Loko Solutions: Policy Analysis for Carbon Sequestration Potential of Aquaculture in Hawai‘i

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Executive Summary

Pursuant to the goals set out in Act 15 for Hawai‘i to become carbon neutral by 2045, this policy analysis examined the sequestration potential of policy alternatives affecting the aquaculture industry. Given our assessment, we recommend our Best Hits policy package, comprised of a supply-side tax expenditure, a statewide offset program, and deregulation policies. A supply-side tax expenditure provides tax breaks for Best Management Practicing (BMP) aquaculture ventures’ permitting fees and revenue. An offset program establishes a statewide compliance program in which public and private entities are required to either reduce or offset an increasing percentage of their emissions to reach carbon neutrality by 2045. A voluntary offset market is implemented in tandem to enable individual consumers’ participation. Deregulation policies remove barriers to entry, streamline permitting processes, and promote BMP adoption. Together, these policies make BMP-abiding aquaculture products less expensive to consumers, internalize the cost of GHG emissions to both public and private producers and individual consumers, financially incentivize BMP adoption by aquaculture operators, and reduce bureaucratic burden to aquaculture operators.

Our analysis included five different policy alternatives on top of an appraisal of the Status Quo: Carbon Offsets, Cap-and-Trade, Demand-side Policies, Supply-side Policies, and a Best Hits package. We assessed each policy alternative across five policy goals, which are, in order of priority: GHG sequestration potential, political feasibility, efficiency, and equity. Each of these policy goals were evaluated qualitatively through impact categories, with scales of Low, Medium, and High, or 1-3. The two policy alternatives which received the highest scores for GHG sequestration potential were Carbon Offsets and Best Hits. The latter received a higher score for this goal’s impact category ‘upward trend over time’, which we weight more heavily than the ‘rate of sequestration’ impact category for its alignment with the long-term climate change mitigation scales. Our Best Hits package also received equal or higher scores for all other impact categories when compared to Carbon Offsets.

We conclude our report with a summary of knowledge gaps which require further investigation as the State of Hawai‘i pursues GHG sequestration in the aquaculture sector. These include methodologies to calculate sequestration quantities and rates across various aquaculture practices, as well as the cost associated with adopting BMPs, sequestration

infrastructure, and implementing a Best Hits package. Perhaps the most critical of our identified knowledge gaps is the resilience of aquaculture systems and their sequestration potential in the face of a warming climate with increasing variability. We hope this synthesis of our current state of knowledge, policy recommendations, key knowledge gap provide a useful foundation for the State of Hawaiʻi as it pursues GHG sequestration and climate change mitigation.

I. Introduction

The accumulation of greenhouse gases (GHGs) in the atmosphere drives climate change and produces a wide array of global environmental, social, and economic impacts. These costs can be found in large-scale negative externalities. In Hawaiʻi, these externalities include the deleterious effects of sea level rise on Waikīkī and other coastal areas and low-lying islands, lives and property lost from rising temperatures, coral bleaching, threats to tourism, and increasing severity and frequency of storms.

Currently, the State of Hawaiʻi is a net emitter of GHGs. In June 2018, Governor Ige signed Bill 2182, committing the State of Hawaiʻi to reach carbon neutrality by the year 2045. This was done in an effort to both stimulate stronger state-level policies for GHG reductions and inspire other states and nations to follow suit. Governor Ige also approved Act 15 in June 2018, establishing the Greenhouse Gas Sequestration Task Force. Act 15 gives the Task Force the responsibility of identifying GHG sequestration policies and "mitigation options" in four sectors: agroforestry, agriculture, urban forestry, and aquaculture.

We conducted a policy analysis to explore the role of aquaculture in sequestering GHGs in the State of Hawaiʻi. The analysis was restricted to "nature-based" mechanisms of GHG sequestration, and to lands, waters, and policies within state jurisdiction. Though revenue generation and funding mechanisms will be considered, our primary focus will be on mechanisms of GHG sequestration, their political feasibility, efficiency, and equity. Our policy analysis began with four types of aquaculture: loko iʻa, algae, shellfish, and integrated multi-trophic aquaculture (IMTA). We have selected these because all are currently practiced in Hawaiʻi, have demonstrated in one form or another the potential to sequester GHGs, and provide socioeconomic benefits (Figure 1).

Aquaculture farms aquatic organisms for food, bait, repopulation, trade, and other purposes. Some types of aquaculture have been identified as net GHG emitters (Good et al., 2010; Adams et al., 2012). In some cases, however, aquaculture has considerable potential to sequester GHGs, for example through increased ecosystem productivity (Boyd et al., 2010; Adams et al., 2012). Hawaiʻi is well-positioned to contribute to such sequestration for its existing aquaculture industry, which ranked as the 9th most valuable state in the 2013 Census of Aquaculture with $58.7 million in sales that year (USDA, 2014).

In the report that follows, we first diagnose the policy issue in Section II. This diagnosis reviews the current state of aquaculture in Hawaiʻi and scientific understandings of GHG sequestration in aquaculture, summarizes the market and government failures we seek to remedy through our proposed policies, and introduces our policy goals. In Section III, Methodology, we introduce our policy alternatives and the policy goal-derived impact categories that we use to assess their fitness. In Section IV, Assessment, we evaluate our policy alternatives across each impact category. In Section V, we describe additional considerations for the resilience and sustainability of aquaculture ventures in Hawaiʻi. We recommend our highest-ranking policy alternative in Section VI, and provide instructions for its implementation. Finally, in Section VII, we present knowledge gaps which require further investigation for the benefit of any aquaculture related GHG sequestration policy.

II. Diagnosis of the Policy Issue

Our policy analysis began with four aquaculture types that are currently practiced in Hawaiʻi, have demonstrated in one form or another the potential to sequester GHGs, and provide socioeconomic benefits (Figure 1): loko iʻa, algae, shellfish, and IMTA. Below, we outline the current state of our four selected aquaculture types in Hawaiʻi, as well as science and policies informing their operations and sequestration potential. Then, synthesizing lessons from each aquaculture type, we present Best Management Practices (BMPs) for directionally correct GHG sequestration aquaculture practices.

Loko iʻa

Hawaiʻi has over 1,500 years of aquaculture experience and ingenuity that may have originated due to increasing population pressures on the production capacities of agricultural and natural ecosystems (Kikuchi, 1976). Nearly 400 loko iʻa (fishponds) once functioned as unique innovations within integrated farming systems in order to maximize productivity and yield (Costa-Pierce, 1987). Historically, loko iʻa provide important ecosystem services, yet over the course of 200 years, loko iʻa systems have lost their functionality due to coastal degradation, fresh water impairment, lack of maintenance, loss of ownership, invasive species, urban development, and natural disasters (State of Hawaiʻi, DLNR, Conservation District Use Application, 2011). Today, there is a growing movement to restore and maintain loko iʻa to perpetuate cultural heritage and reestablish food security.

Two of the most common restoration efforts for loko iʻa involve dredging years of silt buildup from land-based sources and removing invasive plants such as mangroves that have compromised stone structures and encroached on aquatic habitat within loko iʻa. The State of Hawaiʻi Department of Land and Natural Resources' Office of Conservation and Coastal Lands is in the process of creating a guidebook associated with the Hoʻāla Loko Iʻa program and application. This guidebook will discuss the federal and state-mandated BMPs that will need to be observed for the various types of activities (Conservation District Use Application ST-3703: Hoʻāla Loko Iʻa).

In 1901, there were 99 fishponds identified in commercial production on Kauaʻi, Oʻahu, Molokaʻi, and Hawaiʻi (Cobb, 1902). At that time, the estimated total output was 308,303 kilograms (679,692 lbs) of fish: 220,233 kilograms of ʻamaʻama (mullet, *Mugil cephalus*) and 88,070 kilograms of awa (milkfish, *Chanos chanos*). The estimates of fishpond yield ranged from 336 to 560 kilograms per hectare (300-500 lbs/acre). Using the lower end of this range and assuming the average area of a fishpond to be about 7.3 hectares (18 acres), the annual yield of fishponds prior to 1778 (pre-contact) could have approached 907,185 kilograms (2 million pounds). In contrast, the state Division of Fish and Game (now the Division of Fish and Wildlife) reported a total fishpond production yield of only 9,072 kilograms (20,000 lbs) of fish in 1975-76, which included only 544 kilograms of ʻamaʻama. Currently, there are about 221 hectares (545.3 acres) of actively managed fishponds in Hawaiʻi. When fully functional, these systems have the potential of producing 74,203 kilograms (163,590 lbs) of seafood (Teneva et al., 2018).

Each loko iʻa is a unique system receptive to the natural environment that it is integrated within. Therefore it is difficult to generalize the carbon sequestration potential and actual storage across all loko iʻa. Despite this, carbon sequestration estimates have been quantified for the high seas and coastal marine ecosystems, such as mangrove forests, kelp forests, seagrass meadows, and saltwater marshes. Much of the scientific focus for the carbon cycle has been on plankton carbon sequestration and emerging science explores the value of other marine biota, such as fish, in the biological carbon pump. "Fish carbon" is the role that all marine vertebrates have in the carbon cycle and further research is required to understand the sequestration potential of marine environments and the implications for climate change solutions (Lutz and Martin, 2014).

Algae

In 2011, the State of Hawaiʻi Animal Industry Division valued the state's aquaculture industry at $40 million. Micro- and macroalgae accounted for 63% of this figure. According to Singh & Ahluwalia (2013), the photoautotrophic properties of microalgae allow them to grow quickly and fix CO_2 ten times faster than conventional forestry, agriculture, and aquatic plants thus making them an ideal candidate for biological CO_2 sequestration. Besides algae's ability to fix large amounts of CO_2, there is currently an economic incentive since algae produce dietary supplements for human consumption (Singh & Ahluwalia, 2013). However, the majority of the algae that produce these compounds are microalgae, which do not produce root systems to store carbon in the soil. Once the supplement is consumed the carbon that was stored in the plant biomass is released back either into the atmosphere through respiration or into the water system as human waste. One way around this would be to turn the algal biomass into a stable form in biochar, which can contain more than 90% carbon (Heilmann et al., 2010) that will remain in the soil for thousands of years (Lehmann, 2007). In 2008, the International Biochar Initiative "estimated that biochar production has the potential of mitigat[ing]...3.67 Gt CO_2 per year using only biomass wastes" (Yu et al., 2017, p. 3). In addition, the State of Hawai'i could collect invasive algal species and process it into biochar. This could create jobs and help reduce the threat that invasive algae pose to Hawai'i's coral reefs.

Algal biochar would not only be beneficial for aquaculture GHG sequestration, but would also help revitalize soils, and therefore soil health. Due to excessive rainfall, high winds, erosion, and soil properties some of Hawai'i's soils have become acidic and denude of nutrients. Algal biochar, from both macro- and microalgae, has a high pH which can "balance acidified soils, while the higher nutrient content of nitrogen, ash and inorganic elements are beneficial for soil amendment in agriculture" (Yu et al., 2017, p.3). An experiment conducted by Roberts et al. (2015) found that there were "high levels of the remaining exchangeable cations (Ca, K, Mg, and Na)" in the algal biochar, which prevents nutrients from leaching from the soil on agricultural land (p.2).

Macroalgae, such as seaweed or limu, are also vital to the economy and culture of Hawaiian aquaculture. Planting limu in restored loko i'a has the potential to bolster primary production within the loko i'a and provide a locally sourced traditional food to the public.

Molluscs

Several mollusk aquaculture operations exist in the State of Hawai'i. Littleneck clams (and shrimp) in are farmed by Sunrise Capital, Inc. in Kaua'i, and abalone are farmed by Big Island Abalone on the Kona coast. The state's most productive oyster farms are located at Kualoa, O'ahu, at Mōli'i fishpond, selling 10-12K oysters per month, and on the Hualalai Resort golf course, selling up to 4K oysters per month. Despite the relatively high growth rate for oysters in Hawai‘i, these numbers pale in comparison to an estimated 300K oysters imported into the state monthly (K. McCarty, personal communication, November 6, 2018). Neither the littleneck clam or *Crassostrea* spp. oysters have been identified as invasive species. The state's most recent Aquatic Invasive Species Management Plan states that the ecological impacts of their intentional introduction "are largely unknown… but *Crassostrea* spp. is very dominant in Pearl Harbor West Loch" (Shluker, 2003, pp. 2-5-2-6).

The carbon sequestration potential of calcifying molluscs is often assumed, as their growth requires the precipitation of calcium carbonate shells. Calcification, however, behaves as a source of gaseous, atmospheric CO_2, and it is the opposite chemical reaction, which dissolves the calcium carbonate of mollusk shells, that sequesters atmospheric CO_2 (Wallmann & Aloisi, 2012). Coupled with metabolic respiration, the calcification processes of molluscs classify them as net carbon emitters. Thus, the aquaculture of molluscs in Hawai‘i should not in itself be considered an opportunity for GHG sequestration.

Under some conditions, however, molluscs traditionally utilized for commercial aquaculture can be integrated into diversified systems which promote GHG sequestration. For example, maintaining oysters in shallow living stands limits the burial and preservation of remnant calcified shells, while enabling their ecologically beneficial roles (Fodrie et al., 2017). The latter includes sediment and particulate organic matter (POM) deposition through filter feeding, which contributes to carbon burial. Additionally, oysters may serve as ecosystem engineers, expanding habitat for other GHG sequestering ecosystem components (e.g. vegetation) through sediment deposition. Fodrie et al. (2017) found that these factors sequestered carbon at rates of ~1.3$\frac{tC}{ha \cdot yr}$ in saltmarsh-fringing oyster reefs. But, these values are specific to their North Carolina study sites and ecosystem components, which have unknown applicability in Hawai‘i environments.

Integrated Multi-Trophic Aquaculture (IMTA)

Integrated multi-trophic aquaculture (IMTA) is the process of growing finfish and shellfish with seaweeds or plants from different trophic levels in an integrated farm to increase profitability and productivity through efficient recycling and reuse of nutrients (Ahmed et al., 2017; Granada et al. 2018). The farming of aquaculture species from different trophic levels and with complementary ecosystem functions allows one species' uneaten feed and wastes, nutrients, and by-products to be recaptured and converted into fertilizer, feed, and energy for the other crops, and to take advantage of synergistic interactions between species (Chopin, 2013; Granada et al. 2018). The by-products from one species are recycled to become inputs for another (Ahmed et al., 2017). In a balanced system recycling by-products, IMTA has a potential to sequester carbon by integrating species that contribute to this process and carbon drawdown.

IMTA can benefit farmers by increasing sustainability, profitability, and resilience of aquaculture farms (Chopin, 2013). Feed costs are reduced because of their reuse in multiple niches and because of biomitigation (partial removal of nutrients and CO_2 , and supply of oxygen). IMTA solves some negative environmental effects of aquaculture and has economic benefits because farm diversification generates additional income while reducing risk (Ahmed et al., 2017). Other benefits that IMTA can have are the contribution to the provision, safety, and security of food. Despite many benefits there are great challenges associated with IMTA, for instance, appropriate organisms need to be chosen at multiple trophic levels based on the complementary functions they have in the ecosystem, as well as for their economic value or potential (Chopin, 2013). Additionally, IMTA will require technical and financial assistance as well as institutional support to address several changes to existing aquaculture systems and challenges to implementing new systems.

Defining Best Management Practices (BMPs)

Through our research, we discovered the science informing the sequestration potential of our four aquaculture types – even aquaculture generally – is in its infancy. As a proxy for quantitatively modeling GHG sequestration in Hawai‘i aquaculture, we compiled our knowledge into the following BMPs (underlined), which serve as operational guidelines to promote directionally correct GHG sequestration activity. Our policy alternatives promote BMP adoption to ensure sequestration.

We have determined that aquaculture ventures should establish at least two trophic levels in their systems, selected for their complementary ecosystem functions which provide some environmental or sequestration benefit (e.g. nutrient or CO_2 removal). If molluscs are selected to meet this requirement, the aquaculture venture must incorporate those conditions which promote mollusc aquaculture as a net carbon sink, as outlined earlier in section III. That is, molluscs should be maintained in shallow living stands which, if possible, expand habitat for other sequestering ecosystem components through sediment deposition (Fodrie et al., 2017). If an aquaculture venture chooses to ‘green’ its operation by incorporating seagrasses, microalgae, or macroalgae to meet this requirement, the aquaculture venture should include native species only and provide ample sunlight and flowing water. In order to sequester more GHGs, farmers should try to grow macroalgae on soft sediment where detritus can be buried (Duante et al., 2017). Microalgae are hardy and diverse and can grow in both saline and freshwater. Algae farmers should grow algae in brackish water or water that is unsuitable for human consumption in order to use undesirable water and land to sequester more GHG.

Aquaculture ventures must also holistically consider their environmental impacts in a way that increases sustainability, profitability, and resilience of aquaculture farms. For example, aquaculture operations have high energy costs for production, maintenance, and feed (D. Anderson, personal communication, November 14, 2018). Thus, aquaculture farms and facilities should use renewable energy such as hydroelectric, solar, and wind to meet the energy demands of production.

Symptoms: Market and Government Failures

The three overarching issues our policy analysis seeks to address are the lack of aquaculture in Hawaiʻi, current aquaculture in Hawaiʻi not sequestering as much GHGs as they could, and imported and pelagic seafood outcompeting local nearshore seafood on the local market. These three issues are symptoms of underlying market and government failures, or situations in which the free market and government, respectively, fail to allocate resources in a way that maximizes social welfare. Table 1 outlines a wide variety of market and government failures pertaining to aquaculture in Hawaiʻi, in general and in relation to the specific aquaculture sectors we are considering in our analysis. This section highlights the most important ones, and explains how exactly they pertain to the concerns of our policy analysis.

There are four key market failures relating to all four considered aquaculture types in Hawaiʻi. The first is that tuna and salmon popularity in Hawaiʻi is partly due to marketing, which has caused these fish to be established as dietary norms on the islands, replacing many other seafood that used to be much more present in Hawaiian diets, such as ʻamaʻama (mullet). This has led to the extreme prioritization of imported fish over most other seafood in Hawaiʻi. The second market failure is that the societal costs associated with GHG emissions are not accurately represented in the costs faced by private commercial operators. This has allowed the under-pricing of imported fish that have associated emissions from transportation and shipping, and has failed to properly incentivize the adopted of BMPs by existing aquaculture facilities. The third market failure is that the average consumer likely does not know the extent of the environmental harms caused by the overconsumption of tuna and salmon. This has allowed demand for salmon and tuna to remain high. Additionally, consumers do not know about the sustainability of, or potential environmental benefits from, local aquaculture products. This has caused demand for these goods to stay relatively low. The fourth market failure pertaining to all of the considered aquaculture types in Hawaiʻi is that changing food systems has a lot of associated costs. These adjustment costs hinder the adoption of BMPs by current aquaculture ventures and make it difficult for local aquaculture products to fully integrate into local markets.

For algae aquaculture, there are two crucial market failures. The first is that algal growth has numerous environmental benefits. Additionally, limu production has additional sociocultural benefits, which are not reflected in societal demand for algae production. The second market failure is that, despite the fact that biochar has numerous benefits for soil health there is currently a limited market for biochar made from algae in Hawaiʻi.

Loko iʻa also has specific market and government failures that are key to this policy analysis. The market failure focuses on the recent colonization of Hawaiʻi. This colonization has caused a notable loss in preference for many nearshore fish in the local seafood market. This has contributed to the neglect of the loko iʻa that would normally raise these fish. The government failure associated with loko iʻa is that the permitting process to establish or restore loko iʻa is split across numerous organizations and agencies. This decentralization makes the process far more taxing.

Policy Goals

Given the Task Force's priorities and the aims set out in Act 15, as well as the aforementioned policy issues, we assembled four policy goals to guide our analyses: GHG sequestration potential, political feasibility, efficiency, and equity. GHG sequestration potential is the additional rate of GHG sequestration that would result because of a policy or policies. Political feasibility is how likely stakeholders, especially in the government, are likely to support the policy alternative and how likely it is to be implemented. Efficiency is the amount of GHG sequestered by the implementation of a policy alternative by the 2045 deadline, adjusted for the cost of implementing said policy alternative. Equity is how the policy alternative would impact Hawaiʻi in terms of socioeconomics and culture.

Because the Task Force is primarily concerned with increasing nature-based sequestration, we prioritize the GHG sequestration potential. Additionally, because of the 2045 deadline to become carbon neutral, political feasibility and efficiency are next in terms of relative weighting. We give equity the lowest relative weighting largely because we intentionally designed our policy alternatives so that there would not be any foreseeable negative socioeconomic impacts.

III. Methodology

Policy Alternatives

In this section, we describe each policy alternative we have chosen to address the issues outlined above. With the exception of the Status Quo, each policy alternative is created by packaging together several specific policy interventions. Policy interventions were grouped based on how they specifically affected the market, rather than by which specific aquaculture types they would address. The policy alternatives were chosen to account for issues that the Task Force has the ability to address. Areas such as shipping and the military are not within the jurisdiction of the state and thus are not included in the policies or within the analysis.

Status Quo

The first policy alternative we consider is maintaining the status quo with current climate change mitigation efforts in Hawaiʻi. Rather than regarding the status quo as complete inaction, we treat it as maintaining the same course, within a range of uncertainty, with Hawaiʻi's actions towards the state becoming a net GHG sink. These include actions such as reducing tillage in agriculture, reducing imported foods, and increasing the state's renewable energy portfolio. We also consider the effects of current land use and land types in Hawaiʻi, such as mangroves which are invasive, and therefore harm native marshland habitats, but also sequester considerable amounts of carbon. However, there are no specific policy initiatives that are included in the analysis of this policy alternative.

Carbon Offsets

In a carbon offset program, GHG sequestering entities sell offsets, often via a third-party mediator, to GHG emitting entities. With this command-and-control approach, the state requires GHG-emitting entities to either reduce emissions or purchase carbon offsets from GHG sequestering entities. As emitting entities purchase offsets, they internalize the otherwise "unseen" social cost of their emissions. The revenue generated through their offsetting activity can then be funneled toward GHG sequestration and other initiatives to reduce adjustment costs and produce other co-benefits, such as water filtration by molluscs, cultural restoration through loko iʻa development, or local food production.

We propose a statewide compliance offset program in which public and private entities are required to achieve carbon neutrality by 2045, either by emissions reduction or through offsets. In addition to public and private entities participating in the market as consumers, individuals may participate in the market voluntarily. The added benefit of providing individual consumers with voluntary offset opportunity is that it will increase their awareness of local, sustainably produced aquaculture and agricultural products. This will also partially remedy the information asymmetry between consumers and the GHG economy in which they participate.

If offset demand is high, the market will stimulate innovation in and expansion of GHG sequestering industries. Some argue that because offset demand is generated primarily by emitters, a carbon offset market may hinder emissions reductions initiatives. To combat this effect, and to transition the state toward its 2045 goals, the state should lower emissions ceilings progressively through time. Or, for a more politically feasible option, the state may transition from a compliance offset program where emitting entities can choose between emissions reduction or offsets, toward mandatory emissions reductions initiatives and a voluntary offset program.

This intervention requires oversight by a third-party standards organization to define Hawaiʻi- and aquaculture-specific protocols to quantify emissions and sequestration, validate offsetting practices, and maintain a registry for offset production and sale. This has some potential to create local jobs. This task is significant because the sequestering role of aquaculture in GHG carbon offset markets is yet undefined (Forest Trends, 2017). Until methodologies can be developed for aquaculture-specific sequestration verification, the adoption of directionally-correct BMPs may qualify as offsetting activity.

Cap-and-Trade

Another way to assign a monetary value to carbon to address climate change and the negative externalities that are associated with production of GHGs is through a cap-and-trade program. Unlike a carbon offset program, a cap-and-trade program would require the government to implement regulations or laws that “cap” the amount of GHG emissions produced by a single sector. According to Nathaniel Keohane, president for international climate at the Environmental Defense Fund, this “lets the market find the cheapest way to cut emissions” (Environmental Defense Fund, n.d.) and depending on how strict the regulations are, could result in a sudden dramatic decrease in GHG emissions through the implementation of BMPs within sectors. Thus, the newly created market operates to cut emissions and push for a clean energy economy which encourages innovation in technology (Union of Concerned Scientists: Science for Healthy Planet and Safer World, n.d.).

Over time the cap limit would decrease. Companies that have reduced their emissions through the implementation of BMPs and new technologies will be able to sell or trade their unused carbon credits to companies that need more credits than the allowances provided. This provides incentives to “cut pollution faster and rewards innovation” (Environmental Defense Fund, n.d.).

As of 2015, Hawai‘i placed a 16% GHG emissions cap on large stationary sources that produce above 100,000 tons of GHG per year, however, at this time they are not trading any carbon credits. This cap would not affect the aquaculture sector since it produces less than the 100,000 tons of GHGs.

Demand-Side Policies

Tax expenditures, vouchers and commodity taxes are three demand-side policies which in conjunction promote consumption of local aquaculture goods. These would also help overcome endogenous preferences that prioritize imported and pelagic seafood over local and nearshore seafood. Tax expenditures and vouchers are two methods of providing demand-side subsidies. The purpose of subsidies is to increase the consumption of particular goods by reducing their price to consumers. In many cases, issues arise because the efficiency and equity dimensions are not clearly distinguished (Weimer & Vining, 2011).

Tax expenditures are used to stimulate individual demand for a number of goods and services by lowering the after-tax price of preferred goods. By reducing the after-tax price of BMP-abiding aquaculture products, the competitive advantage of these relatively sustainable aquaculture operations increases. This maintains stable revenue for BMP aquaculture operators, while also improving the relative appeal of BMP products to consumers. Importantly, this improved competitive advantage for BMP products results in a decrease in average product price. Vouchers allow general consumers to purchase marketed goods at reduced prices. Typically, the vouchers are distributed to selected consumers at prices lower than their face value. This is an important policy component to allow access to local aquaculture products that may still be high for lower-income groups even though a commodity tax is applied to imported seafoods and aquaculture products (Weimer & Vining, 2011).

A commodity tax internalizes the impacts of goods with negative externalities. Presumably, commodity tax on non-BMP aquaculture products decreases the competitive advantage of relatively unsustainable aquaculture operations with the added benefit of generating revenue. The commodity tax improves the relative appeal of BMP products by raising the price of non-BMP products and increasing average product price. If this does not affect consumer behavior in the manner intended, a commodity tax imposes a greater burden on the consumer while maintaining revenue for non-BMP aquaculture operators. In this case, we can assume that taxes will either minimally affect demand and raise substantial revenue, or taxes will substantially decrease demand and generate less revenue (Weimer & Vining, 2011).

Supply-Side Policies

We propose a policy package focused on supply-side policies of supply-side tax expenditure and indirect information provisions. Supply side tax expenditures include deductions to some taxable income and credits against taxes otherwise owed under corporate income taxes (Weimer & Vining, 2011). In Hawaiʻi, supply-side tax expenditure for the aquaculture industry would provide tax breaks for permitting fees and revenue from BMP practicing aquaculture. Implementing supply-side tax expenditures would incentivize BMP implementation and make BMP aquaculture products less expensive to consumers (Weimer & Vining, 2011).

Indirect information provisions register, license, or certify providers who meet some standard of skill, training, or experience (Weimer & Vining, 2011). Licensing is a regulatory regime under which only the duly qualified who have sought and obtained a license to practice an appropriate agency or delegate of the state are legally permitted to perform or to take responsibility for given functions. Registration allows those seeking to practice to do so through a simple declaration. Certification allows qualified practitioners to receive special designations or certifications which other practitioners cannot legally use. However, uncertified practitioners are legally permitted to provide the same functions, provided they do so under some other designation. Certification involves exclusive rights to a professional designation but not to practice.

Indirect information provisions would include certification for any BMP aquaculture practice and labelling of such products. Such labels would include information of the products place of origin and information about the ecological benefits provided. These indirect information provisions would promote supplier compliance with BMP and aid consumers' decision making, ultimately promoting more sustainable seafood production and consumption.

Best Hits

We propose a package that we believe will incorporate some of the ‘best hits’ of policies presented above including new policy alternatives. These policies include supply-side tax expenditure, offsets, and deregulation. As mentioned above, supply-side tax expenditure would entail tax breaks for permitting fees and revenue from BMP practicing aquaculture. Implementing supply-side tax expenditures would incentivize BMP implementation and make BMP aquaculture products less expensive to consumers (Weimer & Vining, 2011). Offsets establish a statewide compliance program in which public and private entities are required to achieve carbon neutrality by 2045, either by emissions reduction or through offsets. In addition to public and private entities participating in the market as consumers, individuals may participate in the market voluntarily.

Permits and regulatory requirements for aquaculture in Hawaiʻi need to be updated to account for new laws, science, technologies and practices, and for the establishment of new aquaculture ventures that would incorporate BMPs to promote carbon-sequestration and other sustainability goals. In addition, deregulation is appropriate to remove unnecessary barriers to entry into the aquaculture industry. ‘Deregulation’ includes streamlining permits, refining regulatory frameworks, and reviewing current policies that create substantial barriers for entry into the aquaculture sector, especially for loko iʻa. The *Permits and Regulatory Requirements For Aquaculture in Hawaiʻi* was last completed in 2011. According to this guidebook there are many permits required for aquaculture in Hawaiʻi. Streamlining the process can result in vast improvements which was the case for the DLNR streamlined permit application process for the Hoʻāla Loko Iʻa program by the State’s Office of Conservation and Coastal Lands. Although there have been improvements for loko iʻa permitting process, the Army Corps of Engineers has not been effectively incorporated into the current permitting process, which currently delays. Further streamlining will greatly improve the ability for loko iʻa managers to conduct restoration and eventually produce aquaculture products. Likewise, currently the state leases state-owned loko iʻa and should consider other agreements with loko iʻa managers (i.e. non-profit organizations) that do not involve substantial costs. Potential models include no or lower leasing costs, or, stewardship agreements at no-cost to loko iʻa managers for maintaining state-owned loko iʻa, or agreements that require the state to provide tax breaks or payments to loko iʻa managers for stewardship of state-owned lands. These agreements will depend on the state’s rights and responsibilities and must be in accordance to state laws and policies (B. Asuncion, personal communication, October 23, 2018).

Impact Categories

To use our four policy goals to assess the efficacy and strength of each policy package, for each goal we established one or more impact categories, which are the specific measurements we place value to in order to judge how well a goal is met. Figure 2 highlights each of the impact categories our analysis considers, and the goals that they relate to. Each impact category was selected and defined to address different concerns the State has about potential methods to increase GHG sequestration. Below we elaborate on each impact category, sorted by the different goals they address.

For the first goal of **GHG sequestration**, we use two impact categories: the rate of the GHG sequestration and the upward trend over time. The GHG sequestration rate is defined as the amount of additional GHGs that would be sequestered as a result of the policy package; this is not meant to measure the total amount of GHG sequestration, but rather qualitatively measure how much additional sequestration there would be given present land use scenarios as a baseline. The second impact category, upward trend over time, refers to how the GHG sequestration rate changes over time (e.g. does it plateau, increase linearly, increase exponentially, etc.). For this analysis, we assume that sequestration rates would not decrease over time as a result of any of our policy packages, and therefore measure this impact category as the degree to which GHG sequestration rates would increase over time, if at all. Both of these impact categories are measured on a sliding scale from Low to High, given constraints on available sequestration measurements that prevented any sort of quantitative estimates.

For the second goal of **political feasibility**, we also use two impact categories: stakeholder support and funding. For stakeholder support, we considered various stakeholders and the degree to which the policy package aligns or overlaps with their current goals and efforts. This impact category was measured on a sliding scale from Low to High. For funding, we considered three key questions: 1) Is there existing funding to support the policy package? 2) Would the funding be stable over time (e.g. funding based on unstable grants would get a 'No' whereas funding based on increasing sales would get a 'Yes')? 3) Would funding not decline or disappear over time (e.g. funding sourced from emissions taxes)? This impact category measured from 0-3, based on the number of 'Yes' answers to the three questions.

The third goal, **efficiency**, is largely based on the first goal of sequestration potential, but accounting for cost. Our one impact category for this goal is the GHG sequestration potential per cost, or how much sequestration impact the policy package would have compared to its cost of implementation. Because of the lack of precise sequestration estimates or cost estimates, this impact category was measured from Low to High.

For the fourth goal, **equity**, we consider three impact categories: sociocultural benefits, job creation, and food security. For sociocultural benefits, we consider two main questions: 1) Is the policy package, and what it supports, consistent with Hawaiian culture? 2) How much will the policy package benefit locals? For job creation, we consider the number of jobs, especially permanent jobs, that would be created as a result of implementing this policy package, either through the direct result of the policy alternative or due to its impacts. Lastly, for food security, we estimate the degree to which the policy package would promote local food production and the consumption of locally produced foods. Each of these three impact categories are measured on a sliding scale from Low to High.

IV. Assessment

Evaluating Policy Alternatives

In this section we evaluate the efficacy of each policy alternative, offering detailed explanations of the criteria they were judged on and the reasoning for why they were scored the way they were. We score each policy alternative according to our criteria and provide a brief narrative justification for our scoring decisions. For a summary table of our final scores, please see Table 2 in the Appendix.

Status Quo

GHG sequestration potential

- **Sequestration rate, Low** – Since we use current land use/types as a baseline, keeping the status quo would have little effect towards increasing local sequestration rates from the baseline, especially since current efforts focus more on emissions reduction than increasing sequestration.
- **Upward trend over time, Low** – Although sequestration rates are likely to increase locally due to current efforts and initiatives, there is no reason for us to believe that these rates would increase dramatically without any additional significant policy intervention.

Political feasibility

- **Stakeholder support, Medium** – Although keeping the status quo would be contrary to Act 15, any policy intervention would require significant energy whereas relative inaction is often implicitly favored by government officials.
- **Funding, 3** – Current funding is already existent for existing projects, it is sustainable in that there would not be any impetus for any new funding sources (and we assume existing ventures have, at least mostly, figured out sustainable funding sources), and it is non-declining since there is currently no carbon market in Hawaiʻi.

Efficiency

- **Sequestration potential per cost, Medium** – While the sequestration potential is Low, so too is the cost of implementation since there would be no new policy initiatives to implement; an important note is that this does not consider the long-term costs associated with failure to mitigate and adapt to climate change, but only considers costs associated with implementation.

Equity

- **Sociocultural benefits, Low** – Current sequester carbon efforts in Hawaiʻi are largely devoid of cultural context and do not directly benefit locals.
- **Job creation, Low-Medium** – Current efforts, such as the Aloha+ Goals, mention green job creation as a goal, but fail to explicitly say how; we are therefore skeptical as to the degree of job creation that would come about from the status quo, although there would likely be a fair degree.
- **Food security, Low** – Although current efforts have explicitly stated increasing domestic consumption of domestically produced foods as a goal, the lack of action around this goal considerable skepticism as to whether there would be any significant increase in food security in Hawaiʻi with the status quo.

Carbon Offsets

GHG sequestration potential

- **Sequestration rate, High** – A carbon offset program allows emitting entities to internalize the cost of their emissions, then transforms that cost into direct benefit for sequestering entities. Because this is a very cost-efficient way to allocate funds toward sequestration infrastructure, and because funding is available as soon as the carbon offset program is functional, we assign a high sequestration rate to carbon offsets. This is based on the assumption that initially, offsets will be more cost-effective or feasible than emissions reductions. This, of course, will depend greatly on the determinations of the standards organization's work, as they refine methodologies for sequestration measurement and validation.

- **Upward trend over time, Medium** – Carbon offsets ensure that the state community invests, to some extent, in sequestration initiatives. This is guaranteed by the infeasibility of immediate emissions reductions, and supported also by opportunities for voluntary offsetting. The latter of these may continue, and even increase, in perpetuity but, the former may not. Emissions reductions strategies will evolve to become more numerous and cost-effective through time, making the compliance offset market less lucrative through time. Thus, rate of sequestration will eventually plateau unless voluntary offsets increase dramatically.

Political feasibility

- **Stakeholder support, Medium** – Given the challenges in offset validation, stakeholders may be skeptical of an offset program's ability to sequester the GHGs it promises. There are also those who argue that offsetting shifts responsibility from emitters to sequesterers in a way that propagates inequity and evades real movement toward climate change mitigation. Coupled with emissions reductions which go hand-in-hand with the state's 2045 goal for 100% renewable energy and net neutrality, however, a carbon offset program has the ability to reduce emissions while also minimizing negative effects to emitters. Gaining stakeholder support, as with any policy implementation, will require community engagement to promote understanding.
- **Funding, 2** – Carbon offsets draw on funding which is existent today and self-sustaining, because revenue is generated from entities that opt for offsetting in lieu of reducing their emissions. Funding will, however, may be highest at the start of the program before declining. This is because emissions reductions strategies will likely become more cost-effective as time passes, and GHG emissions will decrease as we approach our 2045 100% renewable energy target. We could hypothesize that as the state's sustainability and climate change mitigation initiatives become more prevalent and widespread, the demand for voluntary offsets will increase. This is merely speculative and so we will not include this assumption in our valuation.

Efficiency

- **Sequestration potential per cost, High** – A main concern for creating carbon markets is the cost of implementation and enforcement. A carbon offset program would utilize a third-party standards organization in all of its phases. These costly and time-consuming processes are streamlined through the carbon offsets' revenue generation and standards organizations' procedural literacy and resources.

Equity

- **Sociocultural benefits, Medium** – The carbon offset program will generate most of its sociocultural benefits through its support of local economies of emissions reduction, sequestration, and sequestration-capable businesses. For those emitting entities that are required to achieve net carbon neutrality by 2045, a carbon offset program also enables pursuit of the most cost-efficient solutions.
- **Job creation, Medium** – The offset program will require a local stronghold for the selected standards organization, whose function is indefinitely required, while stimulating both the sequestration and emissions reduction economies.
- **Food security, Medium –** The carbon offset program is expected to increase local food production as it funnels revenue into sequestering aquaculture, agriculture, and agroecology operations.

Cap-and-Trade

GHG sequestration potential

- **Rate of sequestration, Low** – After the cap is put in place companies would not be able to exceed the limit and would have to trade for carbon credits. After a specified amount of time this cap would be reduced, further limiting companies emission rates. While this will drive down GHG emissions it does not mean companies will sequester more GHG, thus making its potential rate of sequestration low.
- **rend over time, Low –** This policy could encourage innovative thinking that leads to projects that sequester more GHG but it does not have to. This would largely be driven by company behavior.

Political feasibility

- **Stakeholder/structural support, Low –** We do not think that local communities would support implementation of a cap-and-trade program due to the public not wanting new caps put in place. However, cap-and-trade would reduce GHG emissions, which is in line with Act 15's goals.
- **Funding, 2 –** While there is currently no funding for this, once a cap is put in place it would be self-sufficient and self-perpetuating. It would require industries to trade credits amongst themselves or drive development of alternative sources of energy. After

implementation the EPA found that cap-and-trade could cost as little at $98 a year for American households (Yale Environment 360, 2009).

Efficiency

- **Sequestration potential per cost, Low** – Cap-and-trade puts a limit on the amount of GHG emitted, but does not examine sequestration amounts.

Equity

- **Sociocultural benefits, Medium** – Implementing a cap-and-trade system could be beneficial for reducing GHG emissions to help achieve the goals of becoming carbon neutral by 2045, but its reliance on innovation and clean-technology could be detrimental to traditional practices in aquaculture such as loko iʻa.
- **Job creation, Low** – Cap-and-trade policies likely would not greatly benefit job creation. It may create a few long-term monitoring jobs.
- **Food security, Low** – Does not consider food production.

Demand-Side Policies

GHG sequestration potential

- **Sequestration rate, Low-Medium** – The demand-side policies would support sequestration activities in the aquaculture sector by addressing market failures that prevent adequate demand for local aquaculture products in Hawaiʻi. The policies are an indirect means to sequester carbon therefore it is determined to be low-medium.
- **Upward trend over time, Low-Medium** – Demand can support production, yet it is uncertain whether or not demand-side policies will encourage consumers to purchase local BMP aquaculture products that sequester carbon.

Political feasibility

- **Stakeholder support, Low-Medium** – Taxes are largely unattractive for legislators and other decision makers to support although given the purpose and commitment that the state has made, there may be some support for this option. The combination of multiple demand-side policies, should have positive outcomes in theory, but there is a large degree of uncertainty.
- **Funding, 2** – The tax expenditures would not bring in revenue. Commodity taxes may provide substantial revenue if the tax does not change consumer behavior. Otherwise it will not produce revenue if consumers choose to purchase local aquaculture products.

Efficiency

- **Sequestration potential per cost, Medium** – The cost would be relatively low and would depend on implementation and government internal procedures, among other factors associated with the aquaculture sector in Hawaiʻi.

Equity

- **Sociocultural benefits, Low-Medium** – Higher-income individuals are able to take more advantage of tax expenditures than lower-income groups who pay little tax. Commodity taxes puts the burden on consumers regardless of economic status. Even though the imported seafood product has a commodity tax, the local option may still be relatively expensive for lower-income groups.
- **Job creation, Low** – Demand-side policies would have little to no direct observable correlation to the creation of jobs in the aquaculture sector.
- **Food security, Low-Medium** – In terms of merit goods, the policy can incorporate a mix of redistribution and market failure arguments, which include positive externalities, information asymmetry and also non-traditional market failures such as endogenous preferences (e.g. local preference for salmon and tuna).

Supply-Side Policies

GHG sequestration potential

- **Rate of sequestration, Medium** – Supply side tax-expenditures will encourage BMP and provide tax breaks to practices that employ BMPs. In addition, certification and labelling of products being sold using BMPs will make these products more desirable to informed consumers. These policies both encourage and provide incentives to employ BMPs that would sequester carbon.
- **Upward trend over time, Medium** – These policies largely encourage the establishment of BMPs. By implementing BMPs, over time species may grow and become more efficient at sequestering carbon.

Political feasibility

- **Stakeholder/structural support, Medium-High** – Supply-side tax expenditures would receive a lot of support since they encourage BMPs, which encourage traditional practices that are supported by the local people, and allow restoration efforts to be less expensive. Certification and labelling projects will also likely have support as they inform consumers and benefit producers. Depending on the manner of certification and how much opposition aquaculture operations receive from the local people, stakeholder support is ranked as medium-high.

- **Funding, 2-3** – Tax expenditures given to aquaculture ventures using BMPs make BMPs less expensive and encourage ventures to use them. Since there would be no tax revenue generated from BMPs, there would not be a decline, thus the funding for tax expenditure would be ranked 3. However, the certification and labelling programs may need funding to operate and would require a “standard of operation” to be implemented. There are state-independent interests in creating certification and labeling programs that this operation could piggyback off of, making the funding stable and non-declining. Certification and labelling programs could operate with aquaculture volunteers to promote BMPs. Assuming the availability of a state-independent program, certification and labelling would get a ranking of 2, and overall these policies would be 2-3.

Efficiency

- **GHG sequestered potential per cost, Medium** – The GHG sequestration potential of supply-side policies has a medium ranking. The cost would be low to medium depending on the cost of certification of labeling. The efficiency of GHG potential compared to cost would be a medium.

Equity

- **Sociocultural benefits, Low-Medium** – Supply-side policies would only be beneficial to those operations that are able to afford to implement BMPs. While these policies will encourage loko iʻa production they will also likely be more beneficial to larger and wealthier aquaculture operations.
- **Job creation, Low** – Supply-side policies likely would not greatly benefit job creation other than perhaps specialists required to establish BMPs and use some of the costs saved or earned from policies on labor.
- **Food security, Medium** – Supply side policies will encourage the establishment of BMPs and make such operations less expensive. If these operations produce foods or are used in food production this may contribute to food security.

Best Hits

GHG sequestration potential

- **Rate of sequestration, Medium** – Potential supply-side tax expenditures and offset sales will incentivize the adoption of necessary BMPs and lower the adjustment costs of adopting BMP infrastructure for aquaculture operators. Both supply-side tax expenditures and streamlining permitting mainly address the construction of more aquaculture infrastructure, which might not cause high sequestration rates immediately, but could lead to higher sequestration over time.

- **Upward trend over time, High** – Offsets, supply-side tax expenditures, and streamlined permitting processes for our four aquaculture types will encourage the infrastructural development of BMP-abiding aquaculture. The aquaculture will sequester once fully operational. Deregulation is an important aspect for most sectors, especially for loko iʻa.

Political feasibility

- **Stakeholder/structural support, High** – The deregulation process will ease the lengthy permit process and make implementing new aquaculture efforts more accessible. This is particularly relevant to loko iʻa where the permitting process hinders many efforts. Supply-side tax expenditure and carbon offsets will also provide financial support that will assist in BMPs.
- **Funding, 2** – For our Best Hits package, we maintain the carbon offset's score of 2 for funding given its declining nature. A supply-side tax expenditure and deregulation policies do not require funding for implementation, so they did not affect this score.

Efficiency

- **GHG sequestered potential per cost, High** – Despite a Medium score for our rate of sequestration impact category, the relatively low cost of this policy package produces a High GHG sequestration potential per cost.

Equity

- **Sociocultural benefits, High** – Because loko iʻa production will be more accessible this will provide social-cultural benefits that will support the local community. Aquaculture efforts that employ BMPs will also be supportive of policies that make such endeavors more accessible and financially feasible.
- **Job creation, Medium** – The offset program will require a local stronghold for the selected standards organization, whose function is indefinitely required, while stimulating both the sequestration and emissions reduction economies. Deregulation and supply-side tax expenditures themselves will not in themselves create jobs, but these policies will encourage the implementation of new aquaculture systems that in turn may provide new jobs.
- **Food security**, **Medium** – Supply side tax expenditure, offsets, and deregulation will encourage the establishment of BMPs and make such operations more advantageous. If these operations produce foods or are used in food production this may contribute to food security.

V. Recommendations

We recommend that the State of Hawai‘i adopt our Best Hits policy package to promote GHG sequestration in the aquaculture sector. This package implements, in tandem, a carbon offset program, a supply-side tax expenditure, streamlined aquaculture permitting processes, and addresses the leasing of state-owned loko i‘a.

In consideration of our most heavily weighted policy goal (GHG sequestration potential) only two policy alternatives received both Medium and High scores for its impact categories (rate of sequestration and upward trend over time). No policy alternatives received High scores for both of these impact categories. The carbon offset policy alternative received a High rate of sequestration and a Medium upward trend over time, and the Best Hits policy alternative received a Medium rate of sequestration and a High upward trend over time. This is because the Best Hits package facilitates aquaculture establishment and expansion, which may initially increase the GHG emission to sequestration ratio, but will in the long-term promote net sequestration activity. Despite short-term goals set by the state, the need to plan for long-term climate change mitigation calls for policies that will promote GHG sequestration in perpetuity. Thus, we weight upward trend over time more heavily than rate of sequestration. All of the Best Hits' impact categories received equal or higher scores than that of the carbon offset policy package.

Implementation

A compliance carbon offset program should be implemented for both public and private entities. Additionally, a voluntary offset program should be implemented to enable voluntary participation by individual consumers and non-emitting private entities. Within a voluntary offset market, for example, grocery shoppers might be offered the opportunity to donate to directionally correct practices which diversify local aquaculture and agriculture systems. Or, tourists might be offered the opportunity to offset their GHG footprint while in the islands by providing donations upon entrance to the islands.

For the compliance offset program, the state should first select a standards organization, which will establish emissions and sequestration methodologies specific to Hawai‘i and, more importantly, its aquaculture systems; certify offset buyers and sellers; and maintain an offset registry. If possible, the standards organization should provide local employment opportunities. We cautiously cite the Forest Trends report's 2.5-year timeline from offset program conception to implementation (2017). This timeline will likely be slowed because of the standards organization’s first task to design protocols for Hawai‘i’s aquaculture. Both aquaculture- and Hawai‘i-specific protocols are poorly defined, if at all. As an example, Forest Trends’ 2017 report on voluntary carbon markets, which reports on survey data from 231 voluntary offset market organizations across the globe, makes no mention of any type of blue carbon sequestration. During this period of methodology development, we suggest qualifying directionally-correct BMP adoption as an offsetting activity. In any case, offset activity must be additional (not to be performed without offset revenue). If, for example, an aquaculture venture already integrates two trophic levels in its system, it should either add one more trophic level to its system, or spatially expand its BMP area.

The state should select a basal price per ton of carbon sequestered at which offsets are bought and sold. We suggest the Forest Trends’ (2017) average price per metric ton of carbon (or equivalent) sequestered by the forestry and land use sector: \$5.10/MtCO_2e. This sector most closely represented our own given its requirement for area, its cultivation of food and other products, and the biogeological processes of GHG sequestration. This basal price per ton of carbon sequestered may be flexible based on the co-benefits that are derived through offsetting behavior, or offsetting entities’ development. For example, a hypothetical loko i‘a that adopts BMPs or proves net sequestration may sell its offsets at a higher price. The basal price should be committed to sequestration activity, but the remainder may be made available for cultural restoration, local food production, and community engagement activities. Additionally, to simultaneously ensure progress toward the state’s 2045 goals for net neutrality and encourage emissions reduction, the state should require that participants either reduce or offset an *increasing* percentage of their emissions, for example every 5 or 10 years.

To encourage aquaculture BMPs that will promote carbon sequestration and environmental integrity, more needs to be done to make these practices accessible and appealing. One way to do that is to simplify the permitting process and provide financial incentives. There are numerous permits and agency regulations involved in the aquaculture sector in Hawai‘i (Aquaculture Planning & Advocacy). The state should work with these numerous agency to streamline the permitting process to make the whole thing less daunting and more efficient. This streamlining process could be to the aquaculture industry as a whole or specifically to BMPs that exhibit desirable attributes.

Another way to promote BMPs and to make them more accessible is through supply-side tax expenditure. This would reduce or eliminate taxes imposed on permitting fees income for BMP-abiding aquaculture production. This makes BMP adoption less expensive, incentivizing directionally correct sequestration activity.

Currently, global and national public and private sector groups are working on various forms of best practices or aquaculture certification. Some groups are focused on managing environmental impacts, while a few are addressing social and community impacts. Three efforts are emerging as the leading global approaches (including in the U.S.) to managing and certifying sustainable aquaculture practices: 1) The Global Aquaculture Alliance (GAA), 2) The Global G.A.P, and, 3) The World Wildlife Fund (Aquaculture Planning & Advocacy, 2011). The State of Hawaiʻi would benefit from these and other examples, and should consider a state-initiated approach to these efforts that could work in conjunction with other policy approaches.

VI. Knowledge Gaps

We recommend that the following areas of uncertainty, which exist beyond the scope of our policy analysis, be investigated further as the State of Hawaiʻi pursues GHG sequestration in the aquaculture sector:

- Methodologies to calculate sequestration quantities and rates [tC/ha*yr] for various aquaculture practices in Hawaiʻi, and predict changes change over time;
- The full extent of different funding sources for different aquaculture ventures;
- The exact costs associated with the adoption of BMPs or sequestration infrastructure, as well as for the implementation of different policy interventions;
- Technoscientific support needed to implement BMPs and sequestration infrastructure;
- The quantity of emissions associated with the materials, construction, and maintenance of aquaculture facilities;
- Climate change interests of loko iʻa managers and other aquaculture operators, such as mitigations for sea-level rise;
- And finally, the vulnerability of GHG sequestration in aquaculture to increasing climate variability.

This final knowledge gap is critical. We gave it some preliminary consideration during our policy analysis, which we summarize here. The uncertain future that climate change shapes for the Hawaiʻi and its mitigation efforts has obvious significance. We can ground this concept in mitigation policy when we consider the key criterium of permanence in a carbon offset program. Permanence refers to the guarantee that current sequestration activity (sold as an offset) will produce permanent sequestration benefits. It is difficult to say what permanence truly means in a Hawai'i vulnerable to climate change. For example, Hawai'i's susceptibility to high rainfall events of increasing frequency make the aquaculture sector's ability to sequester carbon through carbon deposition and burial extremely vulnerable. Climate change and variability may affect even an organism in various ways. For example, though we may understand that mollusc physiologies become increasingly vulnerable as the ocean acidifies, that their phytoplankton food sources also suffer with increasing temperatures, and that mollusc growth rates increase in warmer temperatures, we cannot accurately predict how these factors will interact. Other elements of aquaculture that are inherently more climate change resilient should be identified and elevated. For example, seaweed aquaculture can act as a buffer for ocean acidification since it increases the pH and supply of oxygen locally (Duarte et al., 2017).

Paired with our recommendations for implementation in section V, we hope these key knowledge gap provide a useful pathway forward for the State of Hawai'i and its GHG sequestration policies.

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VIII. Appendix

Table 1. Market and Government Failures in Aquaculture

Aquaculture Sector	Realm	Failure Type
General	Market	**Endogenous Preference -** Tuna & salmon, instead of near-shore & local fish, has become dietary norm.
		Negative Externalities - Societal cost of GHG not internalized into budget of emitting entities.
		Information Asymmetry - Avg. person does not know the harm caused by overconsumption of tuna/salmon.
		Open Access - No clear jurisdictional boundaries/oversight on pelagic fish, this leads to overconsumption.
		Limits to Rationality - People may not change behavior and eat/buy sustainable products regardless of information.
		Endowment Effect - People are resistant to paying more now even though it will help in the long run.
		Adjustment Costs - Switching to local seafood supplies requires building new infrastructure & systems, which can be costly initially. Also seen in cost of adopting new GHG sequestering infrastructure.
	Government	**Posturing to Public Attention -** Public government officials have taken insufficient actions towards improving domestic food production.
Algae	Market	**Positive Externalities -** Algae growth boosts ecosystem resilience. Limu restoration and increased production helps to foster cultural knowledge and build socioecological relationships.
		Missing Market - Market for algae biochar is missing.
Loko I'a	Market	**Endogenous Preference -** Colonial hegemony has decreased the preference for near-shore fish.
	Government	**Diffuse Authority -** Government decentralization splits permitting processes across many organizations & branches, causing inefficiencies.
Molluscs	Market	**Positive Externalities -** Molluscs filter water & POM and are ecosystem engineers, benefits not internalized in mollusc demand.
		Negative Externalities - Shell calcification during mollusc growth is a net carbon emitters.
		Missing Market - Recycled mollusc shells could be used in urban landscaping.
IMTA	Market	**Endogenous Preference -** Aversion to ‘produced’ meat results in a preference against aquaculture fish by general public.

Table 2. Policy Alternative Evaluation

GOALS		GHG sequestration potential		Political feasibility		Efficiency	Equity		
IMPACT CATEGORIES		Rate of sequestration [Low-High]	Upward trend [Low-High]	Stakeholder support [Low-High]	Funding [0-3]	GHG sequestration per cost [Low-High]	Sociocultural benefits [Low-High]	Job creation [Low-High]	Food security [Low-High]
POLICY ALTERNATIVES	Status quo	L	L	M	3	M	L	L-M	L
	Carbon offsets	H	M	M	2	H	M	M	M
	Cap and trade	L	L	L	2	L	M	L	L
	Demand-side policies	L-M	L-M	L-M	2	M	L-M	L	L-M
	Supply-side policies	M	M	M-H	2.5	M	L-M	L	M
	Best Hits	M	H	H	2	H	H	M	M

Figure 1. Aquaculture Type Decision Tree

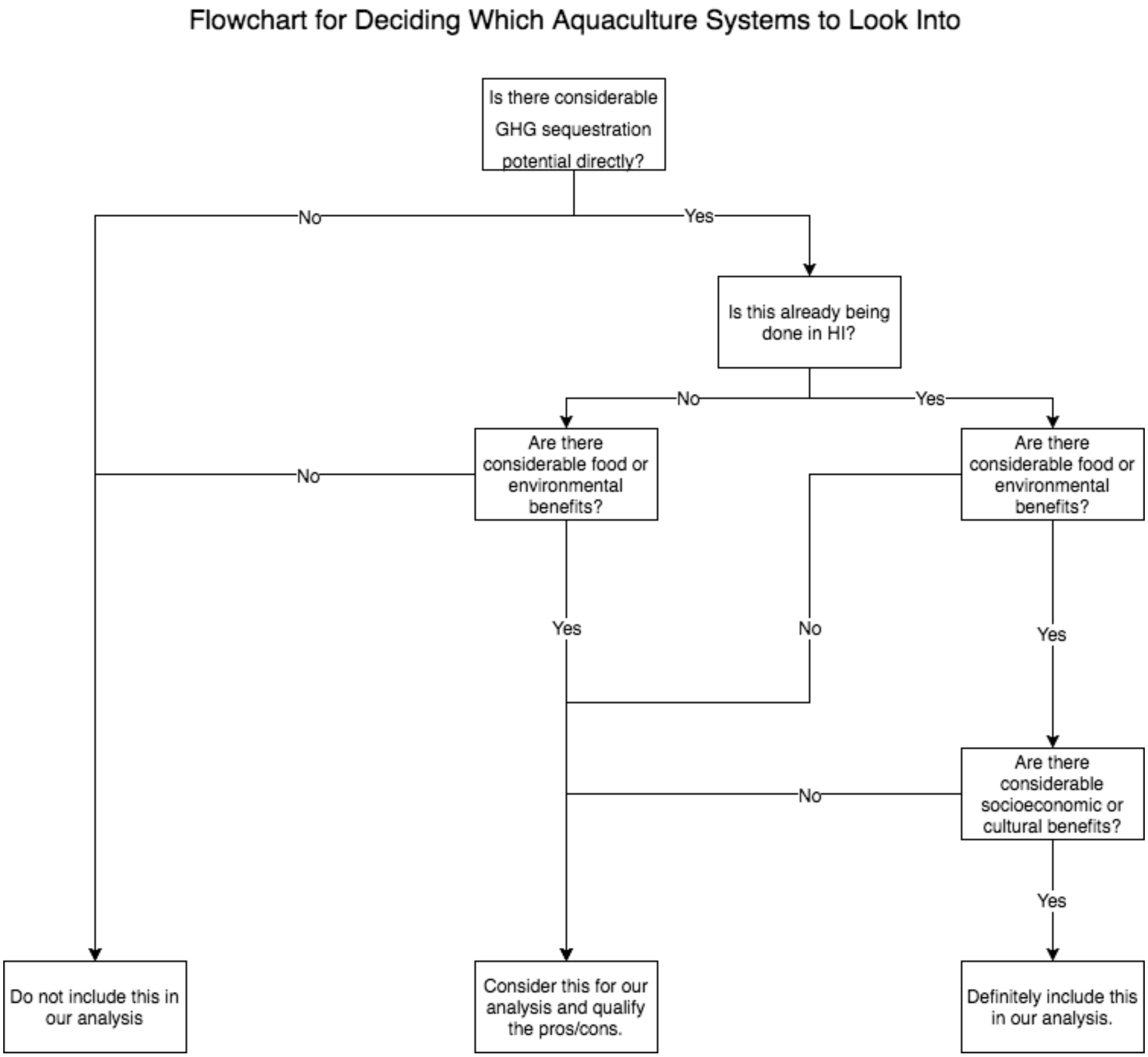

Figure 2. Policy Goals and Impact Categories