

Ensuring sustainability in Hawaii's offshore aquaculture industry:

Environmental, economic, and social considerations for future
development

Author: Zoe Wong

Advisor: Dr. Grant Murray

April 22, 2022

Masters project proposal submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment of
Duke University

Executive Summary

Offshore aquaculture is an emerging industry that has the potential to supplement existing wild fisheries and aquaculture operations. In the United States, offshore or open-ocean aquaculture, also known as submersible cage aquaculture, has received attention and encouragement from the National Oceanic and Atmospheric Administration (NOAA) and Congress. Hawaii is home to the nation's only active commercial open-ocean fish farm and has received increased interest and attention as a potential area for offshore aquaculture growth in both state and federal waters. The state's prior experience in both land-based and offshore aquaculture position it as a prime location for future offshore development.

While the potential environmental impacts of offshore aquaculture are generally understood, the economic and social factors that may influence the industry's development have received little attention. In addition, little research has focused on environmental, economic, and social considerations specific to Hawaii. State officials will play an important role in guiding offshore aquaculture's sustainable development but must take action to avoid the missteps of past projects both in Hawaii and elsewhere.

Through background literature research and semi-structured stakeholder interviews, this research illuminates the factors that state officials should consider in order to ensure the environmentally, economically, and socially sustainable growth of Hawaii's offshore aquaculture industry. Because research examining the Hawaiian situation was sparse, the literature search was supplemented with Hawaii-based news articles. Nine interviews were conducted with representatives from government agencies, industry, non-governmental organizations, and

extension organizations, all of whom had prior or current experience related to offshore aquaculture in Hawaii.

Environmental factors that should be considered in the sustainable development of Hawaii's offshore aquaculture industry include water quality, benthic enrichment, fish escapes, habitat creation, and disease transfer. Economic considerations include the diversification of Hawaii's economy, decreasing reliance on seafood imports, and market competition with existing wild-caught fisheries. Social considerations include community mistrust of Western development, the transfer of aquaculture benefits to local communities, and community participation in offshore projects.

By formalizing environmental standards for offshore fish farm management, initiating economic research at both state and local scales, committing to meaningful stakeholder engagement with affected communities, and reestablishing a program to oversee development of offshore aquaculture in the state, officials can nurture an industry that enriches Hawaii's environment, economy, and people.

Table of Contents

Introduction.....	1
Aquaculture in Hawaii.....	4
Goals.....	8
Methods.....	9
Literature.....	9
Interviews.....	9
Analysis.....	10
Results.....	11
Environmental Considerations.....	11
Economic Considerations.....	19
Social considerations.....	21
Recommendations.....	25
Future Research.....	28
References.....	29
Appendices.....	34

Introduction

Seafood, especially finfish, is the primary protein source for millions worldwide and will likely become even more important with anticipated population shifts such as population growth and increased affluence (Costello et al. 2020). Although wild capture fisheries still provide the majority of edible seafood (more than 80%), marine aquaculture production has experienced substantial growth in recent years (Figure 1; Costello et al. 2020). Marine aquaculture, also known as offshore aquaculture or open-ocean fish farming, refers broadly to the use of net pens or cages to cultivate fish in the open ocean. A more precise definition, using parameters such as depth, current speed, or distance from shore, is elusive in the literature; however, offshore aquaculture farms generally differ from nearshore farms in their placement in areas with deep waters and strong currents (Froelich et al. 2017). Because a precise definition of offshore aquaculture could not be obtained from the literature, this research treats “offshore” or “open-

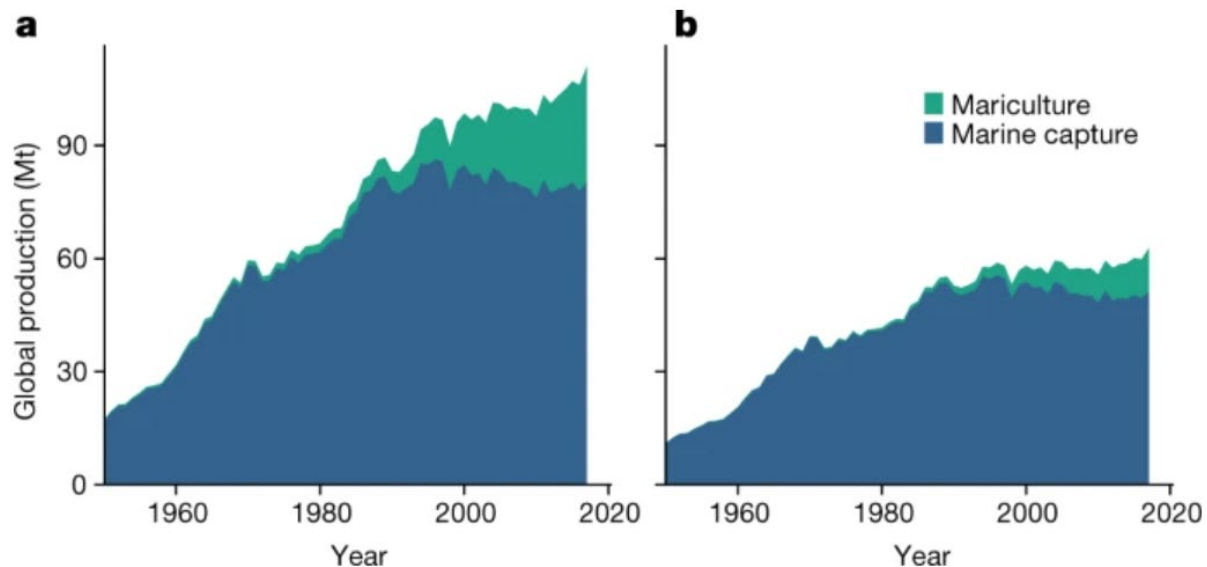


Figure 1. (a) Seafood harvest totals over time (finfish and shellfish). (b) Harvest weight totals converted to edible food weights (excluding non-edible parts of finfish or shellfish), assuming that 18% of wild fishery landings are not purposed for human consumption. (Costello et al. 2020)

ocean” aquaculture as any fish farming that utilizes submersible cages (Figure 2). In Hawaii, these have historically been located in areas with strong currents and waters more than 30m deep (Ostrowski et al. 2001, Seafood Watch 2020).

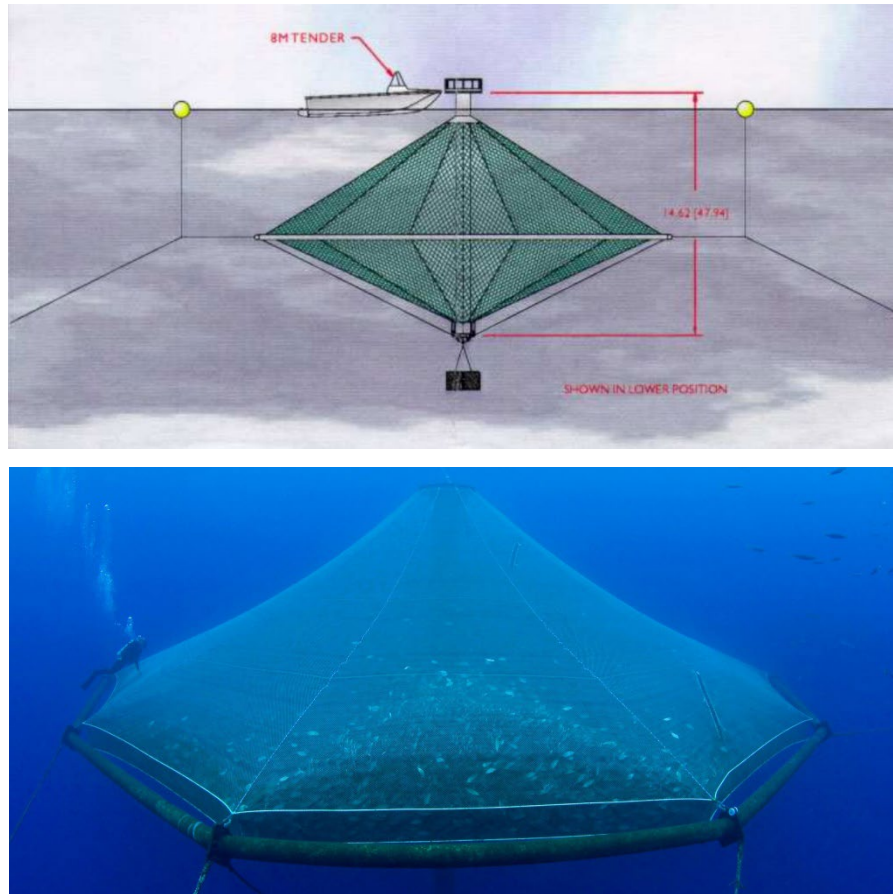


Figure 2. (a) A submersible finfish cage design (Scott and Muir 2000). This diagram shows Ocean Spar Technologies’ Sea Station, the cage type used by Blue Ocean Mariculture in Hawaii, formerly known as Kona Blue Water Farms. The center spar allows the cage to submerge or rise to the surface. (b) A photo of a working cage utilized by Kona Blue Water Farms. Photo by Doug Perrine/Blue Water Archive (Borrell 2020).

Offshore finfish cultivation has proliferated in some areas of the globe, especially Norway and China, and has lagged behind in others (Naylor et al. 2021). In fact, scientists estimate that even with a conservative approach, most countries could sustainably support much more offshore finfish production than they do currently (Gentry et al. 2017). In the U.S., the

offshore aquaculture industry is still in its early stages, consisting of only one operational farm in Hawaii and two prospective projects in New York and California, amidst a handful of pilot or experimental projects (California Environmental Associates 2018).

However, interest in expanding offshore aquaculture operations is growing. For example, Executive Order 13921 directed a more streamlined approach to aquaculture permitting and designated the National Oceanic and Atmospheric Organization (NOAA) as the lead agency for aquaculture projects (Exec. Order No. 13921, 2020). In addition, in October 2021, a bipartisan group of Congressmen introduced the Advancing the Quality and Understanding of American Aquaculture (AQUAA) Act, which would create a federal permitting process for offshore aquaculture and enter many of the provisions of E.O. 13921 into law (S.3100).

NOAA has repeatedly acted to encourage offshore aquaculture development, including the publication of an aquaculture management plan for the Gulf of Mexico in 2016, although the plan was subsequently overturned by a federal appeals court (NOAA 2016). Despite this, NOAA is currently in the process of preparing a Programmatic Environmental Impact Statement for another offshore aquaculture management plan in the Pacific Island Region (NOAA Fisheries 2021a). NOAA is also currently investigating possible Aquaculture Opportunity Areas in southern California and the Gulf of Mexico, which would designate areas with high aquaculture production potential and reduced use conflicts (NOAA Fisheries 2021b). However, these actions have not yet led to widespread industry growth in the U.S.

Proponents of offshore aquaculture argue that this emerging method of seafood production presents an environmentally safe solution to declining global fish stocks. However, whether or not offshore aquaculture can truly be implemented sustainably is still a question of debate. Environmental disasters related to fish farms in nearshore environments have led many in

the environmental community to take a precautionary approach to offshore aquaculture development (Zajicek et al. 2021). Fishers have often taken a skeptical approach to the industry's growth, fearing that they will be outcompeted by farmed fish in the marketplace and that offshore aquaculture could pollute their fishing grounds (Oppenheim et al. 2018). However, others tout the economic benefits of offshore aquaculture development, including commercial profits and employment generated by the industry (Posadas 2004).

The global debate around aquaculture, including open-ocean fish farming, has tended to focus on the tension between possible ecological consequences and potential economic benefits (Kluger and Filgueira 2021). However, equally essential to the success and sustainable growth of open-ocean fish farming is the industry or operation's attainment of a social license. The concept of a social license recognizes that any consequences of industry development, including environmental impacts, will primarily affect local communities; therefore, communities should be able to influence the process of development (Mather and Fanning 2019). This social license is even more important in areas with unique cultural and historical backgrounds, such as Hawaii's history of colonization and the oppression of Native Hawaiians. Over the last 20 years, multiple fish farm proposals in Hawaii have faltered in part because of their inability or unwillingness to address underlying concerns from local stakeholders related to cultural differences, societal divisions, and other uncertainties (Suryanata and Umemoto 2005).

Aquaculture in Hawaii

The presence of aquaculture in the Hawaiian Islands dates back as early as the 1300s, when ancient Hawaiians began cultivating multiple species of fish using specially-engineered fishponds (Kikuchi 1976). Fishpond use declined significantly after contact with Westerners and the colonization of Hawaii during the 19th and 20th centuries (McDaniel 2018). However, these

ponds and their related cultural practices remain important to Native Hawaiians today, and efforts to restore ancient fishponds for modern use are currently underway (Haws et al. 2019).

In contrast to fishpond aquaculture's deep roots in Hawaiian culture, offshore fish farming has only operated in Hawaii since the 1990s and has not been associated with or practiced by Native Hawaiians. Hawaii's first offshore fish farm, operated by Cates International, began production of moi (*Polydactylus sexfilis*) in 2001. Moi, or Pacific threadfin, is native to Hawaiian waters and has cultural roots in the islands, having been considered a delicacy for royalty in Native Hawaiian culture. The farm ran successfully for more than ten years and sold most of its product to both local and out-of-state markets (Essoyan 2001). However, it later closed in 2012 due to financial problems caused by fish survival and hatchery issues while attempting to scale up production (Gomes 2012a).

Since then, Hawaii's offshore aquaculture operations, including both research and commercial farms, have exclusively cultivated kampachi (*Seriola rivoliana*, also known as yellowtail, almaco jack, or amberjack). The only commercial project that continues to be active began cultivation in 2005 as Kona Blue Water Farms and operates today as Blue Ocean Mariculture (BOM). BOM consists of eight submersible net pens sited 0.5 miles offshore near Kona, HI, as well as onshore facilities and a hatchery. Since its inception, BOM has boasted a positive track record on sustainability, including regular water quality tests that show no demonstrable impact from its cages (Gomes 2014). BOM-grown kampachi are categorized as "Good Alternative" (second best rating) by the Monterey Bay Aquarium's Seafood Watch program, which evaluates seafood sources using a series of robust sustainability criteria (Seafood Watch 2020). Seafood Watch's critiques included poor feed conversion, high use of marine-sourced feed, and common small-scale fish escapes (Seafood Watch 2020).

Hawaii has also been home to a series of research projects related to remote monitoring and maintenance technology, free-floating offshore cages, and alternative fish feed studies. However, aside from Cates International and Blue Ocean Mariculture, no other commercial farms reached operation despite the formulation of initial proposals and permit applications from multiple projects, especially between 2000-2010. Notable proposed projects include a 2009 proposal to cultivate 'ahi tuna in 12 submersible cages off the coast of Hawai'i Island, which would have been Hawaii's largest fish farm and the world's first farm to successfully rear tuna for commercial sale (Gomes 2009). Most of these projects faced both technological challenges and substantial, organized opposition from environmental groups and the local community.

Although only one offshore farm is currently in operation, Hawaii has many advantages which make it a promising location for industry growth. First, the state contains a large ocean area with conditions suitable for finfish growth, including areas of deep water and strong currents close to shore (stakeholder interview, industry). Hawaii also boasts a long history of aquaculture development and research, including both public and private institutions focused on improving aquaculture technology and refining cultivation methods for environmental sustainability and economic productivity. For example, Hawaii Island hosts one of three international hubs operated by the aquaculture technology accelerator HATCH and is also home to the Hawaii Ocean Science and Technology Park, which facilitates ocean research and innovation, including aquaculture projects (NELHA 2022). Finally, Hawaii offers a robust local seafood market. Seafood consumption among Hawaii residents is almost double the national average and the state's tourism industry generates additional demand (Baker et al. 2020).

Hawaii's aquaculture policy landscape

Although aquaculture development in Hawaii is being considered in both state waters (within 3 miles from shore) and federal waters (between 3 and 200 miles from shore), this report focuses only on aquaculture in state waters. Hawaii state law authorizes the Department of Land and Natural Resources (DLNR) to “establish and enforce land use regulations on conservation district lands,” which include most state waters. The DLNR’s authorization includes the ability to determine permitting requirements for uses and activities on conservation district lands and places the force of law behind administrative rules created by the DLNR.

The DLNR requires aquaculture projects sited in state waters to apply for a Conservation District Use Permit approved by the Board of Land and Natural Resources (the Board). The Conservation District Use Application (CDUA) must include a management plan that describes short-term mitigation measures for environmental impacts occurring during construction and long-term mitigation measures for impacts occurring during farm operations. The Board also has latitude to request information not explicitly required by law and has used this power to establish a list of specific concerns to be addressed in the management plan, such as shark management, water quality, benthic health, and others. Finally, the CDUA requires the applicant to prepare an environmental assessment or environmental impact statement for their proposed project.

In addition to state permits, offshore operations in state waters must also obtain a number of federal permits depending on the details of each project. These include permits related to water quality, use of navigable waters, protection of endangered species or marine mammals, and use of the coastal zone. Both the federal and state permitting frameworks for offshore aquaculture are complex and considered difficult to navigate even for industry veterans. Between the 1980s and early 2000s, Hawaii’s Department of Agriculture hosted an Aquaculture

Development Program (ADP), which advised potential offshore projects and helped them navigate the necessary legal requirements and permitting. The ADP has lapsed in the past 15 years, leaving potential investors and operators without guidance on this complex system of permits and leases. The program was briefly revived in 2019 after receiving appropriations from the Hawaiian State Legislature but does not appear to have been renewed since. The 2019 appropriations act cites the lack of an ADP as a contributing factor to the open-ocean fish farming industry's recent lack of growth in Hawaii (Act 063 2019).

Goals

With growing momentum behind offshore aquaculture at the federal level and plentiful local resources available to foster industry growth, it is likely that open-ocean fish farming will expand in the state of Hawaii. Development of Hawaii's open-ocean fish farming industry will require a more streamlined, secure permitting and leasing process, as well as substantial outside investment; however, these factors are outside the scope of this research. Ultimately, the long-term success of the industry will depend on how well state officials can ensure that the industry operates sustainably. Here, I treat sustainability as a balance of three elements: environmental sustainability, in which open-ocean aquaculture operations minimize environmental impacts to ensure that Hawaiian waters remain healthy; economic sustainability, in which the aquaculture industry benefits both the state and local economies; and social sustainability, in which aquaculture operators earn a social license from local communities to continue operations. Achieving all three of these is necessary to ensure that the open-ocean aquaculture industry will grow responsibly over the long run.

This project asks how open-ocean fish farming can operate responsibly in Hawaii, with a focus on ensuring environmental, economic, and social sustainability. To answer this question, I will:

- investigate the potential impacts of open-ocean fish farming to Hawaii's marine environment, state and local economies, and local communities;
- assess the approaches available to meaningfully address or minimize these impacts; and
- offer policy recommendations that Hawaiian policymakers should consider in order to ensure the sustainable development of this nascent industry.

Methods

Literature

A literature review was conducted to identify factors that may contribute to the sustainability or unsustainability of offshore aquaculture. Because this field of study is new and still growing, literature focused specifically on Hawaii and the Pacific region was lacking; therefore, I reviewed articles and findings from locations around the world. Searches were primarily conducted via Google Scholar and ProQuest. I reviewed both peer-reviewed scientific literature and grey literature reports from a range of sources, including academic institutions, government agencies, and non-governmental organizations. I also reviewed local news media sources to identify recent news or concerns not yet identified in the literature; these were identified through multiple sources, including searches in ProQuest.

Interviews

After reviewing the literature, I conducted semi-structured interviews with stakeholders. These were primarily identified through background research on organizations currently or

previously involved in offshore aquaculture in Hawaii, or through suggestions from other interviewees. I reached out to these individuals via email or LinkedIn. In total, I interviewed 9 stakeholders: 2 current or previous state government officials, 1 federal government official, 2 extension agents, 2 industry representatives, and 2 non-governmental organization representatives.

Because this research involved human subjects, interviews were approved by the Duke University Campus Institutional Review Board (IRB). IRB approval required an informed consent process (Appendix 1), conducted at the start of every interview, to share details about how the interviewee's information would be used and cited, what records I would keep (including an audio recording and transcript), and their rights as a voluntary participant.

My semi-structured interview format included a set of preestablished questions that were open-ended and used to start the conversation (see Appendix 2). Each interview was unique according to the interviewee's expertise and type of involvement in offshore aquaculture. Interviews were completed via Zoom and lasted about 60 minutes. My questions probed interviewees' views on the environmental, economic, and social risks of offshore aquaculture development, as well as their views on future industry growth potential.

Analysis

Each interview was transcribed by Zoom's transcription software then edited for accuracy. The transcriptions were uploaded to NVivo and coded for sub-themes within the major categories of environmental, economic, and social considerations. After coding, I analyzed the results to draw out consensuses and areas of disagreement between stakeholders.

Results

Within the three major themes of environmental, economic, and social considerations, multiple subthemes emerged (Table 1). With respect to environmental considerations, my research uncovered water quality, benthic enrichment, fish escapes, habitat creation, and disease transfer as major potential impacts to Hawaii’s marine environment. With respect to economic considerations, my research identified three main issues: diversifying the state economy, decreasing reliance on seafood imports, and market competition with wild caught fisheries. With respect to social considerations, my research revealed concerns related to a mistrust of Western development, the transfer of benefits to local communities, and community participation.

Themes	Subthemes
Environmental	Water quality
	Benthic enrichment
	Fish escapes
	Habitat creation
	Disease transfer
Economic	Diversifying the state economy
	Decreasing reliance on seafood imports
	Market competition with wild caught fisheries
Social	Mistrust of Western development
	Transfer of benefits to local communities
	Community participation

Table 1. Themes and subthemes derived from stakeholder interviews.

Environmental Considerations

Those who oppose open-ocean aquaculture development commonly cite environmental issues as their main concern. Indeed, because open-ocean farms are exposed directly to the marine environment, operations pose a number of risks which must be addressed and mitigated.

This section will summarize environmental impacts to Hawaiian open-ocean aquaculture revealed in both the literature and stakeholder interviews.

Water quality

Open-ocean fish farms may cause unhealthy nutrient levels in the surrounding water body if large amounts of organic matter (i.e. unprocessed fish feed or fish waste) or chemicals become concentrated near the farm. Although they did not specify whether their study applied to nearshore or offshore conditions, Wang et al. (2020) found that organic matter inputs from fish farms can lead to excess nutrient enrichment and eutrophication if uncontrolled. Chemical pollution may stem from antibiotic and antiparasitic use, hormones and vaccines, or antifoulant coatings for farm infrastructure (Wang et al. 2020). In addition, the concentration of fish in a single area can sometimes lead to lower levels of dissolved oxygen and increased turbidity in the farm's vicinity (Price et al. 2015).

Siting farms in well-flushed areas and deep water can help mitigate effluent impacts, and modern feed formulation practices have allowed farms to limit excess nutrient loading and turbidity (Benetti et al. 2010, Price et al. 2015). Improved husbandry practices, such as lowering the stocking density of each cage, have also reduced the need for chemical treatments by decreasing disease transmission and the need for antibiotic use while also limiting impacts to dissolved oxygen levels (Price et al. 2015).

More than half of interviewees identified the presence of effluents from fish farms as an environmental concern that would require management. However, most felt that this could be mitigated by siting farms in areas with fast currents. In Hawaii, "the current system is strong. Dilution happens so quickly it's hard to measure" (stakeholder interview, extension). Blue Ocean Mariculture's farm site is located in well-flushed waters and effluents are undetectable as little as

100 feet away from the farm (stakeholder interview, government). Another stakeholder recalled a similar personal experience while working at Cates International, the offshore moi farm, where “we could measure [effluents] 100 feet down-current – we actually couldn’t detect the cage. It was already diluted” (stakeholder interview, extension). Outside sources confirm that pollutant concentrations have consistently remained below limits established by BOM’s federal water quality permit (Seafood Watch 2020).

The experience of Hawaiian offshore fish farms is consistent with recent data from farms in other regions. For example, water quality tests at an offshore commercial farm in Panama detected no significant nutrient loading over a two-year period; this matches evidence from multiple other locations with deep, well-flushed waters (Price and Morris 2013; Welch et al. 2019). Furthermore, some studies have suggested that nitrogen and phosphorus from offshore fish farms could lead to regional increases in fish biomass, although this warrants additional research (Machias et al. 2006, Diaz Lopez et al. 2008).

Benthic enrichment

Benthic enrichment is caused by the buildup of organic matter from fish feed and waste below a fish farm. Biofouling detritus, such as macroalgae or bivalves, also sinks to the seafloor during net cleanings (stakeholder interview, industry). In both nearshore and offshore sites, an accumulation of nutrient-rich organic matter can lead to oxygen depletion on the seafloor or alter the makeup of benthic communities (Weitzman et al. 2019). Similar to water quality impacts, researchers agree that siting and management practices can mitigate this risk (Figure 3). Siting farms in deep, well-flushed areas effectively disperses organic matter, while modern feed formulations can reduce the amount of excess nutrients leaving the farm (Borja et al. 2009,

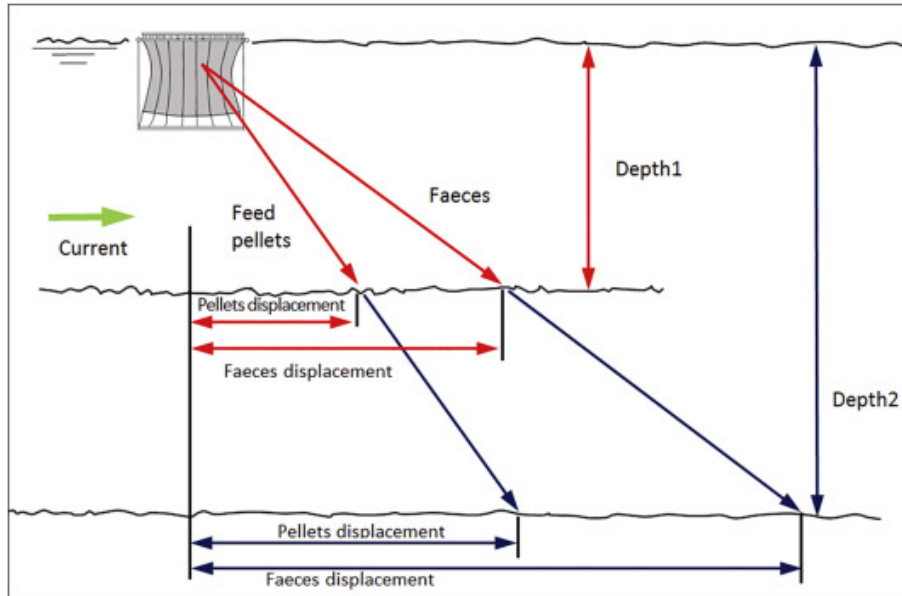


Figure 3. Displacement of organic matter in shallow (Depth1) and deep (Depth2) water (Cardia and Lovatelli 2015).

Morris and Price 2013). Benthic enrichment is more likely near sites with larger farms or multiple farms in close proximity (Gentry et al. 2017).

Only two interviewees cited benthic enrichment as a concern, despite its identification as a major potential impact in the literature. One interviewee discussed benthic enrichment as a concern that can be mitigated with “the old adage of location, location, location”: siting a farm “in deep enough water, far enough offshore with strong enough currents” (stakeholder interview, industry). Indeed, BOM regularly monitors the benthos beneath its farm site and did not observe significant changes in sediments or benthic communities between 2011-2017 (Seafood Watch 2020). Modeling studies of the BOM site also predicted that the farm was unlikely to cause benthic impacts (Rensel et al. 2015). On the other hand, a second interviewee acknowledged that at the Cates International farm site, “the sand community under the cage did have a little bit of an effect. There were more sea cucumbers living there than normally” (stakeholder interviewee,

extension). This stakeholder, however, viewed this observed change as within an acceptable range of impacts from the farm.

Fish escapes

Both the literature and stakeholder interviews revealed concerns about large-scale fish escapes from offshore aquaculture farms. Large-scale escapes are typically caused by structural failures linked to rough weather and stressful ocean conditions, but can also result from holes created by predators, such as seals or sharks, while trying to access caged fish (Northridge et al. 2013, Jackson et al. 2015). Recapture after escapes is typically unsuccessful (~8%) and often delayed when severe weather causes the escape, allowing additional time for fish to disperse into the marine environment before recapture can begin (Dempster et al. 2018). Furthermore, recapture efforts have been associated with high levels of bycatch (Dempster et al. 2018).

In the past, farm escapes in nearshore waters have resulted in the unintentional introduction of both native and nonnative fish species into local ecosystems, leading to detrimental impacts on native populations and environments (Pittenger et al. 2007). For example, some nonnative fish species have been shown to survive and thrive in foreign surroundings, quickly becoming invasive and threatening the survival of local populations of fish and other organisms (Castellanos-Galindo et al. 2018). Native species originating from aquaculture facilities can also compete for food and resources with members of their own species, threatening ecosystem health (Weitzman et al. 2019). Finally, farmed fish are sometimes genetically modified or selectively bred for desirable traits and may also have lower genetic diversity after being bred from non-local broodstock. If an escape occurs, interbreeding between wild and farmed fish may alter the genetic makeup of the local wild population, possibly leading to lower genetic fitness (Pittenger et al. 2007).

Much of the research on fish escapes is taken from nearshore cage systems, but interviewees suggested that these results may not apply directly to the Hawaiian situation. Because Hawaiian farms would be situated in deep, open-ocean waters, multiple interviewees expressed doubt that fish escaping from the farms would survive predation by dolphins, sharks, or other predator fish, especially given husbandry techniques that predisposed the fish to be slow and unaccustomed to a wild environment (stakeholder interview, extension). One interviewee provided first-hand observations of predation on farmed fish immediately after their escape (stakeholder interview, industry).

Although some interviewees downplayed the risk of fish escapes, this threat was the most common environmental impact voiced during interviews. Culture of non-native species was worrying: “if they were invasive and you let them out...now that’s a big problem” (stakeholder interview, extension). Others were primarily concerned by possible genetic impacts from fish escapes “and how that affects the trophic system” (stakeholder interview, extension). However, some stakeholders thought these concerns could be addressed by cultivating only native fish, and one argued that “the likelihood of [genetic impacts from escapes] is very minimal because all the evidence suggests to us that escapes have a very low survival rate” (stakeholder interview, industry). Another stakeholder suggested that “it’s really hard to get these animals to survive in the wild...they just never grew up with predators, they eat pellets their whole life...they don’t survive” (stakeholder interview, extension).

One approach to reducing large-scale escape events is to submerge cages well below the surface, making them less vulnerable to rough conditions above (stakeholder interview, industry; Pittenger et al. 2007). Although some acknowledged the risk of increased storms as a result of future climate change, operators expressed confidence that “those storms tend not to impact

offshore operations” because “our cages are submersible and they are heavily anchored to the sea floor” (stakeholder interviewee, industry). Careful farm maintenance is also essential to preserve infrastructure integrity and avoid preventable escapes such as a net failure that allowed more than 250,000 nonnative Atlantic salmon to escape from Cooke Aquaculture’s facility in Washington (Clark et al. 2018). A state investigation found that the incident was primarily caused by an excessive buildup of biofouling organisms such as mussels and algae, which created heavy drag that led to a net failure during strong tidal currents (Clark et al. 2018).

Records show that BOM reported 11 escape events between 2011-2018 (Seafood Watch 2020). These ranged between 800-6400 fish lost; about half of escapes were caused by incorrect net rigging, while the other half resulted from holes created by shark predation attempts. However, 40% of escaped fish were recaptured across all events, much higher than Dempster et al.’s (2018) ~8% recapture rate.

Habitat creation

Fish farms are commonly known to attract wild fish communities by creating new habitat for marine organisms to settle or shelter (Callier et al. 2018). Biofouling communities, including mussels, algae, and other organisms, quickly colonize new structures and create habitat for a diverse fish community and their predators. The presence of excess feed and nutrients around the fish farm also creates an alternate food source that attracts wild fish, as well as larger pelagic fish, dolphins, and sharks (Price and Morris 2013).

Interviewees often discussed this fish aggregation device (FAD) effect in relation to its consequences for fishers. Multiple participants and studies noted that many fishers appreciate the FAD effect because it increases their catches. However, other participants expressed concerns that the farm would cause an “alteration of marine mammal behavior” (stakeholder interview,

NGO). Researchers have observed that near the BOM facility, bottlenose dolphins appear to frequent the farm and show aggressive behavior towards other dolphin species nearby (Tummons 2021). The dolphins were initially drawn by interactions with farm personnel and have remained nearby because the farm serves as a fixed food source for both wild fish and few farmed fish that occasionally escape the cage as divers enter and exit (Tummons 2021). Sharks are also attracted to the facility and have sometimes bitten through the cage's netting, allowing fish to escape (Seafood Watch 2020).

Disease transfer

Farmed fish are susceptible to disease, especially when pens are stocked at high density. Disease transfer from farmed to wild fish is concerning because wild fish may have a lower natural resistance to farm-associated diseases and thus may be more vulnerable (Weitzman et al. 2019). However, data on the mechanisms or likelihood of disease transmission between farmed and wild populations remains scarce (Lafferty et al. 2015).

Interviewees expressed varying degrees of concern related to the possibility of disease transfer between farmed and wild fish. One interviewee connected this threat to high density fish farming, which increases the risk of disease (stakeholder interview, NGO). Another stated that “the best way to manage [disease transfer] is to optimize the fish health inside the pen...optimizing the best nutrition for the fish, [stocking at] relatively low densities, and siting in an area where there's sufficient current” to flush the pen (stakeholder interview, industry). In general, disease transfer was less commonly discussed by interviewees than other environmental concerns.

Economic considerations

The sustainability and long-term viability of Hawaii's open-ocean fish farming industry must also include economic benefits at both the state and local levels. Stakeholders across all sectors were optimistic that industry growth could benefit the state's economy by decreasing reliance on seafood imports and diversifying revenue streams. However, officials must also ensure that economic benefits from farmed fish do not inadvertently harm local fishers and local economies through market competition with wild-caught fish.

Because Hawaii's open-ocean fish farming industry is so small, data or research on the current and future economic impact of the industry was either unavailable or difficult to access. Based on stakeholder conversations, there does not appear to be any current research underway to examine the economics of offshore aquaculture in the state. Multiple stakeholders recommended outreach to economic research organizations like the University of Hawaii Economic Research Organization (UHERO) or the State of Hawaii Department of Business, Economic Development and Tourism, which compile data and produce reports on an array of themes relevant to Hawaii's economy. However, data on aquaculture was only sparsely available, and discrete data on offshore aquaculture in particular was not available at all. Due to the lack of available data, this section will discuss perceptions from stakeholders but will include only limited perspectives from the literature.

Diversifying the state economy

Hawaiian officials and residents have long acknowledged the state economy's overreliance on tourism and the need to build up other industries; the Covid-19 pandemic reiterated this need and added a sense of urgency to the discussion (Suryanata and Umemoto 2005). Since the early 2000s, lawmakers have suggested that the aquaculture industry could

contribute to the diversification of Hawaii's economy (Speakman 2020). One interviewee pointed out that Hawaii is "really dependent on tourism and it's just not sustainable. Covid has shown us that...so if there are ways that [benefits from open-ocean fish farms] can actually be put towards the community...I think it could definitely work" (stakeholder interviewee, extension). Past development does offer some evidence of the industry's potential: an analysis of Hawaii's foodfish production sector from 2000-2009 suggested that the sector's growth was largely led by the two open-ocean fish farms operational at the time (Naomasa et al. 2013).

Decreasing reliance on seafood imports

Hawaii's seafood market also appears to be conducive to industry growth: seafood demand in Hawaii is almost double that of the mainland US, providing a robust local market for fish produced in the state (Loke et al. 2012). In addition, a 2012 study reported that imports accounted for 50-60% of seafood consumed in Hawaii (Geslani et al. 2012). However, pandemic supply chain difficulties have illuminated the need for Hawaii to reduce its reliance on outside imports (McGregor 2020). One interviewee supported an effort to "try to chip away at that 60% [imported seafood rate]...let's get that to zero" (stakeholder interview, extension). Many interviewees pointed out the open-ocean aquaculture industry's ability to help Hawaii reduce its dependence on imported seafood. An industry stakeholder predicted that the industry will "grow significantly because of the need for our island state to be food self-sufficient" (stakeholder interview, industry).

Market competition with wild caught fisheries

While stakeholders appeared confident that aquaculture industry growth could benefit Hawaii's state economy overall, many worried about impacts on small-scale fishers. In the past, local fishers have strongly opposed open-ocean aquaculture growth and played a significant role

in the 2012 closure of Maui Fresh Fish LLC, a project proposed to grow Opakapaka, or Hawaiian pink snapper, offshore of the island of Lana'i (Gomes 2012b). Multiple interviewees shared concerns about market competition between farmed and wild-caught species of the same fish, noting that fishers see open-ocean fish farms "as competitors...they're concerned about the impact on the fisheries, they're concerned about the economic competition" (stakeholder interview, NGO). Another stakeholder explained that aquaculture operations and wild fishers "compete with each other, especially if you're going to start something like tuna. You know that's going to be a problem for the community" (stakeholder interview, extension). Because tuna is both widely fished and widely consumed in Hawaii, market competition with a farmed tuna operation could be detrimental to local fishers (Loke et al. 2012).

BOM has avoided this issue by choosing to farm kahala (yellowtail), which is native to Hawaiian waters but isn't commercially fished for market (stakeholder interview, extension). Suryanata and Umemoto (2003) noted that some producers commit to exporting all or the majority of their product to avoid local competition; this was an approach that would have been employed by Hawaii Oceanic Technology's proposed tuna farm in 2012 (Gomes 2009).

Social considerations

As state policymakers consider the future of Hawaii's open-ocean aquaculture industry, they must acknowledge local residents' and Native Hawaiian groups' deep mistrust of Western development stemming from Hawaii's history of colonial oppression. They must also address related concerns about whether benefits from fish farms will flow to local communities.

Mistrust of Western development

A significant source of opposition towards open-ocean fish farming comes from local communities' skepticism that the industry will develop in a way that recognizes and

accommodates the needs and concerns of local Hawaiian communities. This sentiment is rooted in the state's relatively recent history of colonial exploitation and the erosion of Native Hawaiian traditional practices and beliefs (Suryanata and Umemoto 2005). One interviewee noted that "one thing that is often overlooked is the history of Hawaii and how the Hawaiian government was overthrown... there's generational trauma attached to that" (stakeholder interview, extension). Hawaii's state history contains numerous instances of Western-influenced decisions that have neutralized Native Hawaiians' cultural heritage and traditions, including property reforms and fisheries management reforms that stripped Native Hawaiians of their traditional access and use rights (Suryanata and Umemoto 2003, Suryanata and Umemoto 2005).

In this context, many Native Hawaiians fear that open-ocean fish farming will compromise their culturally-held belief that "the ocean is a common property resource...the public resource shouldn't be privatized. It should not be given an exclusive use" (stakeholder interview, government). This directly conflicts with open-ocean fish farming, which relies on the Western principle of ownership in the form of an exclusive lease to one company. For Native Hawaiians, open-ocean fish farm development could easily become yet another Western introduction that further erodes their traditions and heritage. Interviewees cited a range of cultural values that they viewed as threatened by industry development, including ocean access, care for the land, and traditional fishing practices.

Furthermore, interviewees who worked directly with community members expressed a general skepticism regarding the true intentions of government officials and industry representatives. They assumed that developers were pursuing farm projects "for their own purposes, without respect or consideration of the community" (stakeholder interview, NGO) and also perceived a gap between "what they say they're going to do [to address community

concerns] and then what they actually do” (stakeholder interview, government). Interviewees expressed doubt that engagement efforts from officials and industry personnel would be genuine, instead wondering if decisions to move forward with projects would have already been made before community members had a chance to provide input.

Transfer of benefits to local communities

In order to avoid a purely extractive open-ocean fish farming industry, officials must ensure that Hawaiian communities experience benefits from local fish farms, rather than only being exposed to the risks of a failed operation (Benetti et al. 2010). As discussed previously, proponents of aquaculture development argue that increasing local fish production can help Hawaii bolster its food security and decrease its reliance on seafood imports. However, in the words of one interviewee: “is the increase in offshore [aquaculture] beneficial to the local community? Is it affordable? Is it a fish that people from here even want to eat?” (stakeholder interview, extension). This concern reflects the necessity to critically evaluate farm proposals to ensure that their operations will meet the stated goals of industry development.

Officials must also balance the needs of the community with fishers’ concerns about market competition. An affordable farmed fish product may increase food security in a local community, but could also harm “local fishers that you could basically be putting out of business...What does that mean for them and their livelihood?” (stakeholder interview, extension). Past proposed projects have attempted to eliminate the possibility of market competition by promising to export all or almost all of their farmed product; however, this then eliminates possible local benefits for food security and decreased reliance on imports (Gomes 2012). As the makeup and needs of local communities will differ, a tailored approach will be necessary for each farm project.

Community participation

Interviewees who were most concerned about community benefits from fish farm projects emphasized that officials and industry representatives must involve community members in their decision-making process, especially by listening to and meaningfully addressing their concerns. One interviewee stated, “Do I think that more public comment, input, and transparency within the practice could be done? Yes, absolutely” (stakeholder interview, extension). That interviewee also went on to discuss the importance of ensuring that officials and companies were clearly explaining proposals in terms that local communities, without “the same Western educational background,” could understand. An interviewee on the government side of a recent offshore aquaculture regulatory action recognized the need for increased dialogue, recognizing that “building trust [with communities] is the foundation. It’s so hard to build and so easy to lose, and I think it’s even harder given all of the other stressors that we’re all under right now” (stakeholder interview, government). The interviewee also lamented the consequences of the Covid-19 pandemic in preventing face-to-face consultations with community members and recognized that a lack of communication may influence the concerns expressed by the public about aquaculture activities (stakeholder interview, government).

Interviewees also tentatively hoped for benefits in the form of jobs and workforce development, which has already been implemented in Hawaii alongside other forms of aquaculture. Lastly, a few interviewees favored the possibility that offshore fish farming could be “an avenue for local people to maybe make money on their own” as fish farm operators themselves (stakeholder interview, extension); however, others expressed doubt that this could be possible given the high level of investment required for offshore operations.

Recommendations

As interest in developing open-ocean fish farming in Hawaii grows, state officials bear responsibility for ensuring that this growth is accompanied by safe environmental regulations, economic profitability at both state and local levels, and a social license from local communities. A literature search and stakeholder interviews revealed important considerations that state officials should take into account as they determine the future of Hawaii's offshore aquaculture industry. These considerations led to four recommendations for state officials: 1.) formalize environmental standards that will be required in all future operation management proposals; 2.) support economic research to inform a better understanding of how offshore aquaculture will affect the state economy and local fishers, 3.) initiate meaningful, sincere stakeholder engagement with local communities near proposed offshore fish farm sites, and 4.) reestablish an Aquaculture Development Program within state government. With these steps, the state of Hawaii can look forward to the development of a holistically sustainable open-ocean fish farming industry that protects and benefits the interests of Hawaii's residents.

1. State officials should develop standardized criteria for adjudicating the approval of open-ocean aquaculture proposals.

While most interviewees were confident that offshore fish farming was not likely to impact Hawaii's marine environment in major ways, some reflected the concerns expressed by local residents and environmental groups primarily related to genetic impacts from fish escapes and effects on water quality. The management plans approved by state officials for Hawaii's two operational offshore fish farms have proven largely successful in averting large-scale disasters and most impacts from operations. However, Hawaii state law and DLNR policy does not

formally prescribe specific criteria for determining whether a proposed management plan contains appropriately rigorous standards.

In order to ensure that offshore future fish farm proposals are held to the same high bar as the state's existing farms, officials should formally codify environmental management standards. These should include best practices for monitoring effluents and detritus, minimizing the risk of fish escapes, and safely ensuring fish health. Officials should also formalize other decisions that are currently practiced but remain unestablished in written policy or law, such as a ban on culturing non-native species. By establishing these standards, officials can protect Hawaiian waters from detrimental environmental impacts while simultaneously increasing transparency for community members and reducing uncertainty regarding the requirements a proposed project must meet to operate safely in Hawaiian waters.

2. State officials should work with local economic research groups to assess the impact of potential culture species on the state economy and local stakeholder groups.

This study's examination of economic considerations related to open-ocean aquaculture development was hindered by a lack of formal research assessing the potential economic impact of development in Hawaii. Therefore, state officials should partner with economic research groups such as the University of Hawaii Economic Research Organization (UHERO) or the State of Hawaii Department of Business, Economic Development and Tourism to fill this research gap. Analyses should focus on the industry's projected impact on the state economy, especially its potential to displace total seafood imports, as well as the possible economic impacts and benefits to local economies where a farm would operate. If possible, research should also assess how proposed species for culture would affect local market pricing for wild caught fish. These

studies would help officials strategically develop the industry while accounting for market competition with fishers.

3. Officials must commit to meaningful stakeholder engagement efforts, including substantial public outreach and communication.

Results related to social considerations revealed that open-ocean aquaculture currently lacks a social license among Hawaiian residents and natives, largely due to the state's history of colonial oppression from both public and private Western sources. This issue is systemic and will require solutions at a much wider scale than a single industry can facilitate, but officials can begin to build trust within the open-ocean aquaculture sector by demonstrating a sincere commitment to soliciting and addressing feedback on farm proposals from local and Native Hawaiian communities. Deliberate stakeholder engagement would also allow officials and operators to understand the unique needs and concerns of the communities they will work in and tailor their proposals accordingly to meaningfully benefit the community. In the Hawaiian context, officials should ensure that stakeholder engagement is conducted as much as possible throughout the proposal and approval process and that information presented is accessible and understandable to the local community. By actively working to rebuild trust with local communities and earn a social license for open-ocean fish farming, officials and companies can avoid the pitfalls of failed proposals over the past twenty years.

4. The Hawaiian State Legislature and Governor Ige must work together to fund a new iteration of the Aquaculture Development Program.

Currently, the state government has little capacity to support operators and companies interested in proposing an offshore project in Hawaii. The Aquaculture Development Program of the late 1900s and early 2000s was instrumental in supporting the offshore aquaculture industry's

growth during that era, and a renewed ADP can fill the gap left by the former program's lapse. In addition to assisting operators with permitting and leasing requirements, the ADP can lead the implementation of Recommendations 2 and 3 above and can spearhead research, outreach, and stakeholder engagement efforts to support the industry's sustainable growth.

Limitations and future research

This research was limited by a low number of stakeholder participants, due to both lack of responses to interview invitations and a small pool of relevant experts. Due to the currently small size of the Hawaiian offshore aquaculture industry, the number of government, NGO, academic, and industry representatives who could speak to the industry's future was small. In addition, there does not appear to have been much activity around offshore aquaculture in recent years, and the state of the industry in Hawaii has remained largely the same over the past decade. This further limited my research because many stakeholders who had been active on offshore aquaculture issues in the early 2000s were no longer up to date or involved in the industry.

Due to time constraints and lack of accessibility, I was unable to speak with local residents, community members, or Native Hawaiians who could provide a first-hand perspective on their concerns regarding offshore aquaculture development. Additional research should focus on reaching community members; an approach including in-person meetings with local residents was not possible for this research but would be advisable in the future.

References

- Act 063. Relating to Aquaculture, 30th Legislature. (2019).
https://www.capitol.hawaii.gov/session2019/bills/GM1164_.PDF
- Baker, K. K., Watters, C. A., Dannemiller, J. E., Iwamura, S. T., & Brooks, B. A. (2020). Fish Consumption for the Adult Population of Hawai‘i, Collected with a Self-Reported Household Survey. *Hawai‘i Journal of Health & Social Welfare*, 79(2), 51.
- Benetti, D. D., Benetti, G. I., Rivera, J. A., Sardenberg, B., & O’Hanlon, B. (2010). Site Selection Criteria for Open Ocean Aquaculture. *Marine Technology Society Journal*, 44(3), 22–35. <https://doi.org/10.4031/MTSJ.44.3.11>
- Borja, Á., Rodríguez, J. G., Black, K., Bodoy, A., Emblow, C., Fernandes, T. F., Forte, J., Karakassis, I., Muxika, I., Nickell, T. D., Papageorgiou, N., Pranovi, F., Sevastou, K., Tomassetti, P., & Angel, D. (2009). Assessing the suitability of a range of benthic indices in the evaluation of environmental impact of fin and shellfish aquaculture located in sites across Europe. *Aquaculture*, 293(3), 231–240. <https://doi.org/10.1016/j.aquaculture.2009.04.037>
- Borrell, B. (2020, August 24). Show Me the Money Fish. *Hakai Magazine*.
<https://hakaimagazine.com/features/show-me-the-money-fish/>
- California Environmental Associates. (2018). *Offshore finfish aquaculture: Global review and U.S. prospects*. The David and Lucile Packard Foundation.
<https://www.ceiconsulting.com/wp-content/uploads/CEA-Offshore-Aquaculture-Report-2018.pdf>
- Cardia, F., & Lovatelli, A. (2015). *Aquaculture operations in floating HDPE cages: A field handbook*. Food and Agriculture Organization of the United States.
- Castellanos-Galindo, G., Moreno, X., & Robertson, R. (2018). Risks to eastern Pacific marine ecosystems from sea-cage mariculture of alien Cobia. *Management of Biological Invasions*, 9(3), 323–327. <https://doi.org/10.3391/mbi.2018.9.3.14>
- Clark, D., Lee, K., Murphy, K., & Windrope, A. (2018). *2017 Cypress Island Atlantic Salmon Net Pen Failure: An Investigation and Review*. Washington Department of Natural Resources.
https://www.dnr.wa.gov/sites/default/files/publications/aqr_cypress_investigation_report.pdf?vdqi7rk
- Costello, C., Cao, L., Gelcich, S., Cisneros-Mata, M. Á., Free, C. M., Froehlich, H. E., Golden, C. D., Ishimura, G., Maier, J., Macadam-Somer, I., Mangin, T., Melnychuk, M. C., Miyahara, M., de Moor, C. L., Naylor, R., Nøstbakken, L., Ojea, E., O’Reilly, E., Parma, A. M., ... Lubchenco, J. (2020). The future of food from the sea. *Nature*, 588(7836), 95–100. <https://doi.org/10.1038/s41586-020-2616-y>

- Dempster, T., Arechavala-Lopez, P., Barrett, L. T., Fleming, I. A., Sanchez-Jerez, P., & Uglem, I. (2018). Recapturing escaped fish from marine aquaculture is largely unsuccessful: Alternatives to reduce the number of escapees in the wild. *Reviews in Aquaculture*, *10*(1), 153–167. <https://doi.org/10.1111/raq.12153>
- Díaz López, B., Bunke, M., & Shirai, J. (2008). Marine aquaculture off Sardinia Island (Italy): Ecosystem effects evaluated through a trophic mass-balance model. *Ecological Modelling*, *212*, 292–303. <https://doi.org/10.1016/j.ecolmodel.2007.10.028>
- Duarte, C. M., Holmer, M., Olsen, Y., Soto, D., Marbà, N., Guiu, J., Black, K., & Karakassis, I. (2009). Will the Oceans Help Feed Humanity? *BioScience*, *59*(11), 967–976. <https://doi.org/10.1525/bio.2009.59.11.8>
- Essoyan, S. (2001, December 2). Moi Farm Hooks Fishers. *Los Angeles Times*. <https://www.latimes.com/archives/la-xpm-2001-dec-02-mn-10739-story.html>
- Exec. Order No. 13921, 85 Fed. Reg. 28471 (May 7, 2020).
- FAO. 2021. *FAO Yearbook. Fishery and Aquaculture Statistics 2019/FAO annuaire. Statistiques des pêches et de l'aquaculture 2019/FAO anuario. Estadísticas de pesca y acuicultura 2019*. Rome/Roma. <https://doi.org/10.4060/cb7874t>
- Froehlich, H. E., Smith, A., Gentry, R. R., & Halpern, B. S. (2017). Offshore Aquaculture: I Know It When I See It. *Frontiers in Marine Science*, *4*, 154. <https://doi.org/10.3389/fmars.2017.00154>
- Gentry, R. R., Froehlich, H. E., Grimm, D., Kareiva, P., Parke, M., Rust, M., Gaines, S. D., & Halpern, B. S. (2017). Mapping the global potential for marine aquaculture. *Nature Ecology & Evolution*, *1*(9), 1317–1324. <https://doi.org/10.1038/s41559-017-0257-9>
- Geslani, C., Loke, M., Takenaka, B., & Leung, P. (2012). *Hawai'i's Seafood Consumption and its Supply Sources* (SOEST 12-01/JIMAR 12-0379). Joint Institute for Marine and Atmospheric Research.
- Gomes, A. (2009, July 27). 27-acre open-ocean fish farm nears launch off Hawaii's Big Isle: 12 million pounds of fish per year target of project off Big Island. *Honolulu Star – Advertiser*.
- Gomes, A. (2012a, July 25). Fish farm hauls in its cages. *Honolulu Star - Advertiser*. <https://www.proquest.com/central/docview/1030085682/abstract/B0CB8E83DF4843E4PQ/3>
- Gomes, A. (2012b, December 3). Another aquaculture firm sinks. *Honolulu Star - Advertiser*. <https://www.proquest.com/central/docview/1221395950/abstract/F445B40149DD4B8CPQ/19>
- Gomes, A. (2014, July 15). Farm aims to double its haul. *Honolulu Star - Advertiser*. <https://www.proquest.com/central/docview/1545167435/abstract/83AD201966A84D4EPQ/19>

- Gomes, A. (2016, July 11). Investment firm lends \$3M to help Kona fish farm grow. *Honolulu Star - Advertiser*.
<https://www.proquest.com/central/docview/1802753069/abstract/B0CB8E83DF4843E4PQ/5>
- Haws, M., Seale, A. P., Corbin, J., et al. (2019, December 16). Aquaculture in Hawai‘i – Ancient Traditions, Modern Innovation. *World Aquaculture Society*.
<https://www.was.org/articles/Aquaculture-in-Hawaii-Ancient-Traditions-Modern-Innovation.aspx>
- Helsley, C. (2007). Environmental Observations around Offshore Cages in Hawaii. In C.-S. Lee & P. J. O’Bryen (Eds.), *Open Ocean Aquaculture—Moving Forward* (p. 80). Oceanic Institute. <https://nsgl.gso.uri.edu/ocei/oceiw06001.pdf>
- Jackson, D., Drumm, A., McEvoy, S., Jensen, Ø., Mendiola, D., Gabiña, G., Borg, J. A., Papageorgiou, N., Karakassis, Y., & Black, K. D. (2015). A pan-European valuation of the extent, causes and cost of escape events from sea cage fish farming. *Aquaculture*, 436, 21–26. <https://doi.org/10.1016/j.aquaculture.2014.10.040>
- Kikuchi, W. K. (1976). Prehistoric Hawaiian Fishponds. *Science*, 193(4250), 295–299.
- Lafferty, K.D., Harvell, C.D., Conrad, J.M., Friedman, C.S., Kent, M.L., Kuris, A.M., Powell, E.N., Rondeau, D., & Saksida, S.M. (2015). [Infectious Diseases Affect Marine Fisheries and Aquaculture Economics](#). *Annual Review of Marine Science* 7:1, 471-496.
- Loke, M., Geslani, C., Takenaka, B., & Leung, P. (2012). *An Overview of Seafood Consumption and Supply Sources: Hawaii versus U.S.* University of Hawaii at Manoa.
- Kluger, L. C., & Filgueira, R. (2021). Thinking outside the box: Embracing social complexity in aquaculture carrying capacity estimations. *ICES Journal of Marine Science*, 78(1), 435–442. <https://doi.org/10.1093/icesjms/fsaa063>
- Machias, A., Giannoulaki, M., Somarakis, S., Maravelias, C., Neofitou, C., Koutsoubas, D., Papadopoulou, N., & Karakassis, I. (2006). Fish farming effects on local fisheries landings in oligotrophic seas. *Aquaculture*, 261, 809–816.
<https://doi.org/10.1016/j.aquaculture.2006.07.019>
- Mather, C., & Fanning, L. (2019). Social licence and aquaculture: Towards a research agenda. *Marine Policy*, 99, 275–282. <https://doi.org/10.1016/j.marpol.2018.10.049>
- McDaniel, J. (2019, November). The Return of Kū‘ula: Restoration of Hawaiian Fishponds. *Ka Pili Kai*. <https://seagrant.soest.hawaii.edu/the-return-of-kuula/>
- McGregor, L. W. (2020, December 22). Hawai‘i’s Vulnerable Food Supply – Hawaii Sea Grant. *Ka Pili Kai, Ho‘oilō 2020*. <https://seagrant.soest.hawaii.edu/hawai%ca%bbis-vulnerable-food-supply/>
- Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., Little, D. C., Lubchenco, J., Shumway, S. E., & Troell, M. (2021). A 20-year retrospective review of

- global aquaculture. *Nature*, 591(7851), 551-563,563A-563J.
<http://dx.doi.org.proxy.lib.duke.edu/10.1038/s41586-021-03308-6>
- NELHA. (2022). *About*. Hawaii.Gov. <https://nelha.hawaii.gov/about/>
- NOAA. (2016). *NOAA Fisheries' Final Rule to Implement the Fishery Management Plan for Aquaculture in Federal Waters of the Gulf of Mexico*.
https://www.noaa.gov/sites/default/files/legacy/document/2019/Jun/aquaculture_gulf_fmp_faqs_jan2016.pdf
- NOAA Fisheries. (2021a). *Potential Aquaculture Management Program in the Pacific Islands (Pacific Islands)*. NOAA. <https://www.fisheries.noaa.gov/action/potential-aquaculture-management-program-pacific-islands>
- NOAA Fisheries. (2021b). *Aquaculture Opportunity Areas (National)*. NOAA.
<https://www.fisheries.noaa.gov/national/aquaculture/aquaculture-opportunity-areas>
- Northridge, S., Coram, A. & Gordon, J. (2013). *Investigations on seal depredation at Scottish fish farms*. Edinburgh: Scottish Government.
- Ocean Era, Inc. (2021). *Preliminary environmental review for the Ocean Era offshore aquaculture farm off 'Ewa Beach, O'ahu, Hawai'i*. Ocean Era, Inc.
<https://static1.squarespace.com/static/5307ba1ae4b0e7fa5a1becab/t/606bda454be03531c9459cbc/1617680968180/Ewa+Beach+Environmental+Review+21-04-05+-+FOR+PUBLICATION+ON+WEBSITE.pdf>
- Oppenheim, N. (2018, December 4). *Finfish aquaculture has no place in U.S. waters*.
<https://www.nationalfisherman.com/viewpoints/national-international/finfish-aquaculture-has-no-place-in-u-s-waters>
- Ostrowski, A. C., Bailey-Brock, J., & Leung, P. (2001). *Hawaii Offshore Aquaculture Research Project (HOARP)—Phase II* (p. 79).
- Pittenger, R., Anderson, B., Benetti, D., Dayton, P., & et al. (2007). *Sustainable marine aquaculture: Fulfilling the promise; managing the risks* (p. 142). Marine Aquaculture Task Force, Pew Charitable Trust. <https://www.pewtrusts.org/-/media/legacy/uploadedfiles/peg/publications/report/sustainable20marine20aquaculturepdf.pdf>
- Posadas, B.C. (2004). *Potential economic impact of commercial offshore aquaculture in the Gulf of Mexico*. Mississippi-Alabama Sea Grant Consortium.
<https://repository.library.noaa.gov/view/noaa/13655>
- Price, C., Black, K. D., Hargrave, B. T., & Jr, J. A. M. (2015). *Marine cage culture and the environment: Effects on water quality and primary production*. *Aquaculture Environment Interactions*, 6(2), 151–174. <https://doi.org/10.3354/aei00122>

- Rensel JE, O'Brien FJ, Siegrist Z, Kiefer DA. (2015). Tropical Open-Ocean Aquaculture Model Tuning and Validation. Prepared for A. Everson, National Marine Fisheries Service, Honolulu HI, and the National Oceanic and Atmospheric Administration. System Science Applications, Inc. 66p.
- S. 3100, Advancing the Quality and Understanding of American Aquaculture Act, 117th Cong. (2021). <https://www.congress.gov/bill/117th-congress/senate-bill/3100/titles?r=6&s=1>
- Scott, D. C. B., & Muir, J. F. (2000). Offshore cage systems: A practical overview. In J. F. Muir & B. Basurco (Eds.), *Mediterranean Offshore Aquaculture* (pp. 79–89). CIHEAM. <https://om.ciheam.org/om/pdf/b30/00600651.pdf>
- Seafood Watch. (2020). *Farmed Almaco Jack (Seriola rivoliana), U.S. Marine Net Pens*. Monterey Bay Aquarium.
- Speakman, K. (2020, April 22). Lawmakers looking to diversify Hawaii's economy away from tourism. *KHON2*. <https://www.khon2.com/coronavirus/lawmakers-looking-to-diversify-hawaiis-economy-away-from-tourism/>
- Suryanata, K., & Umemoto, K. N. (2003). Tension at the Nexus of the Global and Local: Culture, Property, and Marine Aquaculture in Hawai'i. *Environment and Planning A: Economy and Space*, 35(2), 199–213. <https://doi.org/10.1068/a35116>
- Suryanata, K., & Umemoto, K. (2005). Beyond environmental impact: Articulating the “intangibles” in a resource conflict. *Geoforum*, 36, 750–760. <https://doi.org/10.1016/j.geoforum.2004.11.007>
- Tummons, P. (2021, August). Keahole Kampachi Cages Attract Aggressive Bottlenose Dolphins. *Environment Hawaii*. <https://www.environment-hawaii.org/?p=13772>
- Wang, X., Cuthbertson, A., Gualtieri, C., & Shao, D. (2020). A Review on Mariculture Effluent: Characterization and Management Tools. *Water*, 12(11), 2991. <https://doi.org/10.3390/w12112991>
- Weitzman, J., Steeves, L., Bradford, J., & Filgueira, R. (2019). Far-Field and Near-Field Effects of Marine Aquaculture. In *World Seas: An Environmental Evaluation* (pp. 197–220). Elsevier. <https://doi.org/10.1016/B978-0-12-805052-1.00011-5>
- Welch, A. W., Knapp, A. N., El Tourky, S., Daughtery, Z., Hitchcock, G., & Benetti, D. (2019). The nutrient footprint of a submerged-cage offshore aquaculture facility located in the tropical Caribbean. *Journal of the World Aquaculture Society*, 50, 299–316. <https://doi.org/10.1111/jwas.12593>
- Zajicek, P., Corbin, J., Belle, S., & Rheault, R. (2021). Refuting Marine Aquaculture Myths, Unfounded Criticisms, and Assumptions. *Reviews in Fisheries Science & Aquaculture*, 1–28. <https://doi.org/10.1080/23308249.2021.1980767>

Appendices

Appendix 1

Informed Consent

Introduction: This research is being conducted by graduate student Zoe Wong of the Nicholas School of the Environment at Duke University.

Key Information:

Purpose: I am interested in learning about your views on environmentally, economically, and socially sustainable growth in Hawaii's open-ocean fish farming industry, climate adaptation and mitigation strategies, as well as your thoughts on policy instruments that govern the growth of the industry.

Procedures: With your consent, I will ask you to participate in an interview about Hawaii's open-ocean fish farming industry, its future growth potential, and its efforts to mitigate worsening climate risks. I will also ask questions about how your specific organization views the industry's impacts on Hawaii's environment, economy, and residents as well as the industry's responsiveness to relevant policy instruments. We can talk for as long as you like, but I expect our conversation to take about an hour. I would also like your permission to let me audio-record our conversation so that I can focus on our conversation rather than taking notes.

Risks & Benefits: There are no anticipated risks or benefits associated with participating in this research.

Confidentiality: I will not include your name or title in any products stemming from this research. However, I may attribute information from the interview to your organization/company/agency in our final report, with your consent. If you are uncomfortable with being associated with your company name but still wish to participate, I will only attribute information from your interview to your general industry. The final report will be stored in the Duke University's library database and will be presented to professors and students at Duke University in April 2022. Data from this research that is not linked to your identity may be used for future research purposes.

Voluntariness: Your participation in this research is of course voluntary. Please feel free to skip any questions you do not want to answer, pause the recording, or stop the interview at any time, for any reason.

Questions: Please let me know at any time if you have questions. You can contact me by email at zoe.wong@duke.edu.

For questions about your rights as a research participant contact the Duke Campus Institutional Review Board at campusirb@duke.edu. Please reference Protocol ID# 2022-0141 in your email.

Appendix 2

Interview Questions

1. Do you expect HI's offshore aquaculture industry to grow in the next 5-10 years? 10-20 years? Why or why not? If so, what will this growth look like?
2. How will the industry's growth affect **Hawaii's marine environment**?
 - a. Which environmental impacts are most concerning? Do you expect climate change to augment or resolve any of these impacts?
3. How will the industry's growth affect **Hawaii's local economy**?
4. How will the industry's growth affect **people who live and work in Hawaii**?
 - a. Have you encountered support or opposition to open-ocean fish farming from local residents?
5. What are some opportunities for the growth of offshore aquaculture in Hawaii?
 - a. What might be positive consequences of the growth of offshore aquaculture in HI?
6. What are some obstacles to growth?
 - a. Do you have any concerns about negative consequences related to the growth of the offshore aquaculture industry in HI? What is your primary concern?
7. Do you know of any plans for future regulation of open-ocean fish farming in Hawaii or elsewhere in the US?
8. Are you aware of any state or federal regulations that encourage fish farming companies to consider environmental impacts or future climate impacts?
9. Are you aware of any state or federally funded research programs that investigate environmental and/or climate impacts on finfish mariculture?