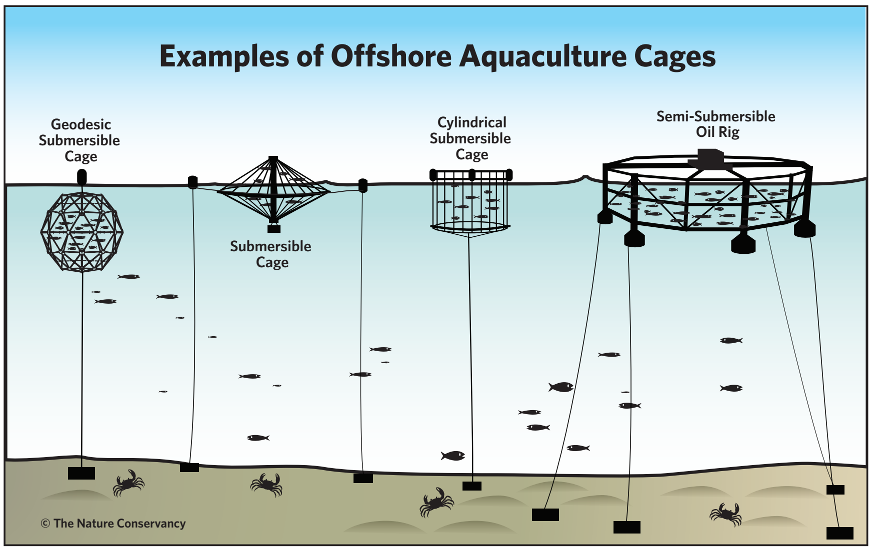
			Production Capacity (mt)					
Project Name	**Company**	**# Licenses**	**2018e**	**2019e**	**2020e**	**2021e**	**2022e**	**Potential**
Awarded Projects								
Havmerden	Nordlaks Oppdrett AS	21.0	–	–	–	6,000	14,000	27,300
Ocean Farm 1	Ocean Farming AS (SalMar ASA, 91%)	8.0	4,000	8,000	10,000	10,000	10,000	10,400
Arctic Offshore	Norway Royal Salmon ASA & Aker ASA	8.0	–	–	–	3,850	9,625	10,400
The Egg	Mowi AS	6.0	–	–	700	2,000	5,000	7,800
Aquatraz	MNH Produksjon AS	4.0	–	720	3,000	4,000	5,000	5,200
Produktsjonstank	Hydra Salmon Company AS	4.0	–	–	2,000	3,000	5,000	5,200
Akva Design	AkvaDesign AS	2.0	–	1,000	1,500	2,000	2,500	2,600
AKVA/Sinkaberg	Atlantis Subsea Farming AS	1.0	–	500	1,000	1,200	1,200	1,300
Awarded Totals		**54.0**	**4,000**	**10,220**	**18,200**	**32,050**	**52,325**	**70,200**
Preliminary Commitments								
Smart Fishfarm	Mariculture AS (SalMar ASA, 51%)	8.0	–	–	–	–	4,000	10,400
iFarm	Cermaq Norway AS	4.0	–	–	–	1,000	2,000	5,200
Stadium Pool	Stadion Laks SUS	2.4	–	–	–	500	1,000	3,120
Sea Platform	Nekst AS	2.0	–	–	–	–	2,000	2,600
Marine Donut	Mowi AS	1.6	–	–	–	1,000	1,500	2,080
Fish Globe	Fish Globe	1.5	–	–	–	1,000	1,500	1,950
Pipefarm	Lerøy Seafood Group AS	0.6	–	–	–	500	600	780
Preliminary Totals		**20.1**	**-**	**-**	**-**	**4,000**	**12,600**	**26,130**
Other High-Potential Candidates								
Project A	Company A	6.0	–	–	–	1,000	2,000	7,800
Project B	Company B	5.0	–	–	–	1,000	2,000	6,500
Project C	Company C	4.0	–	–	–	1,000	2,000	5,200
Project D	Company D	4.0	–	–	–	–	1,500	5,200
Project E	Company E	4.0	–	–	–	–	1,500	5,200
Project F	Company F	3.0	–	–	–	–	1,500	3,900
Other Potential Totals		**26.0**	**-**	**-**	**-**	**3,000**	**10,500**	**33,800**
PROJECTED TOTALS		**100.0**	**4,000**	**10,220**	**18,200**	**39,050**	**75,425**	**130,130**

Note: Calculation of potential capacity uses Pareto Securities' assumption of 1,300mt of annual production per license (each license permits 780mt of allowable biomass)

In response to the DLP, companies representing 104 projects applied for 898 development licenses. As of July 2018, 53 licenses had been awarded to 8 projects, representing 69,810 mt of production capacity. Producers representing another 26,000 mt in anticipated project capacity have received preliminary commitments, pending final approval. Pareto Securities, a Norwegian investment bank, estimates that a total of 100 licenses, representing 129,610 mt of annual production will ultimately be awarded.[91]

While not all project applications were affiliated with the large incumbent sector leaders, the leading candidates are generally backed by very skilled, experienced management teams. The leading companies pushing ahead in this segment skew to the large end and leading candidates are backed by experienced operators that have dedicated substantial R&D resources to invest into new, mega-scale technologies. Initial R&D for these projects is typically financed as corporate R&D, though several offshore units are structured as separate legal entities able to issue private debt, equity, and project-based financing.

Figure 4.5: Types of offshore aquaculture pens



All the offshore facilities being developed under the DLP are designed for finfish production, with a focus on salmonids, per the Fisheries Directorate objective. The industry players investing in these technologies are likely to focus on Atlantic salmon for the foreseeable future, with other salmonids like trout and arctic char as potential alternatives. Executives have suggested that these designs could eventually be used to produce non-salmonid species like cobia, barramundi, sea bass, and sea bream.[92]

Offshore operations in Norway have borrowed from offshore oil rig technology, with design input and project management assistance from experts in the offshore oil and gas sector. Although the offshore-specific applications remain somewhat experimental, these facilities are heavily reliant on automation, economies of scale, and production efficiencies. They are also semi- to fully submersible and resilient, able to withstand extreme weather, currents, and large waves. As with RAS, China may also emerge as a significant developer of offshore technologies as it implements regulatory changes for in-water CNP production.

As offshore projects are at such an early stage of development, their economic and operational profiles are still emerging. The only project currently producing under Norway's DLP, Ocean Farm 1, is just over a year into its pilot phase, with an initial harvest scheduled for the fall of 2018 (see case study). No public performance metrics have been released, but the company has indicated that progress is continuing according to plan. However, there are reports of sea lice, one of the primary issues with coastal farming that the offshore model had hoped to solve. The company has downplayed this development as "expected," and it remains to be seen whether this will in fact be a pervasive problem.[93]

Case Study: SalMar Ocean Farming AS[94]

Ocean Farming AS is a subsidiary of the vertically integrated salmon farming giant SalMar, which produced 151,000mt of salmon in 2017. SalMar is publicly traded on the Oslo Stock Exchange with a market capitalization of $5.7 billion. An early leader in the offshore space, SalMar recently acquired 51% of Mariculture AS, another offshore subsidiary that is developing even larger vessels with twice the production capacity of the Ocean Farm model.

SalMar was awarded eight Norwegian development licenses under a seven-year concession, and launched Ocean Farm 1 in April 2017, stocking a single Ocean Farm vessel with 1 million smolt. Ocean Farming AS executed a contract in April 2017 to build five additional Ocean Farm vessels in anticipation of future expansion.

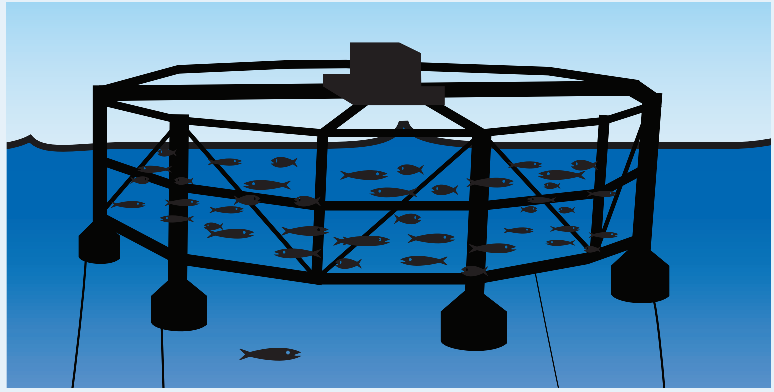


Figure © TNC

The Ocean Farm 1 vessel design is based on semi-submersible oil drilling rigs used in North Sea, and has the following specifications and characteristics:

- *Size: 110m x 68m; 245,000m3 volume*
- *Operational at depths from 100m to 300m*
- *Able to withstand wave heights of up to 15m*
- *Production capacity of up to 6,000mt (~1.5 million fish)*
- *Total capital investment of $86.0m*
- *Target mortality rate <2.0%*
- *14-month grow-out*
- *Highly automated; requires 2-4 people to operate*

While salmon prices experienced significant volatility in 2018, a strong long term price trend since Q4 2015 has project developers optimistic about offshore project viability under the DLP.[xii] However, it is also likely that diversified players with strong balance sheets are viewing their initial investments under the program as something of a call option to secure long-term licenses relatively cheaply with the expectation of higher future prices, even if some remain unprofitable on an operating basis.

Pure-Play Independent Offshore Producers

In contrast to the large conventional players, a series of independent, standalone companies also compete in the offshore space. They are relative newcomers, not diversified with conventional production, and often emphasize the sustainability aspects of their production. These firms are not drawn to the sector by government concession programs or subsidies, and the majority are based in Latin America rather than Europe.

xii NASDAQ Salmon Index 3-6kg weighted 30/40/30, as of 7/31/2018.

These relative newcomers also tend to produce niche species with private financing from family offices, wealthy founders, or smaller, specialized private equity or venture investors. In most cases these companies and projects are not yet ready for institutional investment, due to their lack of operating history and thin balance sheets. These operations have reached farm-level production capacity in the 3,000 mt range.

Among the independent offshore-only producers, most are concentrating on niche categories of high-value marine finfish, including cobia, yellowtail, and snapper. They are being produced in markets with limited wild-capture substitutes or competition from lower-cost conventional farms. Leading names in this category include Kampachi Farms, Open Blue, Earth Ocean Farms, Ocean Farm, and Martec (Table 4.9).

Table 4.9: Independent offshore finfish aquaculture farms[95]

Company	Location	Species	Estimated Current Annual Production
Kampachi Farms, LLC	Kona, HI / La Paz, Mexico	Almaco jack (Yellowtail)	<100 mt
Blue Ocean Mariculture	Kona, Hawaii	Almaco jack (Yellowtail)	400 mt
openblue Cobia	Puerto Lindo, Panama	Cobia	3,000 mt
Earth Ocean Farms	La Paz, Mexico	Totoaba; Red Snapper	360 mt
Ocean Farm S.A.	Manta, Ecuador	Cobia	0
MARTEC	Costa Rica	Pacific Lane Snapper	Unknown
Indigo Seafood	Palau	Rabbitfish (Siganus lineatus), grouper	0

Other Exploratory Efforts:

Concerns over limited nearshore sites, environmental sustainability, and food security have also led to new, state-sponsored development projects for offshore aquaculture. As removal of coastal net pens continues in China, we anticipate a significant move towards offshore aquaculture facilities. The U.S. is actively working to develop an offshore aquaculture industry by improving regulatory conditions and investing in science and technology. Exploratory efforts are also under way in Indonesia and Japan. A number of more storm-resistant, industrial-scale, and "professional" net pen aquaculture businesses are developing in Southeast Asia—these operations are sometimes referred to as offshore aquaculture facilities, but do not truly operate in the open ocean environment.

Environmental and Commercial Value Proposition

Environmental Value Proposition

Offshore productions systems offer a potentially scalable, sustainable alternative to conventional coastal production. Table 4.10 provides a comparison of the conservation benefits and drawbacks of offshore compared to business as usual, CNP finfish operations. Because there are few examples of full-scale commercial offshore aquaculture operations, the ecological impacts of offshore aquaculture have not been as well documented as other aquaculture subsectors, and studies with direct comparisons to coastal sites are few.[97] Additional comprehensive ecological assessments and comparative studies are needed. Nonetheless, the current state of science demonstrates potential ecological benefits and risks of offshore aquaculture. Figure 4.6 shows average sustainability rankings of CNP relative to offshore aquaculture by the Monterey Bay Aquarium Seafood Watch Program.

Commercial Value Proposition

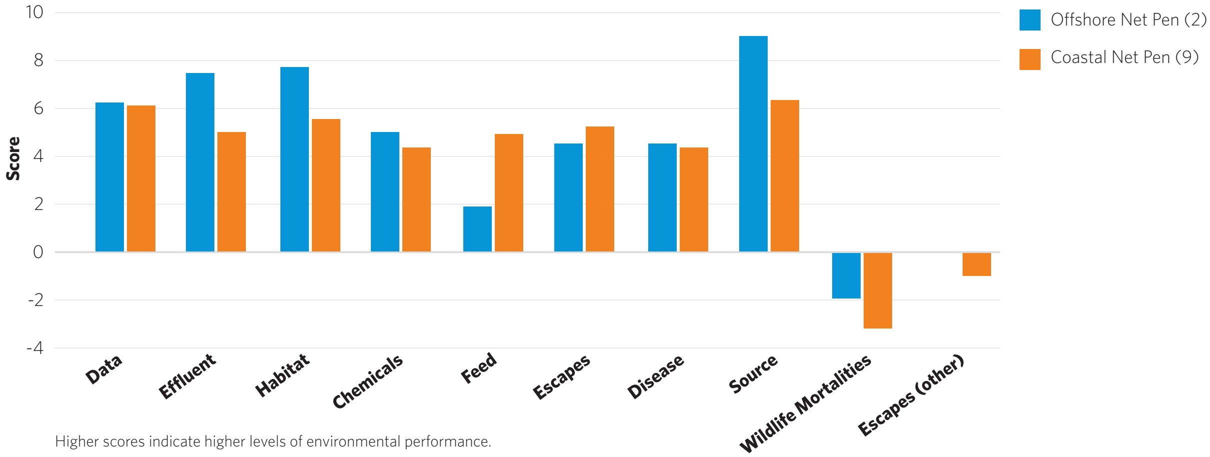
Offshore aquaculture has the potential to become a scalable, transformational, and profitable production alternative. Despite considerable variability across projects, the following value drivers suggest a path to viable business models over the next decade:

1. **Water quality:** Abundant, clean, oxygenated water is essential to all fish farming. Unlike coastal sites located in sheltered bays, deep water offshore sites generally have much greater water cycling and flow and are isolated from land-based runoff, vessel pollution, seabed disruptions, and conflicting industrial uses. As with RAS, higher water quality offers distinct operational and financial advantages relative to traditional coastal production:
    a. Reduced mortality: better water quality improves animal health and reduces both run-rate mortality, as well as potentially reduces the threat of catastrophic loss from events like harmful algal blooms.

Table 4.10: Comparison of environmental impacts of offshore finfish aquaculture to business-as-usual CNP aquaculture[98]

Environmental Factor		Expected Impacts Relative to Coastal Net Pen Farming *(other things equal)*	Rationale
Impacts to Wild Stocks	Source of Fry	Neutral	Similar to coastal net pen farming and RAS, fry are ideally produced from broodstock within a closed system hatchery rather than collected from the wild.
	Escapes/ Genetic Interactions	Neutral to Improved	Offshore facilities are designed to be more durable and withstand the harsh, high energy conditions of the open ocean environment. Compared to near-shore farming, offshore systems are generally robustly engineered to reduce the chances of structural failures and mass escapement. As fish are located away from sensitive coastal habitat and river systems utilized by native fish, the risk of genetic interactions from certain wild fish populations are potentially reduced.
	Marine/coastal Macro-faunal interactions	Neutral	Appropriately located offshore facilities can result in reduced interactions with coastal macro-fauna. However, as operations are located in deeper water, there is a potentially increased risk of interactions and entanglements with animals that more frequently inhabit oceanic environments, such as whales, sharks, and other protected species (e.g., sea turtles).
	Feeds	Neutral to Improved	In some cases, cleaner, oligotrophic water may allow fish to grow faster with reduced mortality rates, which in turn improves the overall FCR for a given species and feed type.
Habitat Impacts		Improved	Offshore facilities, when located in deeper, higher flow waters, minimizes or negates impacts to the seafloor and sensitive nursery or spawning habitats.
Water Pollution		Improved	Offshore net pens sited in oligotrophic deep water with fast currents are subject to greater flushing due to wave action, wind, and currents, which dilutes and disperses effluent from food waste and excrement. This flushing reduces nutrient loading and the corresponding risk of formation of low dissolved oxygen 'dead zones' that can become problematic in sheltered marine environments. Generally, studies on existing offshore farms have shown that farm impacts on water quality have not been statistically significant or have been imperceptible beyond 90 meters from the farm.
Disease		Improved	Pathogen introduction is possible with any culture operation. However, improved water quality, a high energy water column, and long distances to shore or other farms may reduce the need for antibiotics or chemicals and may limit the spread of disease, both among farmed and wild populations.
Freshwater Usage		Neutral	Transition to offshore farming would likely have no effect.
Land Usage		Neutral	The land usage of offshore is neutral to that of coastal farms.
Energy Usage		Worsened to Improved	Offshore production would likely increase carbon emissions associated with farm maintenance and harvest due to increased distance from shore. However, looking beyond the farm-gate, siting farms in proximity to major markets may enable greenhouse gas savings over traditional CNP aquaculture products that are typically air freighted to end markets.

Figure 4.6: Average sustainability rankings of offshore vs CNP aquaculture by the Monterey Bay Aquarium Seafood Watch Program[99]



  b. Improved feed conversion ratios: due to better growing conditions for the fish, feed is more efficiently converted to biomass.
  c. Reduced animal welfare costs: improved water quality and exchange should limit disease and parasite outbreaks, reducing the need for costly animal welfare inputs like de-lousing and application of antibiotics.

2. **Site availability:** The limited availability of biologically viable, economically attractive coastal sites, along with growing regulatory hurdles to new coastal projects, means that coastal supply alone will not be able to meet growing seafood demand. The physical abundance of offshore sites, and greater physical space per site, offer a scalable path to supplying this demand growth.[xiii] This will also benefit offshore producers by reducing license costs. In theory, an abundant supply of new sites should allow licenses to be offered to producers at a discount. By contrast, coastal salmon license prices have increased markedly in Norway over the past decade as site supply has dwindled.
3. **Reduced conflicts:** Appropriately located offshore sites should have fewer competing uses, reducing conflicts with other users. This should benefit operators by limiting political risk and reducing restrictions on farm size.
4. **Scale advantages to offshore production:** Because offshore technologies are suited for deeper water, the size and scale of facilities can be much larger than traditional coastal net pens, even with lower stocking densities. These scale advantages can amortize the higher capital and fixed operating costs and make increased investment in automation and other supporting technologies financially viable.

xiii Assuming regulatory restrictions do not prevent such new development.

5. **Market proximity:** Since coastal production is limited to locations with specific environmental attributes and minimal coastal populations, these facilities are often located far from end markets, adding significant freight costs, which can be up to 35-45% for fresh or live markets. By locating offshore production facilities closer to major markets and processing infrastructure, producers can achieve substantial savings on shipping and further offset the higher production costs.
6. **Automation:** With the greater scale and longer-lived infrastructure of offshore farms, and the higher costs associated with servicing a facility far from shore, there is a greater financial case to invest in automation. Leading offshore facilities today are highly automated, improving the operating profile of the businesses and addressing many of the challenges of managing operations far from shore.
7. **Technology innovation & falling costs:** Because offshore production is capital intensive and reliant on technology, it is likely that increased innovation will continue to drive down the levelized costs of production. Artificial intelligence and machine learning tools should especially benefit projects far from shore given higher real-time monitoring costs and access challenges. In addition, the greater proposed production capacity of offshore facilities will be best able to leverage technology to improve productivity given that it is a substantially more capital-intensive technology with a long-useful life. These developments promise to reduce or even eliminate the full life-cycle cost discrepancy between offshore and coastal farms. These systems will reduce the need for costly human interventions in sometimes inhospitable environments by automating routine tasks like feeding and providing data and addressing health issues. Strong and growing industry investment in the offshore space over the past decade, spurred by Norway's development license program (see below) should also benefit independent producers of niche species, and is likely to significantly benefit the entire offshore sector over the next 5 to 10 years.
8. **Product quality:** Although data is limited, offshore aquaculture may offer quality advantages, as animals experience lower stress levels and reduced exposure to pathogens and parasites. Better water quality and cycling may avoid issues of off-flavoring and concerns about the impact of contaminants on human health.[xiv]
9. **Higher output & lower unit cost:** The advantages of higher energy, clean water, and large scale, automated facilities may allow for higher stocking densities, lower mortality rates, and lower servicing costs, potentially achieving a cost advantage to coastal facilities from an operating basis.
10. **New species cultivation:** Offshore production offers the potential to produce novel and potentially more sustainable species at scale, such as cobia and yellowtail.

xiv Assumptions of price premia are speculative, given that these are commodity markets, and any competitive advantage may prove fleeting.

Competitive Disadvantages & Risks to Offshore

There are several clear disadvantages to offshore aquaculture, which include:

- **Capital and operating costs:** The greatest disadvantage of offshore facilities is the high cost of constructing, installing, operating, and maintaining cages and feeding and monitoring systems that must be able to withstand wave and wind conditions in an exposed ocean environment. This environment also adds to the required size and operating costs of support vessels.
- **Regulatory uncertainty:** Perhaps the greatest non-market barrier to widespread adoption is the lack of suitable governance frameworks in many jurisdictions to license, plan, and regulate offshore production. In the U.S., the maritime jurisdiction ends at three nautical miles offshore for most states, beyond which are federal waters. Both state and federal licensing remains underdeveloped for offshore aquaculture. Effective management of offshore resources requires comprehensive marine spatial planning, which considers competing uses and the local and regional environmental and social impacts of various maritime activities. In jurisdictions around the globe, the lack of an effective governance framework will result in one-off projects managed under a patchwork of regulations and could allow for projects that are inappropriate for the local ecological context.

Risk Analysis

Commercial Risks

Because there are so few large-scale production facilities with established track records, it is hard to know exactly how successful a transition to offshore production will be. The following challenges may limit the sector's development in the near-term. Utilizing the commercial risk matrix developed in Table 3.5, we identify the offshore finfish aquaculture specific commercial risks:

Salmon fish farm in Norway.

Photo © Adobe Stock

Offshore-Specific Development Risk: Due to the uncertain policy/regulatory environment identified above, offshore operations often have a very high level of permitting uncertainty in the development phase. Many operations may get held up months or even years in the permitting phase. This risk varies greatly by country.

Offshore-Specific Technology Risk: Even if offshore operations are properly maintained there is a risk that offshore cage technologies fail. While farms are generally "over-engineered" such an event would result in significant to potentially catastrophic losses.

Offshore-Specific Operational Risk: There are very few individuals with the experience, skills, and track record of successful operation in the offshore space. This will change with substantial industry investment and is arguably less pronounced for offshore than for RAS, since most of the concepts are adapted from coastal net pen farming. The threat of vandalism and theft of product may be more pronounced than in coastal operations, where continuous monitoring and enforcement may be more practical. This risk is a serious impediment to industry growth in some countries without strong maritime enforcement.

Offshore-Specific Obsolescence Risk: Offshore technologies are developing quickly, and obsolescence risk may be a concern. There is a wide range of experimental offshore farm designs, some of which diverge significantly from traditional or early offshore engineering designs.

Impact Investment Considerations

Environmental Considerations

Even though offshore systems may systematically offer sustainability benefits compared to business as usual, these benefits are not guaranteed solely because of use of this production system alone. Environmental benefits are only likely to accrue if farms implement sound siting, management practices, and environmental monitoring. Environmental due diligence procedures will vary significantly depending on the phase of project development, (e.g. greenfield versus farm expansion). Table 4.11 offers guiding principles and mitigating measures and metrics towards responsible investing in recirculating aquaculture systems. This list is not exhaustive of the multifaceted environmental considerations of offshore farms. For more guidance on appropriate targets for the principles, mitigating measures, and metrics identified, refer to certification standards (e.g., Aquaculture Stewardship Council, Global Aquaculture Alliance Best Aquaculture Practices) and seafood rating guides (e.g., Monterey Bay Aquarium Seafood Watch).

Commercial Considerations

Assessing the financial performance and potential of the offshore sector is challenging. Production economics vary by type of system, species, and stage of development, and financial data is largely unavailable to the public. While the gap with conventional aquaculture is narrowing, operating costs of offshore remain higher on a per unit basis, a result of the logistical and operating complexity of cultivating animals further from shore. This includes transportation of feed, animals, and workers to and from the site, and challenges to feeding, caring for, and harvesting animals in sometimes harsh environments. Additionally, costs of offshore cage technology and moorings are generally higher compared to coastal net pens. However, the ability to amortize fixed costs via greater economies of scale presents an opportunity to close the production cost gap. Automation and ancillary technologies are facilitating this transition by further decreasing operating costs through novel remote feeding technologies.

Table 4.11: Offshore finfish aquaculture environmental impact considerations[100]

Environmental Factor		Guiding Principal	Metrics
Impacts to Wild Stocks	**Source of Fry** *Eliminate or minimize reliance on wild resources*	• Broodstock are not sourced from wild resources, except in the cases where necessary to ensure genetic health/sustainability of farming operations	• Documented proof of fry supply/source
	Escapes/ Genetic Interactions *Eliminate or minimize escapes and genetic interactions*	• Use of native species and local genetic stock, or alternatively, utilization of sterile fish • Risk assessment and modeling of potential genetic impacts under escape scenarios • Optimized siting to minimize storm exposure to minimize escape incidents • Use of appropriate cage design and mooring systems to prevent impacts from storms and damage from predators • Appropriate gear maintenance and farm protocols to minimize escapes • Ensure proper farm protection to prevent vandalism, theft, and resulting environmental impacts that could ensue from damages • Take particular care during fish transfer	• Number of escape events • Type of species and genetic make-up of stock
	Marine/coastal macrofaunal interactions *Eliminate or minimize interactions*	• Optimized siting to minimize interactions with protected/endangered species • Use of and appropriate maintenance of gear (e.g. cage materials, moorings, predator nettings) • Farm monitoring, ideally in real time (e.g., video monitoring) • Emergency planning (e.g., in the case of entanglement)	• Number of entanglement events, interactions or "takes"
	Feeds *Minimize feed impact to wild fishery resources; Maximize feed efficiency/ resource utilization*	• Develop appropriate, high quality feeds and specialized diets for cultured species • Use feeding practices to maximize efficiency, including feed monitoring to reduce feed waste • Utilize feeds with lowest fishmeal inclusion/ fish oil rates as appropriate for species • When sourcing feeds from wild fisheries, ensure sources are from sustainably managed fish stocks • Ensure sustainable sourcing of other feed ingredients (e.g., plant-based products, such as soy)	• Feed Conversion Ratio (FCR; context: under current technologies, generally approaches 1:1 in the case of salmon; often 2:1 for other carnivorous marine finfish) • Fish In–Fish Out Ratio: amount of wild fish required to produce farmed fish • Fishmeal/Fish Oil Inclusion Rate
Habitat Impacts *Eliminate or minimize habitat impacts from farms*		• Site farms away from areas of critical habitat, especially corals, submerged aquatic vegetation, temperate reef structures, and other hard substrate. • Ensure appropriate depth and current to minimize benthic impacts • Ensure appropriate gear and moorings to minimize potential habitat damage from breakaway gear • Ensure appropriate farm monitoring, ideally in real time, through sensors, video monitoring and diver surveys.	• Distance from sensitive habitats • Current • Depth • Stocking density and biomass • Benthic monitoring (see 'Water pollution')

Table 4.11 (continued): Offshore finfish aquaculture environmental impact considerations

Environmental Factor	Guiding Principal	Metrics
Water Pollution *Eliminate or minimize water pollution impacts*	• Ensure appropriate depth and current • Model potential effluent impacts and evaluate nutrient loading / extent of eutrophication • Carrying capacity modeling to assess cumulative impacts of farms in vicinity • Ensure routine water quality and benthic monitoring testing, ideally in real time through sensors and video monitoring and diver surveys to ensure local water quality thresholds are not exceeded • Fallowing, as necessary, to minimize benthic impacts	• Current and depth (see above) • Routine water quality measurements, at least weekly or in some cases continuously, including: total suspended solids, water temperature, oxygen, salinity, nitrogen (ammonia, nitrate, nitrite), phosphorus, silicates, chlorophyll, pH, etc. • Benthic monitoring, including sediment testing for nitrogen, carbon, and phosphorous loading, presence of certain bacteria, anoxic sediment, etc. • Residual chemicals, antibiotics, hormones • Stocking density and biomass
Disease *Minimize or eliminate any potential disease/pathogen transfer to wild resources*	• Optimized farm siting to minimize impacts to wild stocks and disease transfer among farms • Ensure appropriate biosecurity protocols, development of animal health plans including veterinary services, and monitoring programs are in place • Minimize chemical and antibiotic use, and only legally approved animal drugs • Appropriate stocking densities • Deployment of appropriate mortality removal and disposal practices	• Biosecurity protocols in place • Prophylaxis measures taken • Quarantine systems in place • Frequency, type, and extent of antibiotic and chemical use • Stocking density and biomass • Mortality frequency and extent
Freshwater Usage *Minimize water usage and ensure sources of water do not impact local ecology and aquifers*	N/A	N/A
Land Usage *Ensure efficient farm design and areal footprint*	• Ensure efficient farm design and areal footprint of shoreside and open ocean facilities	• Land/water area used per unit of production
Energy Usage *Minimize carbon footprint*	• Locate farms within proximity of major markets to avoid air freight • Utilize renewable sources of energy to mitigate energy usage • Measures to ensure feed efficiency	• KW hrs per day • KW hrs per unit of production • Average distance traveled to market

Operational:

As identified in section 3.2, the six key operational drivers for the aquaculture industry are: (1) feed conversion ratio, (2) stocking density, (3) growth rate, (4) normal mortality rate, (5) animal health and welfare, and (6) product quality consistency and form. Many operational considerations for offshore aquaculture parallel those of CNP aquaculture operations. By operating in clean, deep waters with fast currents, offshore operations may benefit from increased feed conversion ratios, allow for higher stocking densities, and improved growth rates relative to similar operations in a coastal environment. Offshore operations may also benefit from improved product quality and form thanks to improved water quality. A potential major operational benefit is the ability of offshore aquaculture operations to operate far away from other aquaculture operations, resulting in a decreased potential for pathogen and disease transfer. However, animal health must still be a strong operational consideration as new entrants and shared harvesting/stocking operations could compromise biosecurity.

Conclusions

Offshore aquaculture production has looked increasingly attractive in recent years, considering the challenges of disease, local environmental impacts, and limits to supply growth faced by conventional coastal producers. The buy-in from multinational, publicly traded producers in the salmon industry has accelerated the development and adoption of new technologies, and the locational flexibility and potential for scale suggest the potential for significant commercial advantages.

The environmental advantages of offshore production can offer improvements over traditional coastal producers in bays or estuaries, if proper regional planning approaches and governance frameworks are adopted. The economic case is still unproven, and substantial risks to offshore production remain as the technologies develop and scale, but the ability to tap into an exponentially larger open ocean marine resource with environmental conservation advantages presents an attractive opportunity and impact story.

In the short-term, our analysis suggests that this sector will remain high-risk, but promising private investment opportunities may exist for operations with phased development plans, proprietary technologies, vertical integration, or other strategic advantages. Knowledgeable private investors with long investment horizons and higher risk thresholds may find reasonably priced opportunities as early movers in a sector that remains uncrowded. As with RAS, offshore production and ancillary business models should become increasingly recognized as targets for a range of mainstream private capital providers, including real asset/yield focused investors, venture capitalists, and private debt providers as technology and track records improve.

New Candidate Marine Finfish Species:

Working with new candidate species can offer a first mover advantage, product differentiation, and access to higher price-point seafood markets. However, working with new species also entails higher risk. We view several factors as critical to investments in new candidate species. Below is a list of aquaculture species with associated commercial readiness levels, where: 3= full-scale commercial production; culture methods are widely known. 2= commercial production at regional level, with room for expansion; 1= few commercial companies exist or are in commercial pilots. Note that commercial readiness is a function of species and production methods. A species that is currently economically viable for traditional aquaculture methods (i.e., pond or coastal net pens) may be currently not viable for offshore and RAS. Environmental impact is also determined by species. Generally, species with higher FCR and lower survivability can be considered to have higher environmental impacts. The rankings below are not in relation to environmental performance. Other resources that rank aquaculture species according to environmental footprint include the Monterey Bay Aquarium and Global Aquaculture Performance Index.

Critical Success Factors to Mitigate Risk when working with new species:

- **Species Characteristics:**
  - Lower FCR—decrease production cost
  - Growth Rate—shorter production cycles decrease risk
  - Water Quality Tolerances—species which tolerate wide temperature, salinity, and oxygen requirements have lower risk
- **Operational Considerations:**
  - Availability of Species—production methods vary greatly between species
  - Availability of Fry—ensure fry availability or high confidence in larval rearing
  - Disease/Animal Health Interventions Available
- **Market Considerations:**
  - Species with developed, or strong market characteristics—price, shelf life, meat quality, organoleptic characteristics

Table 4.12: Emerging marine finfish species commercial readiness levels[101]

Diadromous Fishes	Commercial Readiness Level
char, Arctic	3
salmon, Atlantic	3
trout, rainbow	3
salmon, Pacific king (*Oncorhynchus tshawytscha*)	2
salmon, Pacific coho (*Oncorhynchus kisutch*)	2
sturgeon, Siberian (*Acipenser baerii*)	2
Marine Finfish	
barramundi	3
cobia	3
croaker, yellow (*Larimichthys crocea*)	3
sea bass, European	3
sea bass, Japanese	3
sea bream, gilthead	3
flounder, olive (*Paralichthys olivaceus*)	2
grouper, giant (*Epinphelus lanceolatus*)	2
grouper, hybrid (*Epinphelus lanceolatus x Mycerteroperca tigris*)	2
pomfret, golden	2
red drum	2
sea bream, red (*Pagrsu major*)	2
trout, coral (*Plectropomus leopardus*)	2
turbot (*Scophthalmus maximus*)	2
yellowtail species (Full Life Cycle Egg to Market) (*Seriola spp.*)	2
bass, striped (*Morone saxitilis*)	1
cod, Atlantic (*Gadus morhua*)	1
dentex (*Dentex dentex*)	1
grouper, Caribbean species (*Serranidae*)	1
halibut, Atlantic (*Hippoglossus hippoglossus*)	1
meagre (*Argysomous regius*)	1
pompano, Florida (*Trachinotus carolinus*)	1
snapper, eastern Pacific species	1
tuna, bluefin Pacific (Full Life Cycle Egg to Market) (*Thunnus orientalis*)	1

NOTE:
3 = full-scale commercial production
2 = commercial production at regional level
1 = few commercial companies exist or are in commercial pilots

Section 4.3: Bivalve and Seaweed Production

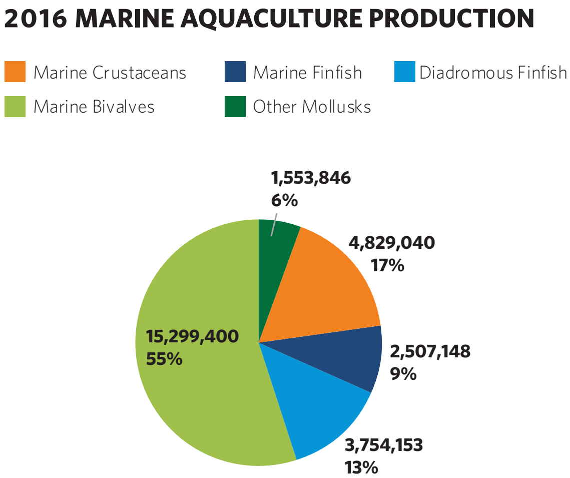
Key Takeaways

- Coastal bivalve production and seaweed aquaculture offers the clearest environmental value proposition, as shelled mollusks and cultured seaweed have low input requirements, and in some cases provide environmental benefits to surrounding ecosystems.
- Bivalves are currently predominantly produced in temperate geographies with production dominated by China, and robust industries in most other continents. There may be growth potential for development in tropical waters and potential for new species development in many regions.
- Seaweed aquaculture production is primarily limited to Asia and modest production in Africa. Significant potential may exist to extend seaweed farming to other geographies and for new species.
- China is a significant player in bivalve and seaweed industries as a producer, importer, and exporter and will continue to be a major and expanding market.
- Interest is growing for new applications of seaweed in biopolymers, cosmetics, nutraceuticals, animal feeds, and energy, which may demonstrate higher risk, but potentially higher reward investments.
- Bivalve and seaweed production remains highly fragmented and product value varies significantly across product, form, and markets; however, this presents an opportunity for investment and aggregation.
- Low inputs and low fixed costs can make the economics of both bivalve and seaweed production attractive. Strong growth and favorable market characteristics enhance the case for investment in the bivalve industry.

Background and Market Landscape

Bivalve and seaweed production were chosen for deeper analysis because of their low environmental footprints, their unique potential to provide ecosystem benefits, and because they are well-adapted for cultivation. Large-scale, high density bivalve and seaweed farming can have certain negative impacts if farms are improperly sited or managed, but they can also confer water quality benefits, habitat creation, wild fish production, and climate mitigation benefits. Commercial production for bivalves and seaweed in most of the world also requires relatively simple grow-out technology, with low capital, input costs, and labor requirements.

Figure 4.7: Relative production of farmed marine species categories by volume



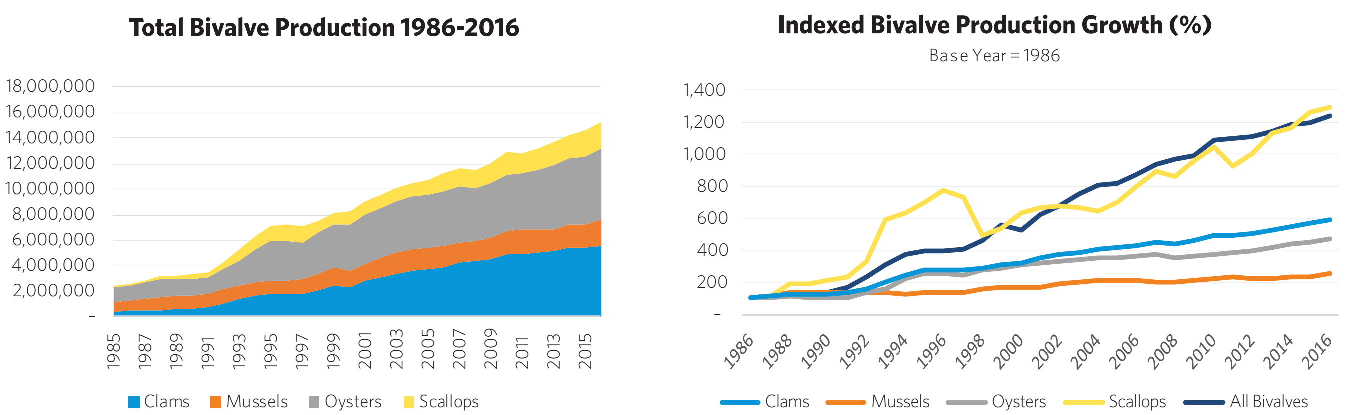
Bivalves are aquatic shelled mollusks with the dominant feature of a shell with two "valves" joined along a hinge that allows the shell to open and close. While there are a very small number of freshwater mollusks produced through aquaculture, the scope of this report includes only marine shellfish. There are approximately 8,000 species of marine bivalves, but four pertinent species groupings: oysters, clams (including cockles and arc shells), scallops, and mussels. Commercially grown bivalves are filter feeders, meaning that they feed primarily on phytoplankton (micro-algae) suspended in the water column. They continuously pump water through a set of gills to filter out food particles, thereby removing suspended solids, organic detritus, and other nutrients. A single oyster may process up to 50 gallons of water per day.

Seaweed, while similar in appearance to a plant, is a form of macroalgae. There are over 48,000 species globally, although only a few have been developed for commercial production. Seaweed production is generally divided into categories based on thallus color: red, brown, and green. Red and brown seaweed are generally found in the marine environment, with green seaweed found in both marine and freshwater. Seaweed, unlike bivalves, uses photosynthesis to convert sunlight, water (with nutrients like nitrogen and phosphorous), and carbon dioxide into food, producing oxygen as a biproduct. Seaweed is harvested live, with most current commercial production dried upon harvest in order to preserve the product for later processing or rehydration.

History & Context

Bivalves may have the longest history of cultivation among marine species, likely the result of the relative ease and technological simplicity of growing species like mussels and oysters. In many ways, the practices of ancient farmers resemble methods still used today. The earliest cultivation likely occurred in China and Japan up to 2,000 years ago, where farmers drove bamboo stakes into the seabed to attract and be colonized by wild larval oysters ("spat") suspended in the water column. Oysters were also farmed in ancient Rome, and mussel culture in Europe dates back nearly 700 years. Large-scale production of coastal bivalve aquaculture and expansion to harder-to-cultivate species like scallops took off in the early 1900's. This growth was led by Japanese growers who first developed the suspended and long-line culture techniques used today, as well as more efficient technologies to actively collect and cultivate wild spat. In the mid-1900s, U.S. researchers developed shellfish hatchery techniques that allowed active cultivation from spawn to harvest. Most of the developments around full life-cycle production of bivalves have only come about over the past 50 years, and growers continue to refine practices to optimize production.[102]

Figure 4.8: Bivalve production (1986-2016), aggregate and percent growth[103]



Seaweed aquaculture has an equally long history. The use of seaweed as a food dates back 1,700 years in Japan and 1,500 years in China. While food production from seaweed was paramount for the majority of its history, the ability of seaweed to produce a thickening gel was discovered in 1658 in Japan. Alginate from brown seaweed was commercially sold in the 1930s, and seaweed extracts for industrial uses increased after World War II. Large-scale production of seaweed grew in leaps and bounds in the 1970s after the first seaweed farm for the thickener carrageenan was established in the Philippines.[104] Like bivalve aquaculture, cultivation methods are relatively simple and consist of off bottom stakes and lines, or floating long lines that are anchored on the sea floor.

Figure 4.9: Bivalve production by continent (2016); including and excluding China[105]

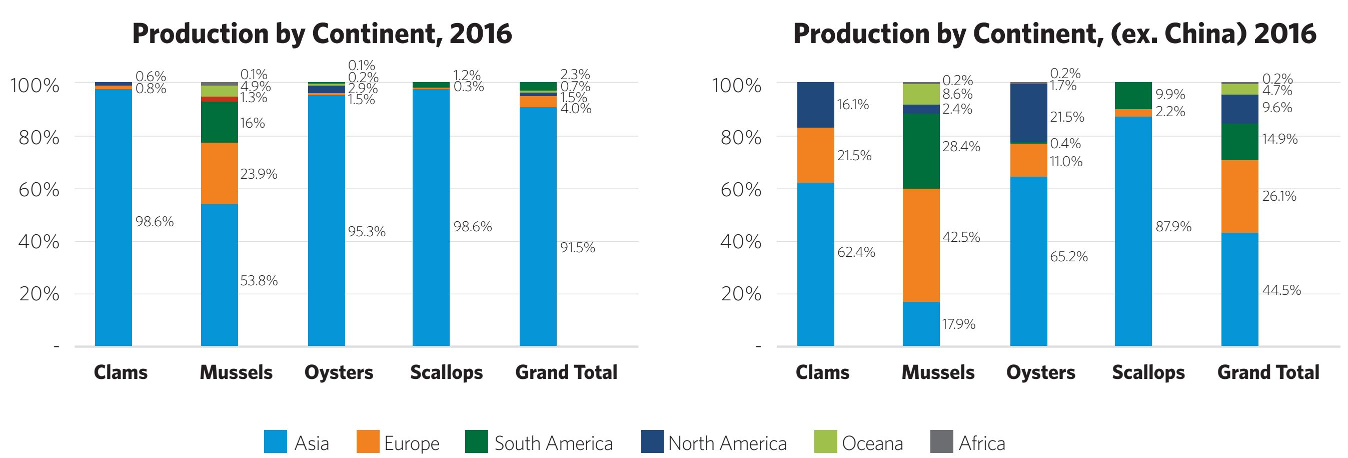
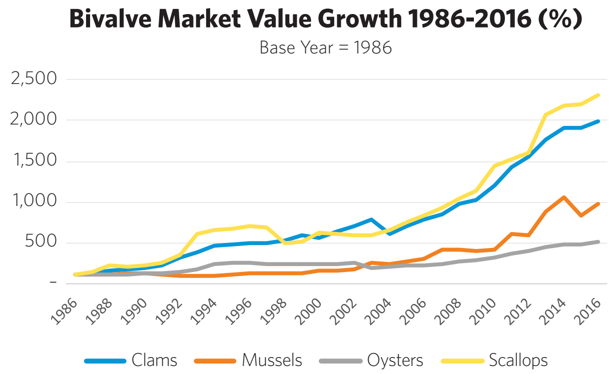


Figure 4.10: Bivalve market value (1986-2016)[106]



Market Landscape

Bivalve Production

In general, bivalve production is large and growing. Of the cultured marine species, bivalves represent the greatest production volumes of any farmed category. In 2016, the total harvest of farmed oysters, mussels, clams, and scallops reached 15.3 million mt, representing nearly 55% of all farmed marine species (Figure 4.7). Bivalve consumption derives largely from aquaculture operations, with wild catch accounting for just 8.5% of global sales.[107]

Within the bivalve category, oysters and clams dominate production, accounting for nearly three-quarters of total volumes, with scallops and mussels making up the remainder.

Farmed bivalve production has averaged 6.1% compound annual growth during the 30 years from 1986 to 2016, slightly less than the average for all marine categories during that time (7.0%).[108] Clams and scallops have seen the strongest continuous growth over that period, 8.8 and 8.9%, respectively, though from a smaller base. Oyster production has accelerated over the past 5 years after stagnating during the Great Recession, a reflection of weak demand during and following the 2008 financial crisis.[109]

Bivalve production, like the industry overall, is heavily weighted toward Asia, and especially China. This region accounted for roughly 90% of the global volumes produced and 80% by value. The remainder of production comes from the temperate coastal nations of Western Europe, North America, South America and Oceania (Figure 4.9).[110]

The total farmgate market value of bivalves falls behind other shellfish-crustaceans (primarily shrimp) ($28.0 billion) and marine/diadromous finfish ($29.5 billion), but is still substantial, generating $25.7 billion in 2016. As these numbers indicate, bivalves tend to be of lower value, averaging $1,680/mt, though there are exceptions and significant variability at the species level. Demand for all four bivalve species has been increasing, driven by consumer interest in bivalve health benefits, growing incomes, and changing tastes.[111]

Most bivalves are traded on regional, rather than global markets given the cost and challenges of transporting live animals long distances, though there are exceptions (e.g., most Chilean mussels are exported to the EU). Processed frozen or packaged bivalve products, such as scallops, frozen mussels, or smoked oysters, are more likely to be exported.

We expect the high growth of the last decade to continue, as the industry continues to benefit from positive consumer perceptions of bivalve taste and nutritional characteristics.

The industry is also positioned to meet increased demand through improvements in selective breeding programs and genetically selected seedstock that possesses commercially attractive traits (e.g., faster growth, disease resistance, and survivability). Development of technology used in the grow-out phase of production, greater operational efficiencies, better use of sites, and access to more sites will also enable production growth.

Seaweed Production

There exists limited publicly available data on the overall seaweed production market, though FAO provides some economic and social data trends, and isolated academic studies provide evidence of economic benefits associated with seaweed aquaculture in temperate and tropical regions. Seaweed production is dominated by Asia (Figure 4.11), and prices have hovered at an average of about $250/mt over the last decade, with increased production in China exerting some downward pressure on prices for temperate species.[112]

Figure 4.11: Seaweed production by geography[113]

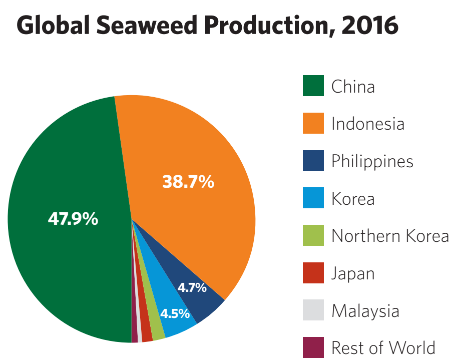
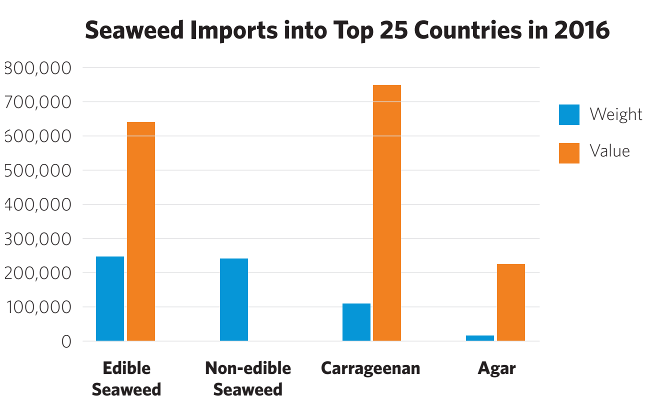


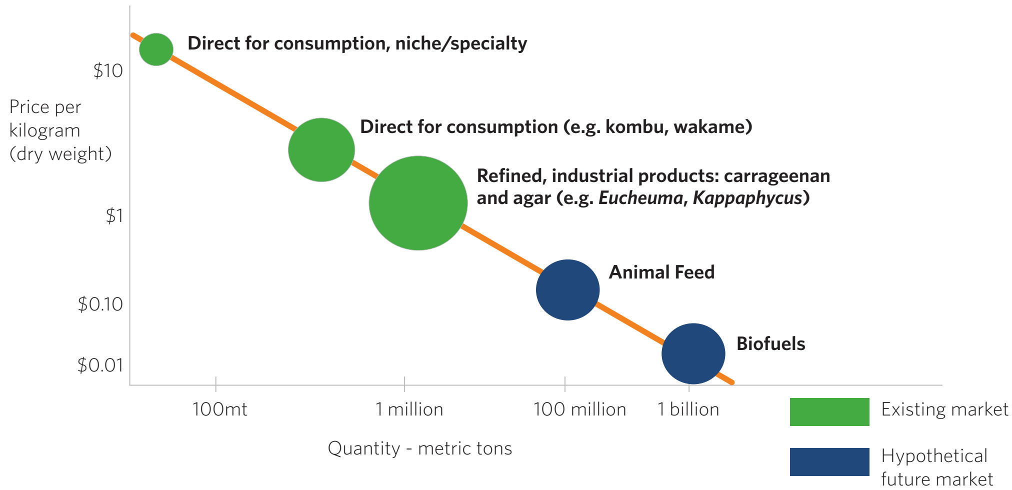
Figure 4.12: Seaweed imports by weight and value into top 25 purchasing countries[114]



Globally, the seaweed industry produced 30.1 million mt in 2016, worth $11.7 billion. Eighty-five percent of seaweed is harvested or produced for human consumption, with the remaining 15% used as an ingredient in beauty and wellness products, soil fertilizers, and animal feeds. New research also suggests that seaweed may be useful in biofuel production and as a bovine feed ingredient that may reduce methane emissions.

The largest farmed species by volume are *Eucheuma* seaweed species, which are primarily farmed for the hydrocolloid market. Two of the largest hydrocolloid types, carrageenan and agar, are used as thickening agents within processed food, a growing commodity for both developed and developing country consumers. Carrageenan, agar, and alginates derived mainly from *Eucheuma*, *Kappaphycus*, and *Gracilaria* comprise approximately 40% of the global hydrocolloid market for food. Carrageenan alone is estimated at $600-700 million in value. At current growth rates, it is expected to reach $1 billion by 2024.[115] Over the ten-year period from 2006 to 2016, there was a 342% increase in the global production of red seaweed for use as hydrocolloids. This production is dominated by small-scale farmers in rural areas and the majority of

Figure 4.13: Projected demand curve for seaweed with existing and hypothetical markets



Offshore bivalve and seaweed aquaculture: an emerging trend?

Offshore, open-ocean bivalve and seaweed operations operate on the same principle of submerged longline production used for the conventional, coastal bivalve production but on a larger scale. Such projects have been slow to come online in North America, largely due to federal permitting challenges/lack of precedent; abundant competition from local conventional bivalve producers; and finally, the need for these operations to achieve massive scale before achieving stable profits. As with open-ocean finfish operations, the infrastructure must remain submerged to avoid damage from the elements, and automated systems are needed to help drive cost savings at scale and manage these complex operations.

Bivalves: Several groups have been looking at the potential for large-scale offshore bivalve production, financed almost exclusively from private capital sources. Catalina Sea Ranch, which operates a 100-acre concession on the San Pedro Shelf, seven miles off the Orange County coast south of the port of Long Beach, CA, has raised more than $5 million since its founding in 2013, with a capability to grow 1.1 million mt of mussels, worth about $5.6 million annually, using a technologically integrated series of undersea ropes. Eastern Seafarms Ltd of New Zealand, the first commercial open ocean farm in the country, is another entity that currently has a small amount of bivalve production, but has a tremendous potential for growth, operating a 9,390-acre lease offshore of the Bay of Plenty. The Whakatohea Iwi, an indigenous nation to New Zealand and co-owner of Eastern Seafarms, conducted their first commercial harvest in 2016 and was recently provided consent to farm an additional 7,900-acres of ocean space. Similarly, mussel producers in Prince Edward Island, Canada are exploring potential for offshore aquaculture production.

Seaweed: While there do not appear to be any large-scale commercial offshore seaweed farming operations, there are many concept and pilot-stage initiatives focused on growing these products. The U.S. Department of Energy's Macroalgae Inspiring Novel Energy Resources (MARINER) Program has developed a $50 million grant program to fund critical research and seed pilot projects for offshore seaweed aquaculture in the United States. Other early-stage projects have been explored in in Southeast Asia and the Indian Ocean.

the growth over the last decade occurred in Indonesia, which increased production from 1.2 to 11.6 million mt annually—an almost nine-fold increase over a ten-year period.[116] While Asia dominates carrageenan and agar production, hydrocolloid purchasers and refineries also operate in Europe, Latin America, and North America.

While Asia is the primary producer of farmed seaweed, China, the EU, Japan and the U.S. are the top importers (Figure 4.12). Seaweed produced for carrageenan and agar dominate the current highest value imports, followed by seaweed for direct consumption. China is a significant player in the seaweed industry, serving as a large importer of farmed seaweed, and is also a primary producer. In addition to being directly consumed and converted into thickeners, seaweed is common in Chinese medicine.[117]

While current markets exist for direct human consumption, primarily in Asian markets (e.g., nori and wakame), as well as for industrial products (carrageenan and agar), many additional products could and can be manufactured. Seaweed has potential applications for broader uses as animal feeds and potential biofuels, which would demand seaweed at much greater quality and lower price points. The current cost of seaweed production is generally too high to fulfill new markets (Figure 4.13). Substantial investment in scaled-up systems would be needed to enable cost-effective development of these products.[118] Currently, there are R&D programs such as the US Department of Energy Advanced Research Projects Agency- Energy (ARPA-E) program that seek to develop technologies that would enable production of offshore seaweed for biofuels.

Like bivalves, we expect the high growth of the last decade to continue and even potentially surpass previous growth rates, as research and technological advances continue in the areas such as animal feeds and biofuels. We also expect China to continue to represent

Mussel Aquaculture in Marlborough Sounds, New Zealand.

Photo © Tiffany Waters

a very important player in the seaweed industry as producer and purchaser, with an expanding market for seaweed grown for human consumption for the country's growing middle class.

Producer Characteristics and Competitive Landscape

Bivalve and seaweed aquaculture are both highly fragmented, global industries. Small-scale producers largely dominate the market, but locally consolidated players control production in select national and regional markets. Indeed, global bivalve and seaweed production tends to be even more fragmented than the broader seafood industry. The sub-scale producers are often small family businesses and sole proprietorships working on concessions of less than five acres. There are multiple reasons for this, including low barriers to entry, particularly around startup and capital costs.

The two primary bivalve segments—cottage industry producers and branded producer-aggregators—together account for 15.3 million mt of production. Medium- to large-scale producers may be virtually consolidated through cooperative buying and branded programs. Despite achieving some scale, these aggregators still often focus branding on geography and local flavor attributes. The world's largest producer of mussels, Chile's St. Andrews Seafoods, sold an estimated 30,000mt of mussels in 2017, of which it directly farmed 18,000mt and sourced the remaining 12,000mt from local farmers. While St. Andrews occupies a dominant position in Chile, it still only accounts for about 10% of that country's total mussel production. Bivalve product form varies within and across species groups, driven by raw material quality, grow-out methods, and the demand attributes of the destination market. The primary distinction for the bivalve category is whether the product is sold whole, with the shell still closed and the animal alive, or shucked, with the raw meat removed and sold separately.

Seaweed aquaculture is dominated by many small-scale producers, with little aggregation of farmers in Indonesia and the Philippines where seaweed aquaculture primarily occurs. Due to its location in the coastal environment, relatively easy technology, and quick growing periods, it is often an important livelihood in rural impoverished areas. As farming occurs in more remote and impoverished areas with limited transportation and processing facilities, seaweed aquaculture is often characterized by a complicated and long supply chain with low traceability to source. In China, South Korea, and Japan, some larger producers exist. The industry differs from that of bivalves currently as marketing does not generally focus on geography or local flavor attributes. Seaweed products, particularly in Asia, are most generally sold in raw dried form to be later be rehydrated for consumption, processed into a thickener, or incorporated as an ingredient into other products (e.g., animal feeds).

Table 4.13: Environmental benefits of shellfish and seaweed aquaculture and how to improve delivery[119]

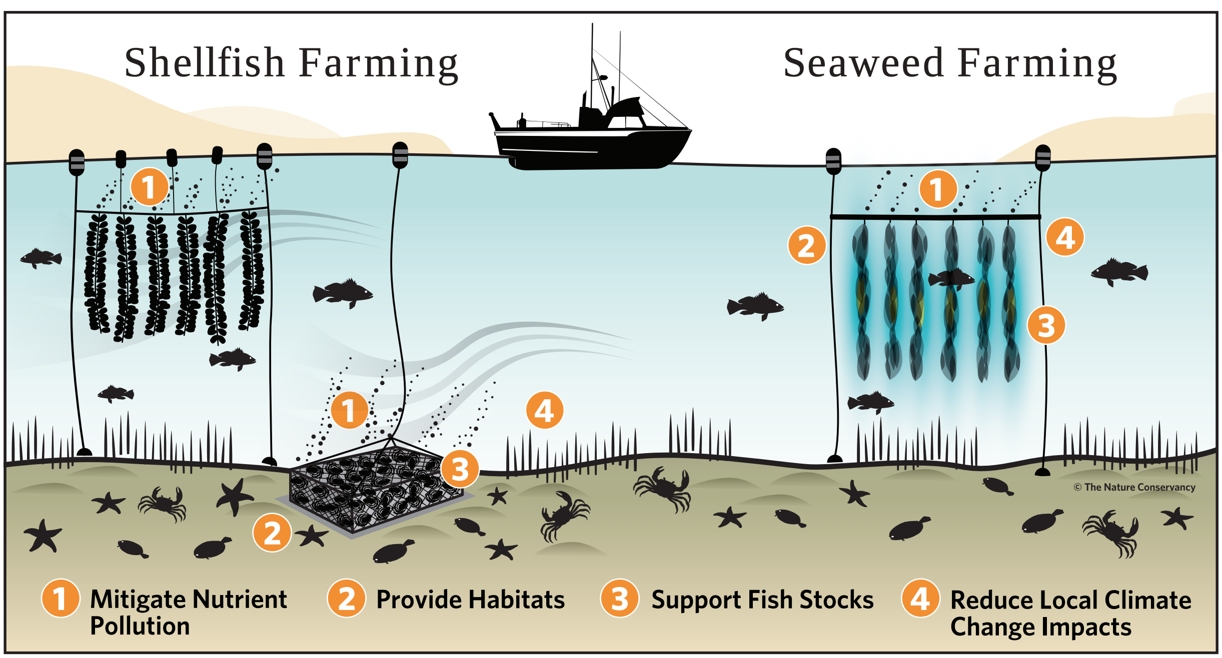
Environmental Factor	What is the Environmental Benefit?	How to Improve Delivery of Benefits
Benefits to Wild Stocks	Seaweed and shellfish aquaculture, due to a free floating embryotic stage, can provide seedstock for wild populations. Through uptake of carbon dioxide from surrounding waters, seaweed can potentially buffer against ocean acidification in localized areas that may benefit calcareous oyster and coral reefs.	• Farm native species and/or naturalized species in areas where the naturalized stocks are valued and culturally appropriate • Site farms appropriately • Use best management practices (BMPs) to reduce netting and debris • Document proof of fry supply/source
Habitat Benefits	Floating bivalve raft production, suspended baskets, or longline bivalve production systems in estuaries has been shown to provide habitat, as well as enhanced benthic community diversity and production. While the habitat services that seaweed farms can provide have not been as well studied as bivalve farms, there are studies that discuss how polyculture operations provide habitat and foraging opportunities for invertebrates, marine mammals, and birds. Water filtration from shellfish can help improve light availability, potentially improving growing conditions for other important coastal habitats, such as seagrasses. Development of hatchery capacity for certain aquaculture species of restoration value can provide additional seed to support shellfish restoration projects.	• Habitat surveys to determine farm proper farm methodology (e.g., using long lines vs. on-bottom in coral reef areas and seagrass habitats) to minimize or negate impacts to the seafloor and sensitive nursery or spawning habitats • Site farms appropriately • Use BMPs to deliver benefits while reducing any potential impacts (e.g., not harvesting during forage fish spawning period as spawn can set on gear) • Develop aquaculture hatchery production of species with high restoration value (e.g., depleted wild species)
Water Pollution	Shellfish filter planktonic algae from the surrounding waters and fix nitrogen and phosphorus within their tissue as part of the filter feeding process. Filter feeding shellfish can filter a substantial amount of water per day, up to 50 gallons per oyster, and seaweed farms have been shown to remove significant amounts of nitrogen and phosphorous, depending on the species, meaning large-scale bivalve and seaweed production can significantly benefit marine ecosystems. Cultivation of shellfish and seaweed in areas of eutrophication (from which 60% of coastal estuaries suffer) can help decrease nutrient loading. Additionally, seaweed can potentially buffer against ocean acidification in localized areas.	• Site farms in eutrophic areas to improve water quality • Site seaweed farms near species and habitat in danger from acidifying waters • Conduct carrying capacity analyses
Disease	A recent study that analyzed the oyster parasite Dermo found that oyster aquaculture may inhibit the spread of disease in wild populations as farmed oysters filter disease-causing parasites during early transmission stages which are subsequently removed during harvest.	Conduct modeling to assess potential of farmed shellfish to serve as 'disease sink' by analyzing stocking density, harvest rates, and farmed species traits

Table 4.13 (continued): Environmental benefits of shellfish and seaweed aquaculture and how to improve delivery

Environmental Factor	What is the Environmental Benefit?	How to Improve Delivery of Benefits
Freshwater Usage	Seaweed and bivalve farming represent an aquaculture production activity that requires no freshwater to grow, which is particularly relevant given a changing climate, projected increase in droughts, and additional resource utilization on land due to a growing population.	• Site farms in the marine environment and/or use minimal freshwater in recirculating tanks • Ensure production facilities use minimal freshwater and/or use marine water for rinsing harvested product when possible
Land Usage	Neither bivalves nor seaweed require direct feed inputs from the land (with the exception of bivalve seed during the hatchery production phase), and they obtain nutrition at the lowest trophic level.	• Intensification rather than expansion of farm area, when within carrying capacity and other environmental limits
Energy Usage	Bivalves are one of the most efficiently produced animal proteins from a resource use perspective, requiring minimal energy and feed inputs (only during the hatchery production phase) to produce. Similarly, the production of seaweed, which provides macro and micronutrients and vitamins, involves minimal energy inputs.	• Site farms close to markets • Utilize renewable sources of energy within association production facilities and vehicles/vessels

*Discussion of minimizing impacts is included in the Competitive Disadvantages and Risks section below.

Figure 4.14: Environmental benefits of bivalve and seaweed aquaculture[120]



Environmental and Commercial Value Proposition

Environmental

Shellfish and seaweed aquaculture can provide positive environmental benefits in some circumstances. The following are the specific environmental benefits that can be generated by shellfish and seaweed aquaculture:

Modest capital and input costs: The capital, operating, and input costs for bivalve and seaweed production tend to be lower than for the other sustainable aquaculture industries discussed in this report. The lack of high upfront or ongoing capex costs may be attractive to investors that are interested in the sector but are unable to find a risk-return profile for RAS or offshore that matches other real asset-based projects. The infrastructure and equipment needed for bivalve and seaweed production is also more fungible than for RAS and offshore, reducing the downside risk of investment if assets do need to be sold. Shellfish can also be kept alive in their shells outside of the marine environment and refrigerated for between three days (mussels) and two weeks (oysters); and seaweed can be dried and stored for months.

Product differentiation: Certain bivalve species, particularly oysters, offer distinct local flavor and product characteristics, which has led to successful branding, product differentiation, and price premiums. Bivalve investment may thus be considered a commodity food production or a value-added premium opportunity. The latter approach can lead to higher margins and opportunities to build brands in key urban markets. There are also many species of bivalves with commercial potential that have not yet been commercially produced (see call out box).

Seaweed is an increasingly in-demand ingredient used for direct consumption and food thickening, as well as in cosmetics, biofuels, pet foods, aquaculture feeds, biopolymers plastic-alternatives, and medicines. For example, La Mer, a high-end reparative skin product brand, highlights algae as an important ingredient, and Korean skin and beauty products that include seaweed are popular globally. An Indonesian-based company, EvoWare, is producing edible seaweed packaging that dissolves in water and has a shelf-life of 2 years. Loliware, a U.S. company, is creating a seaweed-based biopolymer that is both edible and biodegradable, but is durable enough to replace single use plastic materials such as straws, cups, and lids. MARINER, the U.S. Department of Energy program mentioned above, is investigating how seaweed grown in U.S. waters can be used in biofuels and chemical applications.

Industry growth: Bivalves represent a $26 billion industry, which has grown steadily at an average of 6% over the past 30 years (see Market Landscape section for additional details). The growing demand for healthy, sustainably raised seafood is perhaps best exemplified by a surge in oyster bars and oyster menu listings. Consumer demand is projected to outpace supply over the next 3-5 years and will likely remain strong over the next 15 years.[121] Interest in cocktail-sized oysters (<3") at foodservice establishments creates an opportunity for aquaculture operations to harvest their oysters sooner and highlights the possibility for additional product innovation in the bivalve sector.

Other Bivalve Species May Present Investment Opportunities

The bivalves currently under cultivation only represent a small fraction of the bivalve species on earth. Many of these species exhibit commercial characteristics and are at an early phase of development, often via public R&D funding. We have provided a list of candidate species in North America, where production is currently dominated by Atlantic and Pacific oysters and hard clams. The species below may represent an opportunity for increased product differentiation.

Table 4.14: North American candidate bivalve species

Species *(Scientific Name)*	**Region**	**Phase of Development**
Oysters		
Native Oyster *(O. conchaphila)*	Southern Pacific	Unknown
Olympia Oyster *(Ostrea lurida)*	Northern Pacific	Commercial
Clams		
Arctic Surf Clam *(Mactromeris polynyma)*	Northern Atlantic	Experimental
Atlantic Jacknife Clam (razor clam), *(Ensis directus)*	Northern Atlantic	Experimental
Atlantic Surf Clam *(Spisula solidissima)*	Central Atlantic	Commercial
Butter Clam *(Saxidomus gigantean)*	Northern Pacific	Experimental
Chocolate Clam *(Megapitaria squalida)*	Southern Pacific	Experimental
Horse Clam *(Tresus nuttallii* and *Tresus capax)*	Northern Pacific	Experimental
Pacific Native Cockle *(Clinocardium nuttalli)*	Northern Pacific	Experimental
Softshell Clam *(Mya arenaria)*	Northern Atlantic	Experimental
Sunray Venus Clam *(Macrocallista nimbosa)*	Southern Atlantic	Experimental
Scallops		
Atlantic Bay Scallop *(Argopecten irradians)*	Central Atlantic	Commercial
Atlantic Sea Scallop *(Placopecten magellanicus)*	Northern-Central Atlantic	Commercial
Icelandic Scallop *(Chlyamys islandica)*	Northern Atlantic	Commercial
Lion's Paw Scallop *(Nodipecten subnodosus)*	Southern Pacific	Experimental
Mexican Bay Scallop (Pacific Calico Scallo), *(Argopecten ventricosus)*	Southern Pacific	Experimental
Pacific Weathervane Scallop *(P. Caurinus)*	Northern Pacific	Experimental/Commercial (Hybrid)
Purple Hinge Rock Scallop *(Crassadoma gigantean)*	Central Pacific	Experimental

The global seaweed market is estimated at $6 billion, with about 85% of products currently sold for human consumption (see Market Landscape section for additional details). There has been massive growth in the industry, particularly around carrageenan and agar seaweed for use as thickeners. In the 10-year period from 2005 to 2015, the production of both wild and farmed seaweed doubled as wild harvests stayed nearly the same.[122]

Bivalve and Seaweed Competitive Disadvantages and Risks

Commercial

Mortality (predation and disease): Predation can be a significant challenge, for seaweed generally and for bivalve animals particularly when they are small, and operations can be threatened by episodic weather events, pollution, and disease. In addition, commercial-scale operators must ensure that the animals are provided with sufficient nutrition (for bivalves) and non-polluted water (for both species). For bivalves, this requires a location with both ample density of nutrients in the water column and current speeds sufficient to continuously deliver these nutrients; and for seaweed, this requires a location that will not be subject to polluted land-based runoff that can cause disease.

The eastern oyster industry in the U.S. has been historically challenged by several diseases, including MSX and Dermo, although the development of disease-resistant triploid oysters has mitigated some of these challenges. Various methods, such as periodic drying and cleaning of oyster cages to remove biofouling, can minimize pathogen introduction.

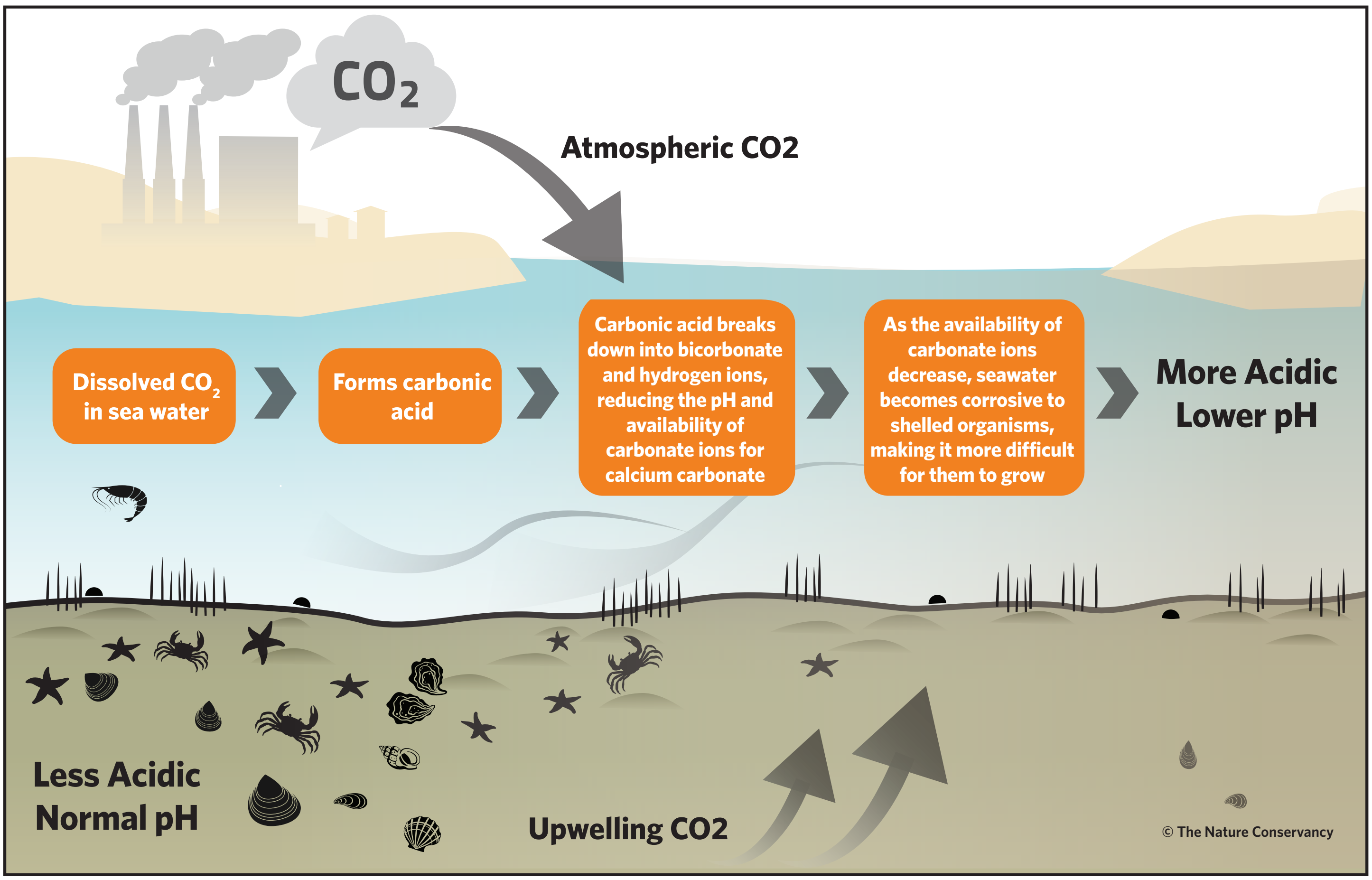
In the tropical marine seaweed production, ice-ice disease threatens the industry, which is due to a suite of factors, including nutrient runoff and pollution, changes in salinity, and poor farming practices. Tropical seaweed is subject to grazing and mortality from marine fish, dugongs, and sea turtles, leading many farmers to install predator fencing (which can lead to marine mammal mortalities). Temperate seaweed is also vulnerable to predation by marine fish, birds, and mammals. All farmed seaweed can be prey to parasitic epiphytes and harmful algal growth, which can lead to rot and disease.

Human health impacts: Harmful bacteria and virus microorganisms can accumulate through filter feeding of contaminated water, and harm consumers. In some cases, this can be remediated through a depuration process, in which the animals are held in clean water for a period of time to expel any bacterial or viral accumulations from the gut. Selective temperature-dependent harvesting during warmer months where naturally occurring bacteria increases in the water, as well as recommendations to fully cook products, can also serve as a preventative remedy for bacteria. In addition, harmful algal bloom conditions can lead to biotoxin outbreaks and cause the suspension of bivalve harvests. While many biotoxins are not harmful to bivalve shellfish, some can cause mass mortalities, or even total crop loss.

Public health agencies are investing more research into heavy metal uptake by aquatic plants and the fitness for human consumption of product grown in areas with significant contamination, but this has not been a large research or regulatory focus to date.

Climate change and acidification: Increased atmospheric CO_2 and warming oceans is leading to ocean acidification. The resulting carbonic acid lowers the natural pH of the water and makes it difficult for bivalves to create their shells and to grow, leading to increased mortality rates (see Figure 4.15 below). The impacts of acidification are most pronounced in the larval and juvenile stages of the bivalve lifecycle, and a variety of hatchery methods have been developed to mitigate against the impacts of acidifying waters (e.g., adding a buffer to increase the pH of incoming water to hatcheries). In some years, acidified water in hatcheries has resulted in major bottlenecks to production.

Figure 4.15: Shellfish and ocean acidification



Impact Investment Considerations

Environmental Considerations

Even bivalve and seaweed aquaculture can result in negative environmental impacts if proper farm siting, practices, and monitoring do not occur. Below we discuss key environmental impacts for bivalve and seaweed aquaculture. Table 4.13 offers guiding principles for eliminating or minimizing those impacts and key metrics for measuring impact minimization. This list is not exhaustive of the multifaceted environmental requirements of bivalve and seaweed farms.

Habitat impacts: In tropical locations, particularly in Asia, seaweed farmers can engage in the removal of seagrasses and corals, the cutting of mangroves, the use of green tonic fertilizer, and the creation of plastic marine debris. In establishing off-bottom seaweed farms, many farmers will choose to remove the important habitats of coral reefs and seagrasses in order to create a smooth bottom for their seaweed lines. Farmers use mangroves as a supply of wood stakes, removing a key habitat, shoreline stabilizer, and blue carbon reservoir. Some farmers, in seeking to stave off disease or increase production, will use a chemical green tonic fertilizer, which introduces excess nutrients into the water and decreases water quality. In the case of shellfish farming, the shading of, or damage to, sensitive habitats (e.g., seagrasses) can be a concern for certain production methods. There have also been concerns regarding potential negative impacts of more intensive bivalve aquaculture methods (e.g., geoduck farming) on soft sediment benthic organisms.

Impacts to wild populations: Pacific oysters are the most common aquaculture bivalve, with production occurring throughout North America, Australia, Europe, and New Zealand. The species is native to the Pacific coast of Asia but was introduced globally to supplant overharvested or diseased native oyster stocks and grows incredibly well in diverse habitats. The introduction of the Pacific oyster has been shown to impact native oyster species through out-competition, as well as through introduction of novel pests and predator 'piggybacking' on the shells of the introduced oysters.[123] Seaweed, due to its prolific nature, can also be highly invasive and serve as a vector for pathogens. Introducing non-native aquaculture species to locations where they are having not already been naturalized should be avoided. Caution and mitigating measures should be taken when transporting cultured organisms between aquatic environments.

Water pollution: Water pollution can be an issue of concern for bivalve aquaculture in poorly managed, intensive production with high stocking densities, which results in in fecal carbon loading and localized low dissolved oxygen impacts on the seafloor that can impact local biota.[124]

Table 4.15: Environmental impact considerations for shellfish and seaweed aquaculture[125]

Environmental Factor	Guiding Principle	Key Metrics
Impacts to Wild Stocks – **Source of Seed** *Eliminate or minimize reliance on wild resources*	• Seed is not sourced from wild sources except in the cases where seed is plentiful, and/or it is necessary to ensure genetic health/sustainability of farming operations	• Documented proof of fry supply/source
Impacts to Wild Stocks – **Escapes/Genetic Interactions** *Eliminate or minimize genetic interactions*	• Use of native species and local genetic stock • Risk assessment if naturalized, non-native species are being grown	• Species grown should be native or naturalized within the surrounding marine environment, with local genetic strains used for seed
Impacts to Wild Stocks – **Feeds**	N/A	N/A
Habitat Impacts *Eliminate or minimize habitat impacts from farms*	• Site farms away from areas of critical habitat, especially corals, submerged aquatic vegetation, and temperate reef structures • When siting farms near critical habitat, use minimally impactful farming practices (e.g., seaweed long lines in coral reef habitats) and develop farm protocol to minimize impacts • Ensure appropriate gear and moorings to minimize potential habitat damage from gear failures • Utilize appropriate predator control methods, utilizing non-lethal methods when possible	• Presence, extent of protected species, submerged aquatic vegetation in area • Acreage/extent area of habitat displaced by type
Water Pollution *Eliminate or minimize water pollution impacts*	• Ensure no fertilizers are used and/or chemicals are added to the marine environment • Evaluation and site selection to avoid any potential for eutrophication • Ensure that hatchery and processing facilities have proper protocols and discharge procedures in place • Ensure proper disposal of debris, or waste • Use environmentally appropriate anti-fouling methods	• Effluent meets or exceeds established water quality standards for hatchery and processing facilities • Chemical use is zero
Disease *Minimize or eliminate any potential disease/pathogen for cultured animals and transfer to wild resources*	• Minimize or eliminate any potential disease/pathogen transfer to wild resources • Ensure appropriate, disease reporting, testing and diagnostic, protocols are in place • Ensure appropriate stocking densities to minimize potential for environmental impacts	• Biosecurity protocols in place • Stocking density • Harvest rate • Farmed species traits
Water Usage *Ensure sources of water do not impact local ecology and aquifers*	• Minimize freshwater usage in processing facilities (e.g., marine water is used in rinsing of product, when possible)	• Freshwater water use/per day and per unit of production
Land Usage/Farm Footprint *Ensure efficient farm design and areal footprint*	• Farm design effectively minimizes land footprint	• Land/water area used per unit of production
Energy Usage *Minimize carbon footprint*	• Locate farms within proximity of major markets to avoid air freight • Utilize renewable sources of energy to mitigate energy usage	• KW hours per day • KW hours per unit of production • Average distance traveled to market

Marine plastic pollution: As part of long-line seaweed farming, single-use water bottles and Styrofoam are generally used as flotation devices, which degrade after 1-2 seaweed cycles and can be a source of plastic marine debris and contributor to microplastics. Farmers in both off-bottom and long-line seaweed farming use polyethylene (plastic) ropes of differing widths for lines and tying seaweed, with the latter creating large amounts of plastic fiber debris with each seaweed cycle. There is a growing concern regarding the environmental impacts from the amount of plastics used in bivalve aquaculture equipment, including predator netting, PVC tubes for geoduck aquaculture, plastic ties, and plastic bags that can become dislodged and lost during storm events. The Monterey Bay Seafood Watch 2016 downgraded geoduck aquaculture from a green "best choice" to a yellow "good alternative" rating, due in part to changing criteria in the effluent category that now includes the use of plastics and concern over plastic debris.

Commercial Considerations

Relative to other species produced via aquaculture, bivalves and seaweed generally present a low cost, lower value opportunity. Bivalve and seaweed production requires relatively low capital investment to achieve economies of scale compared to finfish aquaculture. The fragmented nature of the industries presents opportunities for integration and growth.

Seaweed Case Study: Atlantic Sea Farms[127]

Seaweed farming in the U.S. is a still nascent industry, with few farmers actively engaged in seaweed for a primary or even supplementary income. However, Atlantic Sea Farms (formerly Ocean Approved) is cutting a path towards a profitable and scalable industry in the Northeast of the United States. Atlantic Sea Farms was founded in Maine in 2006 as the first commercial seaweed farm in the U.S. It has grown from a single farm to include a nursery and processing facility and active partnerships with 16 local seaweed farms run by lobstermen and shellfish farmers, which it played a substantial role in developing.

The Atlantic Sea Farms product is fresh frozen kelp, including kelp slaw, kelp cubes, and kelp salad. Atlantic Sea Farms sells to wholesalers, focusing on a US market that imports seaweed from Asia for direct consumption. They differentiate and market their product from established Asian producers by stating that they have superior water quality, do not use chemicals or dyes, and freeze rather than dehydrate their seaweed. Atlantic Sea Farms is currently oversubscribed in their Series A funding round and projects their sales to reach approximately $1.5 million in 2019, a five-fold increase from the year prior.

As part of their social and environmental mission borne from witnessing ocean changes and experiencing collapsed fisheries in Maine, Atlantic Sea Farms seeks to employ practices for which the "ocean would approve," which directed their focus on farmed product and teaching fishers to farm in order to supplement wild fishery incomes.

How they are doing it: Making use of idle capital and supply chain development

Maine's wild lobster industry is primarily a three-season business with most lobster harvest occurring in spring, summer, and fall months. While the lobster industry in Maine is currently doing well, there are increasing pressures on the industry including reduced availability of baitfish, uncertain schedules for lobster shedding which highly affects product price, and a marked trend of lobster habitat moving north and away from Maine as waters warm.[128]

Atlantic Sea Farms recognized an attractive business opportunity that could supplement fishermen livelihoods in winter months and hedge against uncertainty in the lobster business. Unlike lobster, kelp growth thrives during winter months. As the lobstermen have already invested in the large capital costs of a boat, the low cost for entry, minimal maintenance requirements (lines need to be checked only about 10 times per year), and product diversification is appealing for fishers during the lobster off-season.

Atlantic Sea Farms focuses on addressing key bottlenecks for industry development by providing permitting assistance to lobstermen to assist them in obtaining permits and site selection, sharing their open sourced kelp farming manual,[119] and providing free seed for a year as part of an offtake agreement with the farmers.

While Atlantic Sea Farms remains in an early stage of business development, currently working with 16 lobstermen who now have their own farms, the scaling potential is evident. There are currently over 5,000 permit holders in the state of Maine alone, a substantial portion of which could also start kelp farms. By investing in upstream and downstream supply chains (i.e., seed production and marketing), Atlantic Sea Farms is positioned to serve as a broker for the industry as it scales.

Atlantic Sea Farms' management team and board draws from a large range of expertise including investment, large food retailer, non-profit, seafood marketing, aquaculture and fisheries, and food manufacturing industries. The board is embarking on several strategies to scale production and target niche markets, including:

- Strengthen and expand supply chain through creation of a farmer network for innovation and information sharing, assist additional lobstermen who are interested in farming kelp, and create a revenue-generating seed nursery;
- Launch retail product line and improve sales through company rebrand, retail packaging design and creation, and expansion into e-commerce in 2019;
- Seek and obtain organic certification for nursery and farms; and
- Purchase processing equipment and make facility upgrades to increase capacity and lower labor costs.

Table 4.16: Seaweed case study - representative metrics of small Maine kelp farming

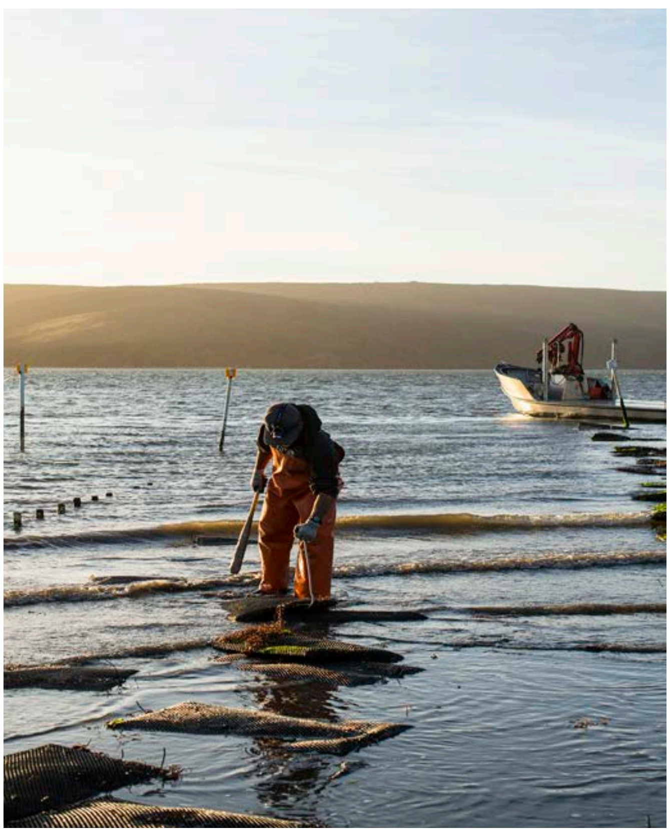
Farm Size	~2.5 acres; 20,000 feet of lines
Initial Investment	$3,000-$5,000
Marginal Production	3-7 lb/ft per year
Atlantic Sea Farms Price	$0.55/lb
Farmer Gross Revenue	$4,500 (1,600ft farm) – $55,000 (20,000ft farm)
Number of Lobster Permit Holders in Maine	5,000

While traditionally a commodity business, some products have achieved a level of differentiation based on local distinctions. Branding for bivalve oysters tends to focus on quality, "merroir," and product story. As consumers continue to demand sustainable and organic food products, branded producers may capitalize on additional marketing approaches relating to the regenerative aspects of bivalve production.

As with most food products, ready access to processing and distribution networks is important to both bivalve and seaweed operations and economics, particularly for growers selling into commodity channels. For local and regional brands, the demography, demand, and accessibility of their region are critical to financial viability. Given siting limitations, the number of seafood farms and related aquaculture businesses in the area should also be evaluated in considering new or expanded operations.

Operational Considerations

As identified in section 3.2, the six key operational drivers for the aquaculture industry are: 1) feed conversion ratio, 2) stocking density, 3) growth rate, 4) normal mortality rate, 5) animal health and welfare, and 6) product quality consistency and form.



Hog Island Oyster Farm, Tomales Bay, California.

Photo © Remy Galvan Hale

As grow-out of bivalves and seaweed are dependent upon availability of naturally occurring algae and nutrients—ideally requiring no inputs from the farmer—selection of a suitable farm site is essential. Selection of an appropriate farm site with sufficient algae or nutrient availability, as well as other appropriate water quality characteristics (e.g., dissolved oxygen) can improve growth rates and reduce mortality rates. High stocking density can help amortize capital and equipment costs; but producers must strike a balance with less intensive growing practices. Lower stocking densities can reduce stress, improve growth rates, and lower mortality, shortening the time to harvest and resulting in higher yields. Bivalve and seaweed production as currently practiced is a relatively low-tech industry, with significant opportunity to employ greater efficiency in mechanization and automation, which could also yield improvements in product quality, consistency, and form. As with any aquaculture facility, it is essential to select and secure farm sites that minimize exposure to weather and other operational risks, such as vandalism or theft.[129]

Bivalve Case Study: Atlantic Aqua Farms[130]

Atlantic Aqua Farms (AAF) has been supplying North American consumers with its Canadian Cove brand of mussels for over 25 years. Headquartered in Orwell Cove, Prince Edward Island (PEI), the company is the largest grower and processor of Prince Edward Island blue mussels under the brand names Canadian Cove, Confederation Cove, and J.P.'s Shellfish. AAF also sells branded oysters, clams, and live Maine and Canadian lobster.

The company serves as an exception to an otherwise highly fragmented industry and possesses one of North America's largest portfolio of shellfish aquaculture acreage and farming operations. The company also holds deep, longstanding relationships with independent shellfish producer-suppliers. AAF can provide its customers with a full suite of premium shellfish products year-round in a variety of packaging formats.

How They Did It: Platform Acquisition and Sustained Growth

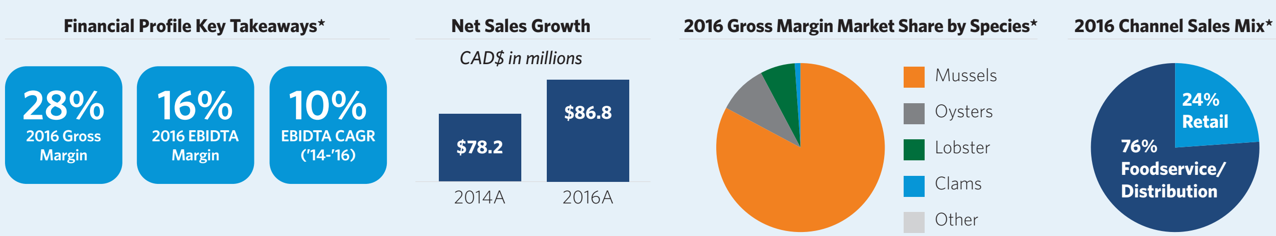
Atlantic Aqua Farms began growing, processing and marketing mussels in 1989, helping to pioneer the mussel farming industry on Prince Edward Island, which today produces over 18,000mt annually. The company grew organically and via acquisition, expanding production and integrating down the supply chain with processing, storage, and distribution facilities. The company now operates several midstream assets including two processing plants in PEI, a live shellfish distribution facility in Maine, and a truck fleet.

AAF has capitalized on strong growth in the global aquaculture segment, as well as heightened consumer awareness and growing demand for sustainable seafood, particularly in the U.S. This has afforded AAF with increased penetration of American markets. AAF also benefits from an experienced management team with a proven track record of driving growth through sales and marketing initiatives, operational improvements, and identification and implementation of accretive acquisitions. These acquisitions have grown the product portfolio and customer base, added complementary processing facilities, and expanded access to supply.

AAF Management is considering several strategies to achieve continued growth:

- Continue to vertically integrate mussel and oyster farming operations;
- Expand lobster and clam production to provide the full suite of shellfish offering;
- Develop accounts with key North American buyers;
- Widen distribution of high-demand, value-added frozen product;
- Increase cross-sell of products across existing accounts; and
- Pursue strategic acquisitions

Figure 4.16: Bivalve case study - Atlantic Aqua Farms financials and margins



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Part 5: Concluding Thoughts

This report explicitly focuses on the potential for private capital investment and the broader financing landscape specific to aquaculture production systems. The three primary motivators for this approach are as follows:

1. **Production systems are at the core of supply chain economics and environmental impact.** While improved farming practices and innovations in ancillary technologies, services, and resource-intensive inputs like feed may be able to enhance the sustainability of a range of production models, the production systems themselves are among the most important drivers of environmental impact.[i] This is a core assumption supported by evidence from analogous sectors, such as agriculture and from early evidence in marine aquaculture. Farm siting, species selection, farm management practices, and other factors have significant implications for the sustainability of various production models, but we believe that ultimately the production systems themselves and their design, efficiency, and financial structure drive a significant proportion of aquaculture's total impact.

2. **Private capital markets have historically been hesitant to finance innovative, resource-efficient impact opportunities where heavy capital expenditures are required.** Private capital market players across a range of profiles express growing interest in the aquaculture sector, but upon further evaluation, many

i Minor editorial change made from the originally published version (1.0).

shy away from capital-intensive, production-model investments such as RAS and offshore aquaculture. Compared to more traditional yield-based real assets like agriculture and forestry, investors have a general lack of understanding about the risk/return characteristics of aquaculture production, which is further compounded by the challenges of high capital intensity, limited availability of debt financing, operational complexity, potential cash flow volatility, and precedent of few successful exits. These challenges present a "chicken or the egg" problem with financing new capital-intensive technologies, however, this situation is not unique to sustainable aquaculture. It has always been challenging to raise capital for pilot projects and even more so for first production plants—notable examples exist within the renewable energy sector, such as– wind, solar, biomass, and now battery storage. However, as pilots evolve into first plants, first plants prove their efficacy, costs curves begin to come down at scale, and costs of capital decrease, mainstream investors will begin to deploy capital. Capital access constraints have led to financing of most investments by large mainstream aquaculture industry incumbents, further entrenching the prevailing high-impact production models such as traditional CNPs and stifling innovation. Without investment from impact-minded private investors, aquaculture production systems themselves will be slow or resistant to change with significant implications for the sustainability of the entire industry.

3. **Despite the barriers to investing in production, optimizing capital structure and limiting operational risks on the production side can create the potential for compelling investments.** While we believe that compelling investment opportunities abound across the aquaculture supply chain and should be a subject of follow-on analysis, if investors can capture a strategic position in the sustainable production of key species employing production systems such as offshore or RAS, they will be better-positioned to invest across other parts of the supply chain and drive systemic improvement in the sector. Holding a position in production assets can be a key competitive advantage to investing in enabling technologies and services because it provides a platform to better understand what is needed and to realize meaningful synergies between these technologies, services, and core production assets enabling faster deployment of those technologies. Investing successfully in production systems followed by investment in the technologies and services to improve efficiency can create tremendous financial value. This approach could tip aquaculture production towards improved sustainability and profitability as market adoption of technologies increases and as costs curves come down. This dynamic has already occurred within the traditional wild-caught industry, such as investments in distressed industrial-scale fisheries to restore depleted fish stocks, feed more people and generate a financial return followed by investments in fishery-wide data collection and port infrastructure.[131]

Table 5.1: Impact investor considerations for RAS, offshore, bivalve, and seaweed aquaculture

	RAS	Offshore	Bivalves and Seaweed
Core Investment Thesis	• Significant cost savings (particularly with freight of fresh products) by locating production closer to demand centers • Fewer biological risks (e.g., disease/parasite issues) relative to farming at sea • Lower environmental compliance and permitting costs relative to traditional farming at sea	• Offshore offers an opportunity to extend aquaculture production to regions where there is less competition for space and potential for conflicts • Scale advantages to help amortize higher capital and operating costs which will likely remain higher than net pens or onshore for the foreseeable future • Potential to site production closer to market	• Already profitable at smaller project sizes with significant financial upside to scaling • Proven production methods with many skilled operators and potential expansion to new species and regions • Large and diverse market opportunity for both globally
Impact Thesis (Environmental)	• Physically separating aquaculture from the marine environment and advanced water treatment technologies results in limited or no interaction with the sensitive ecosystems or species, and reduced water pollution impacts • Improved ability to control culture environment, which can improves feed conversion ratio (FCR) and reduced need for antibiotic use	• Location in deeper, higher water flow areas minimizes or negates impact on sensitive habitats and species • Cleaner offshore water can allow fish to grow more efficiently, improving FCRs. Improved gear may result in lower escapement in some cases and reduced entanglement risk • Lower water pollution impact due to better flushing by currents and farming in low nutrient environments • Potentially lower disease transfer risk both between farmed species and to wild species	• Represent the clearest environmental value proposition given they: • (a) possess the lowest input requirements of any aquaculture production model, and • (b) can provide ecological benefits to surrounding ecosystems in the form of water filtration, nitrogen removal, and habitat provision
Key risks/ challenges	• Few successful models at scale and high capital intensity • High development, construction, and operational risk due to systems complexity • Technology risks compounded by challenges of adapting to new species or significant scale-up • Higher risk of binary/catastrophic loss or mortality • Biological challenges (e.g., early maturation) associated with trying to artificially mimic natural systems • Necessity for higher stocking densities to produce competitive unit economics • Challenges with water access and waste discharge permitting • Customer perception as "unnatural" vs in-water farms or wild-capture	• Further distance from shore increases production costs and risks • Few experienced offshore operators with track record of success • Lack of suitable governance frameworks in most jurisdictions to license and regulate offshore production	• Production amounts and operation sizes have been small • Permitting and regulatory constraints for production at scale • Mortality risk from predation, disease, and temperature changes due to at-sea exposure

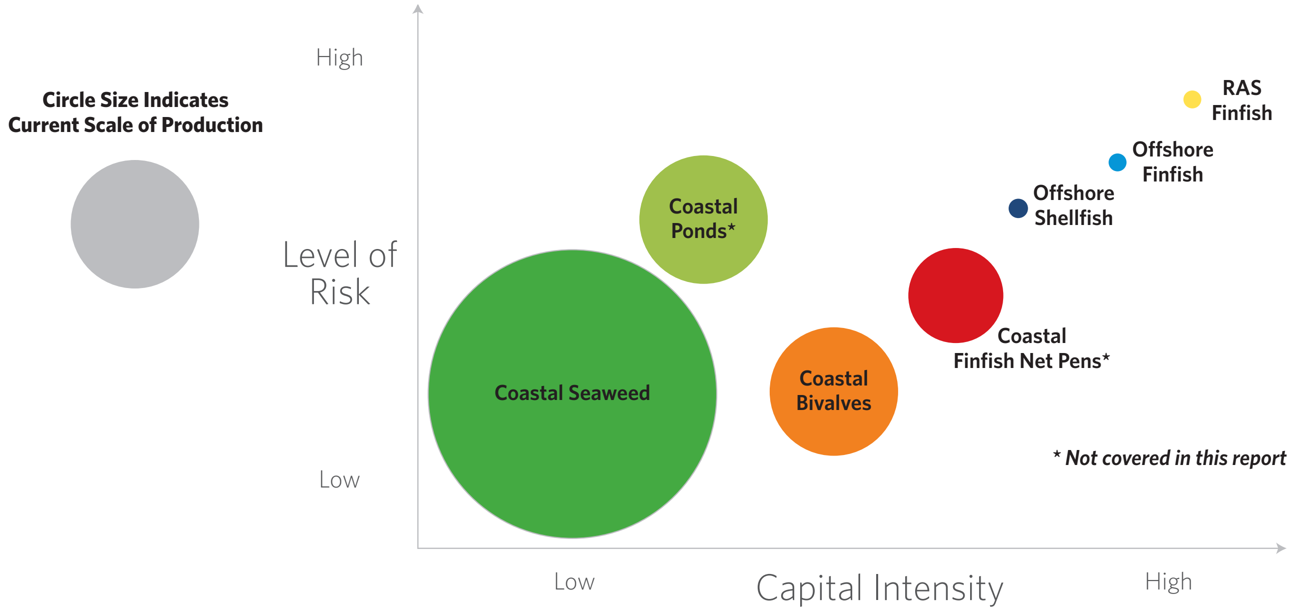
Table 5.1 (continued): Impact investor considerations for RAS, offshore, bivalve, and seaweed aquaculture

	RAS	Offshore	Bivalves and Seaweed
Risk mitigation	• Operational track record • Management team with deep experience with RAS production with specific culture species • Modular systems allowing for phased project development and system redundancy in case of failure • Technology validation via subscale demonstration projects • Ensure high-quality water source • Use of hedging mechanisms and long-term offtake contracts • Backing of local and national government entities • Proximity to major high-value markets	• Operational track record • Strong, experienced management team • Technology validation via subscale demonstration projects • Use of hedging mechanisms and long-term offtake contracts • Favorable regulatory jurisdiction with defined policy framework • Backing of local and national government entities • Proximity to major high-value markets	• Operational track record • Strong, experienced management team • Strategy to achieve scale • Market proximity • Vertical integration and value-added downstream operations
Unlevered IRR Hurdle[i] [132]	20-35%+ (depending on project stage and track record)	20-35%+ (depending on project stage and track record)	10-15%
Average capex/kg[ii]	**Small-Scale Projects (< 2,500mt):** $16.00 - $24.00 per kg **Large-Scale Projects (> 5,000mt):** $8.00 - $12.00 per kg	**Small-Medium Scale (< 5,000mt) Offshore Cage Farms:** $4.00 - $9.50 per kg **Large-Scale, High-Tech Norwegian Development License Farms:** $6.50 - $20.00 per kg	$20 - $60 per bushel (depending on scale, species, equipment type, and location)
Role of Concessionary capital	Subsidize technology R&D and prototyping of new species production and underwriting first plant risk	Subsidize technology R&D and underwriting first plant risk	Provide inexpensive debt for scale up of smaller production efforts
Leading Producers (current and projected)	European Union, Norway, USA, China (projected), Singapore (projected)	Mexico, Japan, Norway, Panama, China (projected), Turkey (projected)	Bivalves: China, Chile, Japan, South Korea, Peru, New Zealand, Taiwan, USA, European Union Seaweed: China, Indonesia, Phillipines, Korea, Japan
Primary species	Atlantic salmon (particularly smolt production), Yellowtail, Seabass/bream	Atlantic salmon, Cobia, Yellowtail, Snapper	Oysters, clams, mussels, scallops, and seaweed (many species of each)
Current Level of Investable Deal Flow	High	Medium	Low

[i] Based on investor interviews, market comparables, and academic research.

[ii] Compiled from estimates by DNB markets, Deloitte, Pareto Securities, interviews with investors, company materials, and reporting by IntraFish Media.

Figure 5.1: Industry context: Current state of aquaculture industrialization by production method



Summary Conclusions

Recommendation for Commercial Investors:

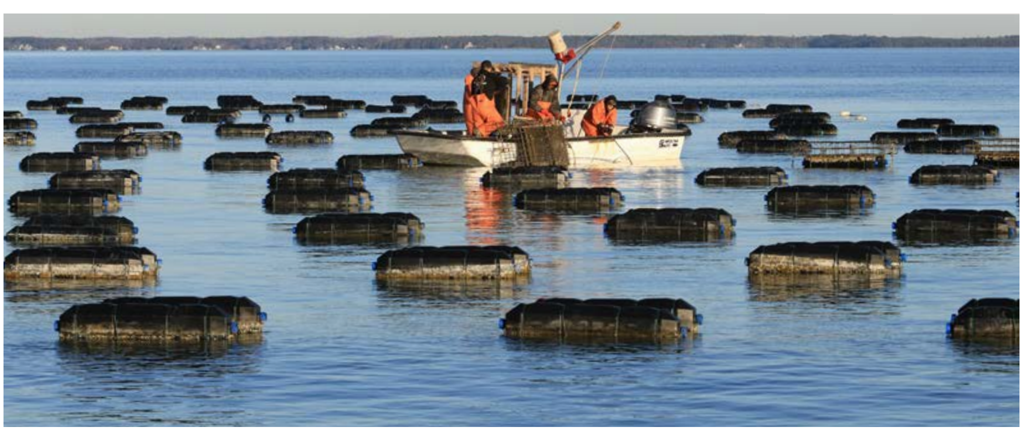
The perceived misalignment of risk and return for novel, more sustainable production methods can be better understood by framing aquaculture projects as a hybrid of a real asset and operating company investment.

Aquaculture production assets are challenging for many investors to assess and categorize in large part because of these hybrid characteristics. Marine aquaculture farming assets share the capital requirements, long-duration hold period, and return profile (capped upside) of real-assets, but appear to have the operational, business, and market risks of an operating company. This discrepancy has challenged financial investors in pricing aquaculture deals and differentiating between lucrative opportunities—characterized by capital-appreciation potential with stable yield—and value traps with bounded upsides, high volatility, complexity, and binary risk. This may be even more pronounced for sustainable aquaculture production assets, particularly those newer innovations without proven track records.

Investors can optimize their capital deployment for the reality that sustainable aquaculture investments are often a hybrid of a real asset and operating company investment by:

- **Seeking equity upside for debt investments.** For example, private credit funds, financing companies, families or other debt providers with in-house project finance experience as well as relevant operational and industry expertise can make debt investments with equity warrants or options to capture the financial upside potential of investing in project sponsors.
- **Securing concessionary capital alongside market rate debt sources.** For highly innovative, early stage, or proof-of-concept models, commercial investors can seek blended capital or concessionary sources (e.g., loan guarantees, credit enhancements or below market rate debt) from foundations, impact investors, mission driven families, governments and multi-lateral institutions to reduce commercial risk.
- **Investing equity in project sponsors/operating companies alongside debt.** To maximize the financial returns for the given risks, investors can also invest in the equity of the companies operating the plants alongside providing debt. Providing relatively small equity investments alongside debt to fund the companies developing or operating the production facilities provides strong potential for financial upside and ensures that often under-capitalized operators have the financial resources to see their projects through to profitability.

As examples for structuring around this hybrid profile, private credit funds with in-house operational and industry expertise should make debt investments with warrants to capture upside potential on the right projects. For highly innovative, early stage, or proof-of-concept models, blended capital or concessionary sources (e.g., loan guarantees) may be a compelling catalyst to leverage the impact capital needed to mobilize the market. Risk-tolerant investors should also consider structuring terms with convertible debt or warrants to offset losses with upside from their successful investments. In this way there are also opportunities to crowd in market-rate equity financing using lower-cost, blended, or hybrid capital sources.



Chesapeake Bay floating oyster aquaculture.

Photo © Andy Lacatell

Table 5.2: Aquaculture real asset comparison

Aquaculture Similarities to Real Assets	Differences to Real Assets
• Capital intensive • Range bound unlevered free cash flows defined by: a) fixed production capacity; b) input costs; c) finished goods price • Limited control over input/output pricing • Production capacity expansion requires additional, potentially dilutive, capital (especially when leverage is limited – see discussion of bankability)	• The most attractive real assets have relatively fungible assets, many potential buyers (price support), price discovery/valuation, comps/mark-to-market, optionality and operational flexibility, few captive or stranded assets • Strong, transferable property rights underpinning the asset; while this differs by jurisdiction, marine aquaculture property rights, often in the form of leased concessions, are generally not as strong • The strongest real asset investments have stable, predictable, and ideally contracted or well-hedged cash flows; while the salmon industry is relatively more developed in this regard, marine aquaculture is still lacking in terms of cash flow visibility • Low cost of capital – largely due to the factors mentioned above, the strongest real assets are able to obtain capital at a low weighted average costs of capital (WACC), supported by high leverage ratios. High leverage ratios, low cost of debt, and relatively low risk can support relatively attractive levered (equity) IRRs; this is not the case for the aquaculture production models described in this report for which is it is generally difficult to attract significant debt financing

Recommendation for Entrepreneurs and Companies:

By better defining project risk-return profiles for investors enabling them to capture equity upside alongside side provision of debt, sustainable aquaculture projects can attract significant private investment. Some strategies for doing so include:

- **Finance the core capital expenditure investments needed to build prototypes, demonstration plants or full-scale operating facilities through a traditional debt-financed real asset model.** This can be done by establishing clear legal property rights backing up a production asset with complementary secured assets that can significantly lever up the equity component. This can allow for use of forward contracts or fixed price offtake agreements and hedging of key volatile inputs to stabilize cash flows, potentially refinancing project debt and taking additional equity out of the project.
- **Build in upside by providing opportunities for investment into the Operating Company acting as the project developer or sponsor.** This approach allows for growth based on low-cost capital, increased efficiencies, scale, and synergies so investors can target aggressive expansion and an exit to a strategic or later stage financial investor if they do not want to manage the asset for the long-term. This allows companies to grow production capacity non-dilutively over

time with ever-cheaper and more abundant sources of capital. It also allows companies to reduce the cost of debt and unlevered equity by: 1) Validating and de-risking the business model; 2) Strengthening the balance sheet and quality/lender acceptability of the asset base; 3) Finding ways to effectively shift future cash flows to the present through hedging and long-term fixed price offtake agreements; and 4) Increasing leverage over time to enable more attractive levered IRRs for equity investors, attracting more institutional capital typically focused on real-asset type investments.

- **Maintain optionality to pivot to new business models, products/species or financing strategies by raising enough capital to meet key milestones and seeking maximum operational flexibility.** The value of asset optionality is a function of volatility in the performance of that asset. In a growing, rapidly changing industry like marine aquaculture, asset optionality can command a premium. This value reflects the ability to pivot the business model, financing strategies, and product/species focus as conditions change. The characteristics of asset optionality within this context include: 1) Strong property rights or resource tenure granted in perpetuity or for a defined long-term period, with little or no chance or expropriation or forfeiture; 2) Property rights or resource tenure not contingent on a certain level, type, or species of production; and 3) Property rights or concessions with the broadest possibly leeway in terms of productive use (assuming compliance with environmental, safety, and zoning parameters).

Recommendation for Impact Investors:

Impact investors should consider catalyzing broader private capital investment into sustainable aquaculture production systems by financing demonstration projects, prototypes, and R&D that can then crowd in and be taken to scale by broader capital market participants.

Even the most mission-driven sustainable aquaculture projects and companies should seek to eventually attract market rate capital. The ideal ultimate outcome would be one in which mainstream private capital markets help take sustainable production systems to scale guided by more impact-minded investors. Despite the opportunities to take advantage of lower capital costs and grants in the early stages of growth, sustainable producers and their impact-oriented backers should strive to build businesses that will attract the full range of investor profiles. We believe an investment strategy focused on demonstrating the potential of sustainable aquaculture to investors of all types, while not sacrificing the commercial integrity of the business model, will prove more viable and impactful in the long run and can serve as a beacon to crowd in other sources of institutional capital normally absent from the impact realm.

Recommendation for Philanthropists, Policymakers, and NGOs:

Philanthropists, policymakers, and NGOs are uniquely positioned to help identify and cultivate the enabling conditions that will allow investment at scale into sustainable aquaculture projects needed for these models to succeed.

These stakeholder groups should work collectively to better define, align, and refine government policies regulating aspects of the Blue Revolution agenda. A stable, predictable policy framework based around sound property rights, frictionless transactions, enforceable contracts, and fair arbitration is necessary for any efficient market. Clear, well-enforced policy and regulations must be established to foster greater aquaculture adoption and shape future growth. To date, the political-regulatory scenario for aquaculture varies widely by region and jurisdiction. In some regions, creating a suitable investment environment requires increased regulation and stability. In other locations, convoluted, restrictive regulatory and permitting processes have stifled investment and growth.

Though the effectiveness of existing policies varies quite widely across jurisdictions, these stakeholder groups should advocate a policy environment supportive of a Blue Revolution movement focused on:

1. **Developing transparent, effective, and protective permitting processes and regulations** that allow for:
    a. protection against issuance of permits to operators employing practices that degrade ecosystems or undermine businesses;
    b. enforcement of protection of assets from theft or vandalism and maintenance of environmental standards; and
    c. permits to be obtained within a reasonable amount of time.
2. **Establishing strong, well-defined, and legally tested property rights and resource tenure guidelines** for aquaculture operations.
3. **Developing enabling infrastructure to support sector development,** such as transportation, storage, sanitation, energy, and water. Insufficient infrastructure can be a major development constraint for capital-intensive, innovative business models (e.g., offshore).
4. **Creating special programs to promote sustainable innovation,** such as establishment of government programs with properly structured incentives that promote industry engagement in "moonshot" undertakings, such as the Norwegian Development License program.

5. **Establishing public finance mechanisms,** such as low-interest loan programs and crop/disaster insurance programs to build up key industries or de-risk sustainable practices.

Together with public policy measures to support innovation, philanthropists, NGOs, and Development Finance Institutions (DFIs) should consider approaches to encourage transformative solutions and enable reasonable risk-taking in early market-development stages. These stakeholders should work collectively to help establish a set of commonly accepted principles for responsible marine aquaculture investment. This would help to alleviate both reputational risks for investors associated with making sustainability claims about novel production methods, as well as with concerns that consumers will be reluctant to adopt the farmed product or discount it relative to wild alternatives. Further, establishment of a set of sustainable aquaculture investment principles backed by a consensus of public, private, and NGO leaders would help eliminate confusion around the sustainability merits or considerations of a particular investment and reduce due diligence costs.

In conclusion, this report seeks to provide an overview of the challenges and opportunities to scaling up RAS, offshore, bivalve, and seaweed aquaculture production in a manner that yields attractive financial returns while improving aquaculture's environmental performance, and makes recommendations for investors, entrepreneurs, and civil society stakeholders including the NGO, foundation, and policymaking communities. We believe that proper, targeted, and in some cases coordinated interventions between these groups could usher in a much-needed Blue Revolution. Transforming how we produce seafood through strategic investment in innovative, more sustainable production methods may ultimately represent the difference between a healthy, abundant, and profitable food system, and one that degrades the environment, destroys value, and fails to meet the growing food security challenge.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Appendix: Indicative Aquaculture Due Diligence Questionnaire

General

1. Provide a brief summary of the lifecycle and commercialization of a typical production run /spawning class from egg/seed to plate, including the following stages and operational activities:
    a. Spawning
    b. Hatchery
    c. Outgrowth
    d. Harvest
    e. Processing
    f. Commercialization
    g. Transport
2. For each stage indicate which of these activities is managed by the company versus a third-party, and the average timeline for each event.
3. Provide a map of all current production sites, including hatchery, farm sites, processing locations, etc. as well as potential future sites (if applicable).

Growth Plan

1. Provide a summary of the Company's business development and growth strategy for the next 5 years.
    a. For each activity above provide the following:
        i. Timeframe for implementation and realization of economic value
        ii. Rationale / opportunity
        iii. Cost (capex requirement, timing, and source of capital)
        iv. Financial implications (e.g., additional EBITDA)
        v. Additional resources required (human, technology, R&D, etc.)
        vi. Any other relevant considerations
    b. Outline target capital structure (debt composition, refinancing, shareholder contributions, etc.)
2. Based on this plan, provide **projected financial statements**[i] (5-7 years) including detailed assumptions on sales by volume, price, costs, working capital, debt service coverage analysis, and rate of return calculations. More specifically, include a breakdown of:

i Should be provided in Excel

a. Gross revenue, discounts, gross margin by main product line, as well as prices and volume sold per product line.
b. COGS by key input, packaging material and other costs (define) of production (excluding depreciation).
    i. Include list of COGS drivers, and real price increases (ignoring inflation); inputs that will be imported, state quantities imported and applicable duties; all inputs subject to foreign exchange fluctuations.
c. Sales, marketing and general administration expenses by staff costs, distribution costs, advertising/ promotion, etc.
d. Other costs – licensing, leases, management fees, (define) etc.

3. Provide detailed capex program for next 5 years, indicating if it is for expansion or maintenance - itemized by equipment, civil works, etc.
    a. Describe capex need to support current volumes (instead of growth) including any vessel, pen, or other upgrades planned.

Ownership, Corporate Structure and Management

1. Provide an overview of the corporate history of the Company, acquisitions, site expansions, divestments, etc.
2. Provide the latest shareholding and organizational structure, detailed management organization (Board of Directors and Management structure), accountability and reporting lines.
3. Discuss additional hires anticipated and share leading candidate profiles if possible
4. Provide the total number of employees presently employed by the Company and the split between temporary and fixed and male vs. female.
    a. How much does the Company contribute to employment generation in its region?
    b. Are employees allowed to be part of labor unions or others?

Financial

1. Provide **historical financial statements**[ii] (at least 5 years and quarters available for current FY) including detailed management accounts and a breakdown of operating revenues and expenses as described in 1(a)-(d) below (in a way that can be reconciled with audited financial statements)[iii]:
    a. Revenue by gross revenue, discounts, and gross margin by product line as well as prices and volume sold per product line
        i. Sales by country, channel, and product grade
    b. COGS by product type and further broken down by raw material & packaging material and other costs (define) of production (excluding depreciation).
        i. List COGS drivers, and real price increases (ignoring inflation).

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ii Should be provided in Excel
iii Where relevant, break out by site and year class

c. Sales, marketing and general administration expenses by staff costs, distribution costs, advertising/promotion, etc.
d. Other costs – licensing, management fees, leases, (define) etc.

2. Discuss nature of inter-group transactions and arrangements – arms-length, market, etc. including transactions with other companies of the Family.
3. Provide list of all short and long-term loans and leases outstanding and to be committed in the next 12 months, term maturity, lender, interest rate, security, borrowers, etc.
   a. Provide detail of available short-term credit lines.
4. Provide description of the tax regime and mechanism (sales tax, income tax, labor and social taxes related contribution, etc.) and their impact upon working capital needs. Discuss rates of any indirect taxes, such as custom and excise taxes and others. Limitation or need to obtain license prior to exports?
5. Provide description of the depreciation regime and mechanism for each subject (e.g., civil works, equipment, etc.).

Operational Performance Metrics

1. Provide the following key operational performance metrics historically and projected (by year and by site, where applicable):
   a. Total harvest volume
   b. Average harvest size
   c. Productivity (kg per unit area per year)
   d. Relevant health data (e.g., lesion, deformity, sea lice rate etc.)
   e. Product quality (% share by grade)
   f. Operational EBIT (EUR per kg harvested)
   g. Feed cost (EUR/kg)
   h. Total cost (EUR / kg)
   i. Other key operational performance metrics
2. Provide the following operational performance metrics historically and projected (by year for the entire operation):
   a. Price by product grade
      i. Cost in box (EUR/kg, GBP/kg, USD/kg)
      ii. Market price (EUR/kg, GBP/kg, USD/kg)
   b. Price premium relative to relevant indices in target markets
3. Provide the following key operational performance metrics historically and projected (by production run/spawning class, by month):
   a. Feed conversion ratio
   b. SGR (%)
   c. SFR (%)

d. Mortality (%)
e. Stocking densities (kg / m^{3})
f. Fish/shellfish health data with explanations regarding challenges and significant mortality events

Environmental Performance Metrics

1. Please provide the environmental impact assessments, environmental monitoring information and reports, for this project that detail impacts and mitigating measures in the following areas:
   a. Impacts to wild stocks, including sources of fry, escape genetic interactions, feeds information
   b. Habitat impacts
   c. Water pollution impacts
   d. Disease impacts
   e. Water usage information
   f. Land usage utilization
   g. Energy usage

Operations

Inputs

1. Discuss sources for all major inputs (e.g., feed, eggs, etc.), competitive supply situation, supply constraints, and any regulatory issues or government restrictions.
   a. Include discussion on price trends, highlight real price changes only (ignoring inflation).
2. Describe feed type, composition and sourcing strategy.
   a. Note any historical changes in diet.
   b. Include discussion on price trends, highlight real price changes only (ignoring inflation).
3. Discuss alliances/partnerships established with key suppliers, if any, and how you ensure adequate supply and best prices.

Hatchery

1. Provide available data and any additional commentary for:
   a. Number of spawnings per year realized in the hatchery
   b. Annual hatchery capacity (in kg sent to farm)
   c. Historical input losses by class (%)
   d. Historical hatchery mortality by class (%)
2. Discuss source of broodstock and broodstock risk mitigation strategy.

Fish Health

1. Provide an overview of the fish health program, including:
    a. Vaccination program and cost/unit
    b. History of antibiotic administration
    c. Discuss key disease issues and management strategy

Farm Management Systems

1. Discuss farm management / ERP systems.
    a. Production Management and Control systems, product costing and control, integration with financial accounting and operational management.

Site, Facilities, and Logistics

1. List all site concessions and relevant considerations regarding production consent, impairments, ownership (own/lease), etc.
2. List all production and manufacturing resources – pens, hatchery, plants, etc. – including locations, ownership (own/lease), capacities, capacity utilization, and capacity bottlenecks (if any).
    a. Describe cage specifications (size, #, depth, capacity) by site.
    b. For each, provide age/installation date, leasing system (where applicable), and useful life.
3. Provide any benchmark of the Company's operations with their local peers, and international industry standards.
4. Discuss quality and environmental management practices, licensing, accreditation and certification, including quality certification, if any (e.g., ISO, HACCP, BRC etc.). Discuss plans to implement any certification programs.
5. Discuss transportation logistics: including logistics costs from the suppliers to the plants and plant to market (finished products).
6. Discuss insurance policies. Are these based on new or replacement value?

Sales and Marketing

1. Provide information on the Company's distribution arrangements, main channels of distribution and weight of each channel - own/ hired/ leased transport, distributors, wholesalers, moms and pops, agents etc.
2. Discuss sales incentives (rebates, discount, etc.) per distribution channel.
3. Provide an overview of competitive position and market share for all the Company's main products, including main competition.
4. Discuss the Company's branding and pricing strategies including identifying the main competitors for each product line, and providing an analysis of strengths/weaknesses.
5. Discuss seasonality of demand for products, if applicable.
6. Provide market studies undertaken and any 3rd party market research undertaken or purchased by the Company if any for every market where the Company operates.

7. Describe sales organization (management, staffing, sales force incentives).
8. Discuss how the Company manages sales and marketing relationship with customers which account for 80% of annual sales. Discuss risk of loss of major customers.
9. Discuss any trade issues/incentives/restrictions which are relevant to the Company's products - such as import duties, quotas, subsidies, anti-monopoly restrictions etc in the domestic markets.
10. Discuss R&D (or new product development) strategy: budget, new products launch/year, etc.
11. Discuss how the Company hedges currency risks.

Regulatory and Other Risks

Regulatory

1. In detail discuss:
    - **a.** Any government controls on any of the Company's main product lines including risks, advantages, and anticipated changes;
    - **b.** Any measures under consideration by the government which may affect the Company's operations in the future;
    - **c.** Existing/projected tariff situation including protection enjoyed by the Company's products against foreign competitors and other export/import restrictions or benefits;
    - **d.** Any government controls or other arrangements influencing the prices or markets;
        - i. Any present or proposed tariffs relating to the Company's market and products;
    - **e.** Any present or proposed tariffs relating to the Company's market and products;
    - **f.** Any present or proposed actions of the government to allocate materials, control imports, etc., which affect raw material supplies.

Farm Productivity

1. In detail discuss any resource/farm productivity risks, considerations, and contingency plans including:
    - **a.** Ecological risks with potentially material impacts (climate change, red tides, sea lice, predation, etc.)
    - **b.** Exogenous anthropogenic risks (pollution, theft, etc.)
    - **c.** Production capacity uncertainties
    - **d.** Equipment failures or anticipated shutdowns
    - **e.** Regulatory changes
    - **f.** Material political issues/movements that may affect future regulation/ability to operate.

Endnotes

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