Charting an Aquaculture Future for the Caribbean

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# Abstract

Marine aquaculture in the Caribbean has been identified as an avenue to stimulate local economies, increase employment opportunities, and improve seafood supply and food security. In particular, offshore aquaculture can alleviate numerous environmental and social impacts associated with farming closer to shore, such as habitat degradation and spatial conflicts with fisheries, tourism, and other stakeholders. We identify areas throughout the Caribbean suitable for offshore aquaculture of cobia (*Rachycentron canadum*) and develop a spatial bio-economic model to estimate yields and profits under different scenarios of economic risk. We find that approximately 50,373 km2 (1.7% is technically feasible for cobia aquaculture, with the potential to produce 80.5 million metric tons (MMT) of seafood annually, an amount roughly equal to the total global production from capture fisheries. Given our estimates of production costs and cobia price, ~ 43,120 km2 (1.45%) is economically viable for cobia farming, with the potential to produce 72.1 MMT of cobia annually. These results are slightly reduced when accounting for country-specific risks of foreign investment, though most farms (85%) remain profitable. Farm-scale production and value varied across and within countries, demonstrating the value of spatial models for decision-making at different spatial scales. This analysis can help prioritize areas in the Caribbean for offshore cobia aquaculture and serve as a framework for evaluating other species.

# Introduction

Global seafood production is expected to exceed 151 million tons by 2030 to meet growing demand, a 10% increase over current levels1,2. The vast majority of new production must come from aquaculture given only modest potential increases from capture fisheries3. Aquaculture seems poised to meet this challenge as the fastest growing food production sector globally, surpassing wild fisheries production for the first time in 20142. Marine aquaculture, or mariculture, is seen as having particularly strong growth potential4. And as mariculture technology advances, production from offshore mariculture, generally defined as occurring more than three nautical miles offshore and/or in depths of greater than 30 m5, is expected to increase2. By moving to deeper waters further from the coast, offshore aquaculture could be a viable strategy to minimize aquaculture’s adverse environmental and socioeconomic consequences5,6. Additionally, production potential in the offshore realm far exceeds seafood demand for the foreseeable future7,8. Despite strong arguments for offshore aquaculture development, how this growth could be realized requires an understanding of the sustainable and economically-viable production potential at different spatial scales, along with an identification of hurdles impeding development.

In recent years, there has been a growing interest in aquaculture development in the Caribbean to increase local seafood and economic development9–12. In 2014, the Caribbean produced 33,704 MT of seafood, 90% of which came from capture fisheries2. To meet seafood demand in the region, over 144,000 MT of seafood, valued at US$ 196 million, is imported annually2,13. Furthermore, seafood consumption per capita in the Caribbean is projected to increase rapidly (22%) over the next decade2. Wild fisheries production in the region is unlikely to play a meaningful role in decreasing exports or meeting growth in seafood demand because of overfished stocks, degradation of coral reef ecosystems, and expected climate change impacts12,14. Aquaculture development could be an opportunity for Caribbean countries to diversify their economic activities, reduce reliance on foreign imports, provide jobs and economic security to local residents15, and promote a seafood industry that is potentially more resilient to the effects of climate change12.

Most aquaculture efforts in the Caribbean to date have been directed towards land-based aquaculture of tilapia (*Oreochromis sp.*) and coastal pond aquaculture of white-legged shrimp (*Litopenaeus vannamei*)16. However, the potential for increased production of land-based aquaculture in the Caribbean is extremely limited due to the requirements of available land, freshwater, and energy resources17. Similarly, expanded development of alongshore and coastal aquaculture in the region is likely unsustainable and difficult due to conflicts over space in highly utilized and ecologically sensitive coastal areas18. For example, coastal aquaculture can harm mangroves and coral reefs by increasing nutrient loads and causing physical damage to the habitat from farm infrastructure18,19, with cascading effects on marine-based tourism, the backbone of many Caribbean island economies19. Offshore aquaculture could be a promising alternative8,20, and submersible cages will allow aquaculture to be developed in areas that were previously considered unsuitable due to wave intensity, water depths and/or high risk of damage from large storms and hurricanes20.

Environmental conditions in the Caribbean, such as relatively small seasonal fluctuations in ocean temperatures and a stable water column, provide ideal conditions for the offshore culture of a number of species. Small-scale trials raising cobia (*Rachycentron canadum*), pompano (*Carangidae sp*), and red drum (*Sciaenops ocellatus*) in offshore environments were successful in the Bahamas and Puerto Rico21. Cobia in particular has been identified as an ideal candidate species for aquaculture in tropical and subtropical regions because of its relatively fast growth rates, high market value, and tolerance for variations in salinity and temperature17,21,22. The largest open ocean mariculture farm in the world, Open Blue, has been successfully culturing cobia off the Caribbean coast of Panama since 2007. Despite the seeming promise, there has not been an analysis examining the Caribbean wide potential for production and value from offshore aquaculture development.

Here, we present a framework that incorporates socioeconomic, biological, and environmental factors to estimate the potential of offshore aquaculture at a regional scale using the Caribbean, a politically and economically diverse region. We assess region-wide production potential, in terms of yields and value, and examine how potential varies spatially and the importance of strategic site selection, in addition to considering some of the factors that may be limiting development in the region. Using high resolution spatial data, we develop a bioeconomic model to: 1) estimate the offshore mariculture production capacity of the Caribbean region (in terms of cobia production and revenue); 2) examine the impact of farm site selection on economic outcomes across and within countries to identify potential development hotspots and determine the importance of strategic site selection; and 3) identify factors that may currently be limiting offshore mariculture development (e.g., technical constraints, biophysical conditions, investment risk, etc.). Our approach could be applied to other farmed species or applied to other regions, and can help to chart a course for a sustainable and economically prosperous offshore mariculture industry in the Caribbean.

# Results

## Suitability

Accounting for technical, environmental and use conflict constraints, we identify 50,373 km2 of ocean space (1.7% of the study region) as potentially suitable for the development of offshore mariculture (Figure 1). Depth is the most constraining factor in the suitability analysis, as 97.85% of the study area falls outside the depth range (25 - 100 m) considered technically feasible for offshore farm infrastructure. By comparison, the second most constraining factor is shipping activity, which only excludes 11% of our study area (Table S4). There is considerable variability in the amount and distribution of suitable area for offshore mariculture in the Caribbean (Table 1; Figure 1). The Bahamas, Trinidad and Tobago, and Jamaica are the top three countries in terms of suitable area, and the spatial distribution and clustering of suitable sites differs considerably among them (Figure 1). Both the Bahamas and Trinidad and Tobago have more than twice the suitable area of the country with the next largest amount of suitable area (Jamaica; Table 2). The large suitable area in the Bahamas can be attributed to its relatively large EEZ. Overall, Trinidad and Tobago have the largest percentage of their EEZ identified as suitable (13.3%), followed by Saba (11.1%) (Table 2). Suitable areas account for < 5% of total EEZ area for all other Caribbean islands and no suitable area is found in Martinque, St. Martin, and Guadeloupe because of the conservation status of otherwise suitable sites (Table 2).

## Cobia production

Ignoring economic constraints (the “suitable scenario”), the Caribbean’s potential to produce cobia from mariculture is extremely large, with an approximate annual production from all suitable sites of 80.5 MMT. The median cobia farm occupying a 1-km2 site in the Caribbean yields an annual supply of 14,217 MT. Not surprisingly, international variability in production is driven by the amount of suitable area within each EEZ; countries with the most suitable area also have the largest production potential (Table 2; Figure 2A). However, countries with the highest production potential do not necessarily have the most productive farms (Figure 2). Cobia growth is a function of temperature, and growth rates vary across EEZs, showing a clear seasonal pattern (Figure 3). As a result, the most productive farm sites are located within the EEZs of Jamaica and several small nations in the southeastern Caribbean, such as St. Vincent and the Grenadines, Barbados, St. Lucia, and Trinidad and Tobago (Figure 3) where temperatures are more optimal (i.e., closer to T\_o\_) for cobia growth throughout the year. Interestingly, farms in Haiti and the Cayman Islands experience below average growth rates during the peak summer months, likely due to water temperatures approaching .

Variability in growth rates, both spatial and seasonal, leads to differences in the length of time required to raise cobia to a market size of 5 kg (Figure S2). While the average farm in the Caribbean completes a harvest cycle in 13 months, harvest cycles range from 12 to 48 months in duration. Longer harvest cycles affect the economics of cobia production by reducing harvestable biomass (mortality/escapes) and by increasing feed use and other operating costs. The economic feed conversion ratio (FCR) - calculated as total feed used divided by total harvested biomass - is a measure of how efficiently a farmed animal converts feed into biomass and is one of the main indicators used to compare the sustainability of different animal protein sources**???**. FCRs of cobia farms in our analysis range from 1.91 to 9.97, with a median FCR of 2.4606309. These findings accord with the literature, in which FCRs for cobia range from 1.5-3 (refs). Our findings also support the conclusion that feed accounts for the vast majority of farm operating costs, with the median farm spending 95% of operating costs on feed.

When economics are considered (the “profitable” scenario), the potential production and/or profitability of offshore cobia mariculture is considerably reduced in several countries relative to when only suitability and temperature-dependent growth are considered (Table 4; Figure 4). In the Bahamas, which has the largest amount of suitable area, average annual production declines by 8 MMT (41.9%), while Cuba experiences a decline of 0.4 MMT (12.8%). The Turks and Caicos and Haiti also both experience small declines (<1%). Overall, the potential annual production for the Caribbean is reduced to 72.1 MMT when only considering supply from profitable farm sites.

In terms of value, farms in most countries are profitable and this result is robust to the discount rate (Figure 4). Farm value is tightly clustered around $3 million for many countries, suggesting site selection is less of a financial concern in these areas. However, farms in Turks and Caicos, Jamaica, the Dominican Republic, Cuba, the Bahamas, and Aruba vary considerably in value and therefore strategic site selection will be critical for prospective cobia farms in these areas (Figure 4). Only the Bahamas and Cuba contained a considerable number of unprofitable farm sites under both discount scenarios, with the median Bahamian farm unprofitable if assessed with a 10% discount rate. When considering country-specific discount rates based on investment risk, the value of cobia farms in certain countries changes considerably relative to others (Figure 4). For example, the median farm in Haiti, where investment is risk is particularly high, drops from 2nd to 20th in terms of highest value. In contrast, Barbados moves from 7th to 2nd and Puerto Rico moves up from 14th to 6th.

The assumed market price of cobia had a large impact on annual Caribbean supply (Figure S3). A market price of $9.50/kg resulted in the development of all suitable farms and a supply equal to our “suitable” scenario using both country specific and a fixed 10% discount rate. Supply was reduced by over ~50% relative to our ‘economic’ scenario at an assumed cobia price of $6.50/kg (?). At a price of $6/kg cobia supply was reduced to 0 MMT and XX MMT using the country specific discount and 10% discount rate, respectively.

# Discussion

This study incorporates biological, environmental, economic, and political data to estimate potential for offshore cobia aquaculture, in terms of yields and profits, across the Caribbean region. Our results reveal remarkable potential; we estimate a total annual production of 80.5 MMT if all suitable areas are developed and 72.1 MMT if only profitable farms are developed. This potential yield is more than two orders of magnitude larger than total current seafood production in the region (~300,000 MT) and is on par with total annual harvest from the world’s capture fisheries (~80 MMT). Impressively, this output requires <2% of the Caribbean’s marine space, a result similar to the findings of Gentry et al.**???** who estimated that current total landings could be produced from farming finfish in 0.015% of global ocean area. In fact, the Caribbean could match its current seafood production using just 179 km2 (0.006%) of its marine space. In addition to highlighting the total production potential of the Caribbean, this study also highlights where in the region culturing of cobia will be most productive, and can be used to identify sites within an EEZ that will be most economically profitable for offshore cobia mariculture development.

This study provides an important contribution to the literature by integrating biophysical, economic and political factors in identifying potential sites for mariculture development [23. Previous studies have found large potential for global mariculture development by identifying suitable areas using solely environmental data7,8, and by estimating biological production rates that could occur in suitable areas8. To date, studies that have applied bioeconomic modeling to examine the economic feasibility of mariculture farms have largely been focused on a single farm in a previously specified area24–27 or on spatial variation in farm profitability within a single national jurisdiction28. This analysis bridges that gap between biophysical production potential and economic profitability across multiple jurisdictions, and is the first assessment of the economic feasibility of offshore mariculture for the Caribbean region as a whole29. The framework provided by our study could be applied to other species in the Caribbean or applied to other regions.

Our results indicate that space for offshore development in the Caribbean is not currently a limiting factor. However, where farms are located can have a large impact on their realized profitability, highlighting the importance of strategic site selection that incorporates economic factors at both the regional and within-EEZ spatial scales. In our study, the Bahamas had large potential in terms of suitable area due to its large EEZ, which aligns with conclusions of previous studies29. However, we find the majority of cobia farms within the Bahamas to not be profitable. Although cobia farming is not currently as promising a venture for the Bahamas relative to other countries, farming of other species that reach an optimal growth at a cooler temperature could be worth exploring given the large amount of suitable area. Cobia appears to be a species well suited for culture in the warmer waters found in Jamaica’s EEZ and the southeastern Caribbean. The most profitable farms, without considering investment risk, were found in Jamaica, Haiti, Dominican Republic, and Trinidad & Tobago, representing countries that may want to consider whether they want to encourage development through regulatory policies or by incentivizing industry development. Given that temperature is a major driver of our results, future studies should examine how optimal location may change given predicted increases in SST associated with climate change.

Within individual countries, those with more farm-scale variability in outcomes represent countries for which strategic site selection for mariculture development is particularly important. The location of farms sited within the EEZs of Cuba, the Bahamas, and Turks and Caicos varies on the scale of millions of dollars annually, and not all suitable farms sites in these EEZs are economically viable. Within-EEZ variability in profits is largely the result of variability in sea surface temperatures, highlighting the importance of carefully considering local oceanographic features when evaluating site location. Although we consider a range of factors that influence profitability beyond temperature (labor costs, fuel costs, water depth), there are also numerous potentially important factors we were not able to account for, such as distance to markets or seafood shipping capabilities, proximity to onshore hatcheries and seafood processing facilities, and availability of a labor force11.

The results of our model are most sensitive to a few key assumptions: the depth range that is technically feasible for offshore development, the current price of cobia feed, and the market price of cobia. First, technology for offshore aquaculture is rapidly advancing, and it is likely that in the near future installing farm infrastructure at greater maximum depths will be technically and economically feasible. Caribbean island countries have large EEZs relative to their land areas and depth was the largest constraining factor in our suitability assessment. As the suitable depth range for this industry expands, the area suitable for offshore aquaculture development will grow exponentially, although there will also be higher costs associated with installation and maintenance in deeper waters. Second, data on the current price of cobia feed is difficult to obtain, and this is an important parameter given that feed costs in our model accounted for on average 95% of operating costs, which is similar to values previously reported in the literature for cobia farms30.

Our model assumes that cobia produced in the Caribbean is sold as an export product at the current global price for cobia of $8.62/kg. Wild caught cobia is considered a high value species and the increasing popularity of cobia sashimi31, along with the recent ASC certification of Open Blue cobia farms32, has opened up the potential for higher-end markets for cultured cobia, in which case $8.62/kg may be conservative. Our assumed price does not account for Caribbean production influencing global prices, an assumption which may not hold under significant levels of development. For example, the rapid increase in farm raised salmon, catfish, and sea bream have all been accompanied with by a substantial decrease in global market price**???**. Predicting how global price will be impacted as production increases in this rapidly developing industry is difficult, but global dynamics of cobia supply and demand should be carefully considered before any rapid development of cobia takes place. One option for moving forward with offshore mariculture development in the Caribbean could be to diversify the species being cultured and choose species that are best suited in terms of optimal temperature-dependent growth for different regions.

Although our results demonstrate huge potential for increased seafood production and revenue from offshore cobia farming across many countries in the Caribbean, there is currently very little mariculture production in the region. Lack of aquaculture development in the Caribbean has largely been attributed to lack of affordable credit to assist private sector development and lending environments that are not attractive to foreign investors11. Risky investment environments are associated with higher discount rates that are notoriously difficult to predict or quantify33. Investment in offshore mariculture is generally considered risky due to the relative newness and unpredictability of the industry34. Our study attempts to account for the risk of foreign investment associated with each country by incorporating political and economic indicators to define country-specific discount rates. Due to the large uncertainty associated with these values, we also evaluate our model using a fixed discount rate of 10% for all countries. Because of the high profitability of most suitable sites across EEZs, the primary effect of incorporating investment risk is to lower the annuity values of farms in many countries. In Haiti for example, a country associated with high investment risk due to the country’s low GDP and high political corruption, accounting for investment risk translated to a loss in median farm level annuity close to 0.5 million dollars, a value that could likely sway an investor to opportunities that are less risky. Only The Bahamas and Cuba contain farms that become unprofitable after accounting for higher investment risk (Table 4).

Policy for aquaculture development varies considerably across the Caribbean and can also play an important role in where and how aquaculture is developed35,36. Countries with aquaculture legislation and policies in place to promote the development of aquaculture, such as fiscal interventions, are more likely to attract foreign investors. For example, all aquaculture related products imported to the Dominican Republic are exempt from import tax. To ensure any development occurs sustainably, however, it is important for countries to have clear policies in place that include an evaluation of the environmental impacts of farms and general guidelines on where and how development can occur. Furthermore, clear policies and processes for aquaculture development can also attract development because countries with overly lengthy or confusing permitting processes can be a deterrent for potential investors. For example, Snapperfarm, a small-scale offshore mariculture farm originally based in Puerto Rico had difficulty obtaining permits to expand due to uncertainty about environmental impacts, and so they recently moved to Panama35. Due to uncertainty about environmental impacts of offshore mariculture farms, Puerto Rico does not have a streamlined permitting process in place and assesses requests on a case-by-case basis, which is often time intensive.

In conclusion, sustainable aquaculture development can be greatly assisted by adopting a planned approach to development28. This study offers the first comprehensive look at the production potential of offshore mariculture in the Caribbean and the results can be used to help guide and plan offshore mariculture development. Projected changes in sea surface temperatures associated with climate change should also be considered. Although our analysis focuses on a single species, the framework presented here can be used to explore the potential for other offshore mariculture species. Lastly, our framework could be adopted in other regions interested in developing offshore finfish mariculture, and could be coupled with a more comprehensive assessment of tradeoffs with other marine uses and management objectives.

# Methods

## Study Region and Overview

The study area includes the Exclusive Economic Zones (EEZs) surrounding the 28 island countries of the Caribbean Sea. We do not consider the potential for offshore aquaculture development in the high seas or disputed waters. EEZ boundaries in our study are are defined using data from Flanders Marine Institute14 and all analyses are performed at a 1 km2 spatial resolution. We develop a spatial bioeconomic model to estimate the production potential, in terms of harvested biomass and annuity, for offshore cobia aquaculture in the Caribbean. We first identify 1 km2 sites throughout the study region that are suitable for offshore mariculture development. Next, we apply a thermal performance curve (TPC) to predict temperature-dependent individual growth and subsequent total production of cobia at each hypothetical farm, over a 10-year period. Finally, production estimates are coupled with an economic model in order to calculate farm-scale annuity values given a 10-year time horizon and several scenarios of investment risk.

## Suitability Assessment

We identify areas that are potentially suitable for the development of offshore mariculture in the Caribbean by considering factors related to technical feasibility, environmental impacts, and current ocean uses that we view as fixed constraints to development (Table S1). We define suitable thresholds for each factor and use high resolution spatial data in a Boolean overlay to identify 1 km2 areas in our study region that are potentially suitable for offshore mariculture development given the defined thresholds.

Physical specifications listed by the original manufacture of SeaStation cages are used to define thresholds for areas that are technically feasible for offshore mariculture. SeaStation cages are submersible, self-tensioned, single rim cages and are currently the most widely used offshore mariculture cages in the U.S.37. The minimum depth for installation of a SeaStation cage is 25 m and the cages are not recommended for areas that experience current velocities exceeding 1 m/s38. We assume the maximum depth threshold for suitable areas is 100 m because cage installation and inspection of mooring and anchoring systems becomes more difficult and costly in depths > 100 m7. We use spatial bathymetry data from Becker et al.39 to identify areas within a suitable depth range. The absolute maximum zonal and meridional current velocities are set using data on daily averages over a 10-year period (2005 - 2015) from40.

Offshore mariculture farms can be associated with increased nutrient levels in the water column and along the benthos from fish waste released from the cages16, which can cause algal blooms, reduced water quality and clarity, and low oxygen conditions, all of which can be damaging to coral reef ecosystems6. Using data from41 on locations of coral reef habitat, we exclude these areas from offshore mariculture development. Additionally, we exclude areas within designated marine protected areas (MPAs) and conservation priority areas42, as many MPAs do not allow aquaculture development and because these locations are likely to include ecologically important or sensitive habitats. Shipping and structures used for oil drilling are offshore activities that may preclude aquaculture development. In order to account for potential conflicts with these other ocean uses, we use spatial data from Halpern43, to exclude areas falling within 10% of the highest relative shipping activity locations and areas with benthic oil structures.

## Growth Model

Temperature is one of the primary abiotic factors controlling growth in ectotherms, including cobia44, and obviously cannot be easily controlled in offshore mariculture farms45. To reflect spatial differences in productivity across farms caused by temperature variations, we use 10 years of remotely-sensed sea surface temperature (SST) data46 to calculate 1 km2 resolution spatial data layers of average monthly SST. We then use a thermal performance curve (TPC) to model temperature dependent individual somatic growth (, kg per month) of cobia for each farm site47.

The TPC is a temperature-dependent piecewise linear function defined as follows:

where is sea surface temperature in degrees C, is the optimal temperature for cobia growth, and and are slope parameters (kg per month per degree C), and , and are intercept parameters (kg per month). At temperatures below the minimum temperature for growth () and above the maximum temperature for growth (), is forced to 0 to reflect the absence of growth. Where is negative, . Our temperature-dependent growth parameters for cobia are presented in Table S2 and are adopted from47, who also use a TPC to model cobia growth.

Individual cobia growth for site in month is modeled using the 10-year average individual growth () for each calendar month as estimated by the TPC from the 120-month historical SST timeseries:

We model offshore mariculture production using a hypothetical fixed farm design, per 1 km2 site, that we apply across the study region. SeaStation cages are typically configured using a mooring system that includes a grid, anchor, and mooring lines secured at varying distances from the cages48,49. The cages are held in position by the mooring system at depths of 15-20 m below the surface37. Our farm design is based on the total cage volume to farm area ratio of offshore mariculture farms currently operating off the coast of Kona, Hawaii50 and the Gulf of Maine48. Our hypothetical farm has 16 SeaStation cages (each 6,400 m3) configured in two eight-cell gridded mooring systems, for a total cage volume of 102,400 m3 per individual 1 km2 farm. The infrastructure of the farm has a footprint of ~0.48 km2, which meets the guidelines issued in NOAA’s Fishery Management Plan for offshore aquaculture development in the Gulf of Mexico that specifies the total mariculture farm area should be twice the size of the total area occupied by farm infrastructure51.

In our farm design, we assume that fingerlings are stocked at an initial weight of 15 grams and fish weight () in each month is calculated as the cumulative growth since the stocking month ():

We apply an instantaneous mortality rate of 0.024, which we adopt from previous studies that estimated a total 12-month survival rate of 75% for cobia raised in offshore cages in the Caribbean30,52. Cobia are harvested when individual fish have grown to a harvestable size of 5 - 6 kg. We adopt as a target harvest density for sustainable offshore mariculture from 21. Because growth rates vary across farm sites, we calculate the optimal number of stocked fingerlings () required to achieve the target harvest density of (19,200 5 kg fish per 6,400 m3 cage). For each site, we first calculate the number of grow out cycles () hypothetically completed over the 120-month historical timeseries by dividing the cumulative individual growth by the target harvest weight:

Next, we calculate the average length (months) per grow out cycle () is as . Given , natural mortality, and the target harvest of 307,200 fish (16 cages each with 19,200 5-kg fish), the optimal number of stocked fingerlings is estimated for each site as:

Finally, the total production acheived from grow out cycles (approximately 10-years) is modeled for each farm site. Total biomass () in each month of the simulation is a function of the initial stocking number, individual fish weight, and the instantaneous mortality rate:

Cobia are harvested in months where (under the assumption harvest occurs at the beginning of the month) and, while , farms are restocked with .

## Economic Model

The total cost () of production for each farm consists of start up costs () plus the sum of operating costs ().

Cost parameters were obtained from published literature or from personal communication with industry experts. Some parameters were fixed across our study region (Table S3) while others are a function of EEZ (Table S4) and/or vary by site within an EEZ. Costs of aquaculture infrastructure and installation increase with depth and distance from shore53. References for parameter values are included in Tables S2-S3z-b.

Start-up costs, which include initial capital expenditures () and installation costs (), vary as functions of average site depth in meters , and EEZ-specific permit and/or lease costs ():

Initial capital expenditures () include the cost of 16 SeaStation fish cages ($269,701 each) plus the cost of one 16-m-long support vessel and two 7-m-long motorboats. Installation costs () include the labor costs and equipment required for installing the culture system. A 10% increase in cage and installation costs are assigned to sites with depths greater than 50 meters to account for a more complex and time consuming installation procedure in deeper water28. Operating costs are organized in two main categories: farm labor and maintenance costs as a function of site depth, EEZ-specific hourly salary and fuel costs, and costs associated with purchasing and feeding stocked fish

Labor and maintenance costs () are modeled as follows:

Where 2,720 is the total monthly labor hours required at each site (17 full time workers); is the EEZ-specific hourly salary; is distance from shore (in meters); 3,219 is average fuel efficiency (meters per gallon); 60 is the number of one-way trips required per month for running the farm; and is the per-gallon cost of fuel as a function of EEZ.

Fingerling and feed costs () include the total cost of stocked fingerlings () plus the total cost of feed. Feed cost is based on a feed price of $2.50/kg and a tapered feeding strategy in which daily feed usage (30 days per month) corresponds to 3% of total farm biomass () for the first three months, 2% for months 4-8, and 1% thereafter.

Farms earn revenue by harvesting market weight (5 kg) cobia. Thus, farms only earn revenue in months where individual fish weight () reaches or exceeds 5 kg, otherwise . Revenue is a function of harvested biomass (, kg) and cobia price (), where .

Cobia farms in the Caribbean are assumed to be price takers and thus production in month does not affect price in month . Total farm profit () is the sum of revenues less total farm costs.

Net present value (NPV) can be used to assess an investment’s long-term economic validity, accounting for the time value of money by discounting future cash flows at a specified discount rate that describes the present value of future cash flows. We calculate NPV for all farms over a 10-year period as:

where is the discount rate. Lastly, for ease of interpretation, NPV is annualized by calculating the corresponding annuity payment:

Production and annuity values for each EEZ are calculated for two main scenarios: 1. “Suitable”, where farms are developed in all areas that meet the criteria used in our suitability assessment, and 2. “Profitable”, where only farms with a positive 10-year NPV at the current global market price of cobia are developed.

## Sensitivity Analyses

Defining appropriate discount rates in bioeconomic models is often difficult and depends on many factors, particularly the cost of capital and project risk54. Therefore, we examine results under two different discount rate assumptions. First, we assume a fixed discount rate of 10% across all farms, which we base on the average discount rate of 10.6% found in a meta-analysis of published bioeconomic models for aquaculture from the last 25 years55. However, lack of foreign investment due to perceived financial risk has been identified as a major barrier to aquaculture development in the Caribbean53. Investment risk can be represented by adjusting the discount rate accordingly when estimating returns on an investment. Therefore, we also examine results using EEZ-specific discount rates that are based on the financial risk of investing in offshore aquaculture in each country.

Foreign investment risk reflects both political and economic risks in a country, which can be calculated into a single risk score using economic and socioeconomic indicators56. We apply the Foreign Investment Risk Matrix (FIRM) method developed by 56 and modified by 57, which utilizes three political and three economic continuous risk variables that are readily available for most countries (Supplementary Methods and Table S3). Risk scores are used to scale EEZ-specific discount rates (Table 1) between 10% and 25%, which aligns with the range of discount rates found in the literature of bioeconomic modelling of aquaculture55. The risk score for the US Virgin Islands is used as a baseline index. The use of current global market price of cobia is a large assumption in our model, as market dynamics in this rapidly developing industry are difficult to predict. Therefore, we evaluate the sensitivity of our results (annual Caribbean supply) to cobia prices ranging from $1.00-$9.50 per kg.

# Figures

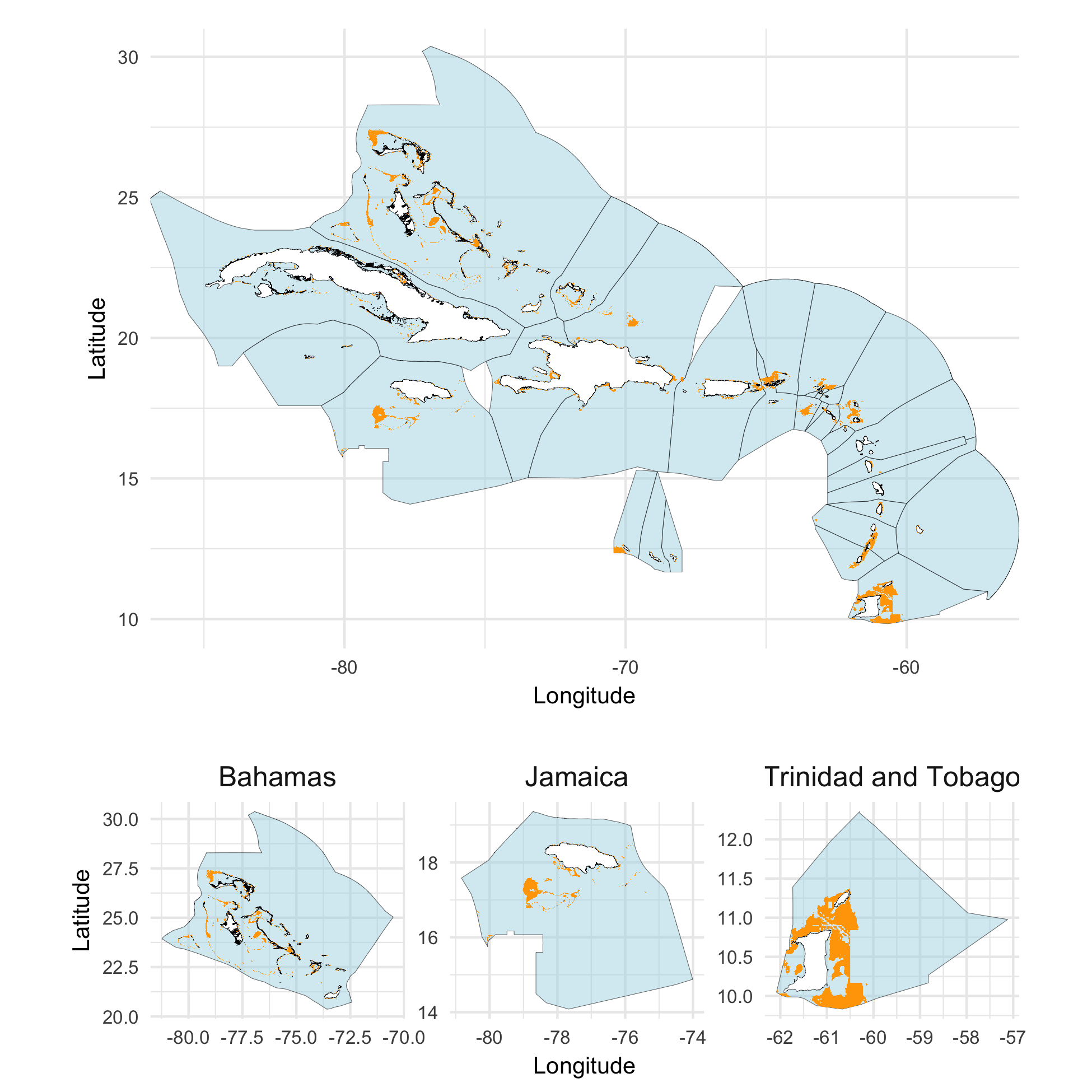


Figure 1. Suitable areas (orange) for offshore cobia mariculture in the Caribbean.

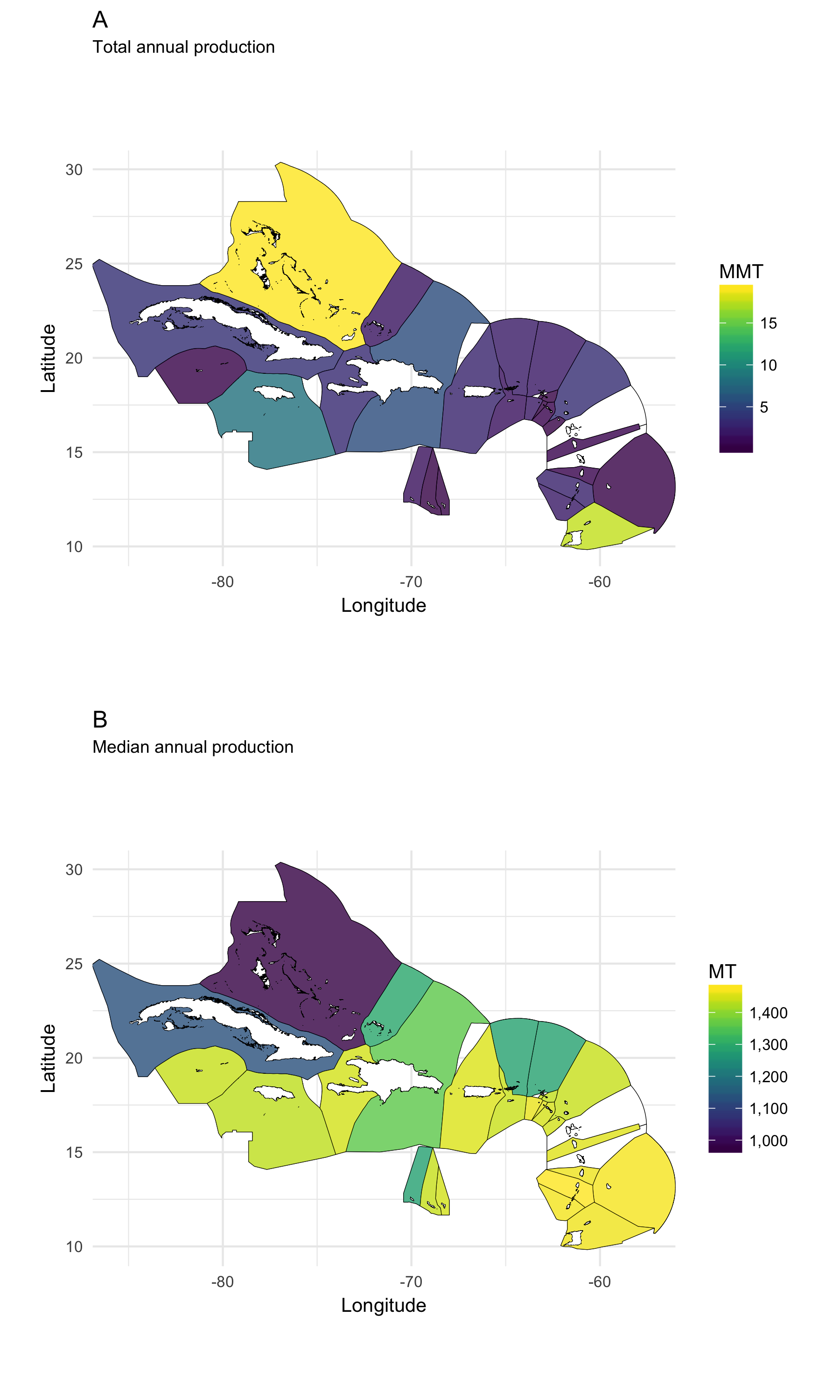


Figure 2. Estimated total annual production of cobia from all suitable farm sites (panel A) and median production from only profitable farm sites (panel B)

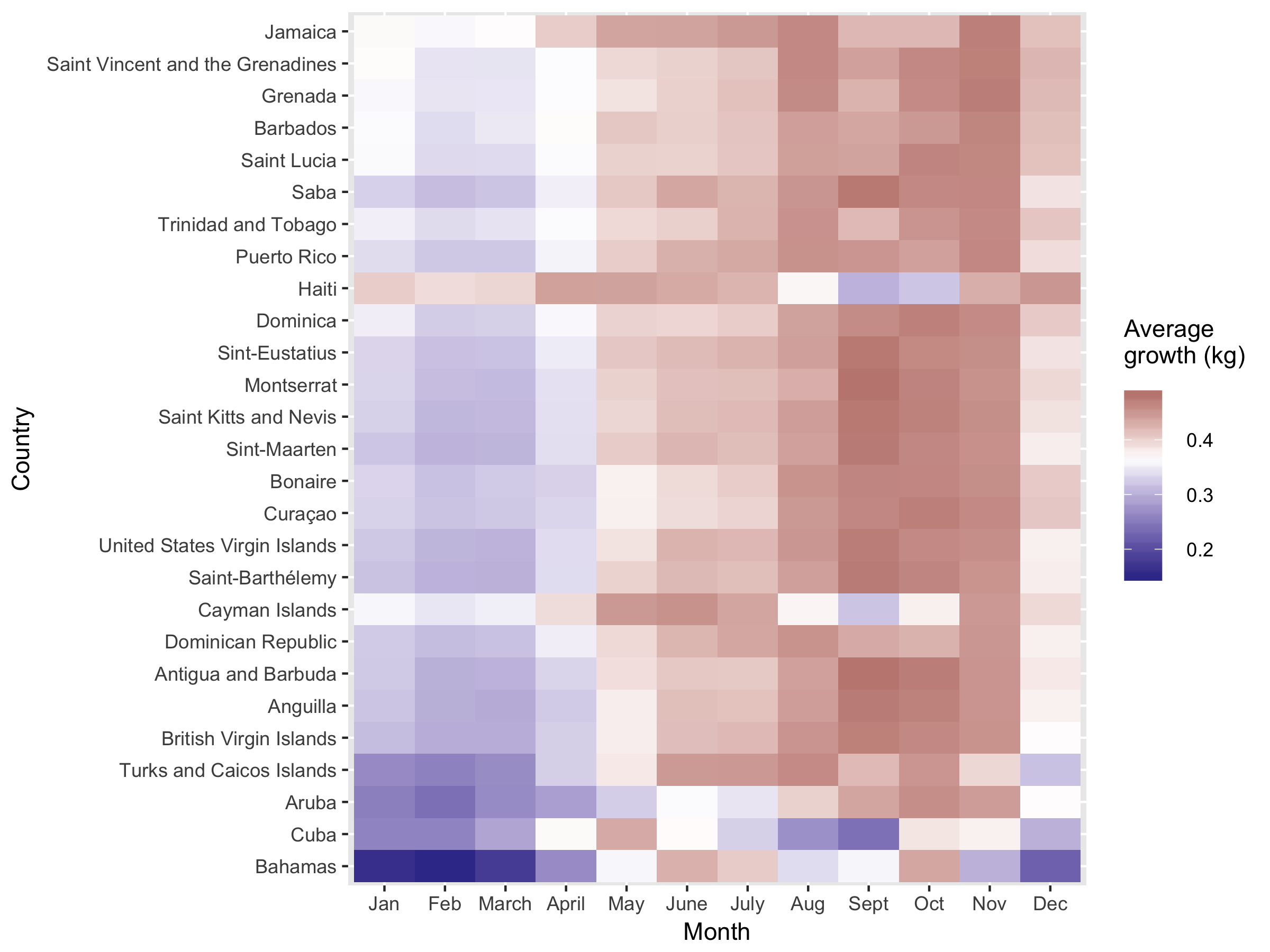


Figure 3: Average cobia growth rates per month by EEZ

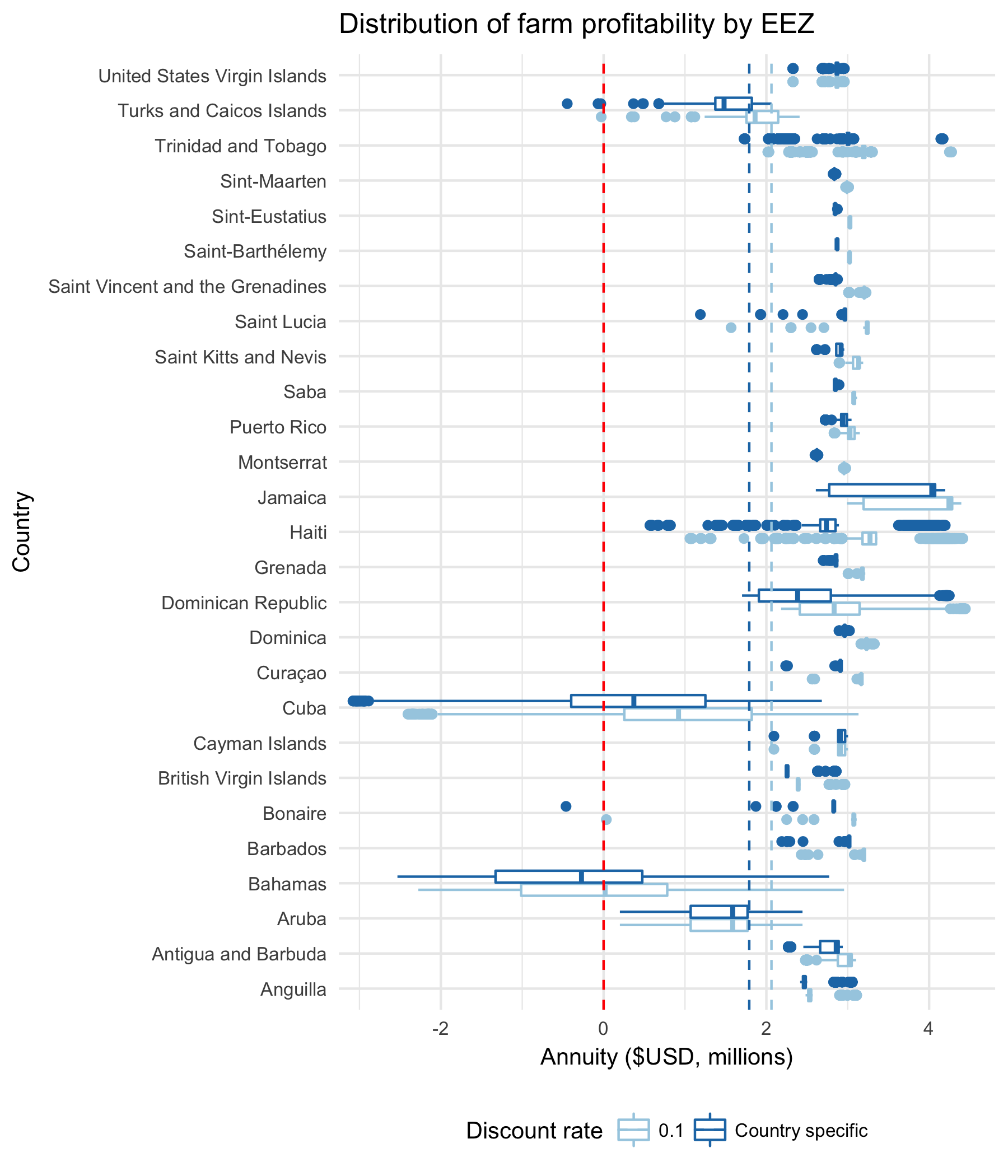


Figure 4: Annualized profits per cobia aquaculture farm by Caribbean EEZ

# Tables

Table 1. Investment risk scores and discount rates by country. A risk score of 1.5 (US Virgin Islands) is used as a baseline for scaling discount rates between 10%-25%

|  |  |  |
| --- | --- | --- |
| Country | Risk score | Discount rate (%) |
| Cayman Islands | 0.53 | 10 |
| Aruba | 1.2 | 10 |
| Martinique | 1.38 | 10 |
| United States Virgin Islands | 1.5 | 10 |
| Anguilla | 1.75 | 12.5 |
| Puerto Rico | 1.87 | 13.7 |
| British Virgin Islands | 1.98 | 14.8 |
| Sint-Maarten | 2.19 | 16.9 |
| Saint-Barthélemy | 2.2 | 17 |
| Bahamas | 2.21 | 17.1 |
| Barbados | 2.25 | 17.5 |
| Antigua and Barbuda | 2.27 | 17.7 |
| Sint-Eustatius | 2.29 | 17.9 |
| Trinidad and Tobago | 2.3 | 18 |
| Saba | 2.49 | 19.9 |
| Turks and Caicos Islands | 2.49 | 19.9 |
| Saint Kitts and Nevis | 2.5 | 20 |
| Guadeloupe | 2.62 | 21.2 |
| Bonaire | 2.67 | 21.7 |
| Saint Lucia | 2.69 | 21.9 |
| Dominica | 2.73 | 22.3 |
| Curaçao | 2.75 | 22.5 |
| Collectivity of Saint Martin | 2.79 | 22.9 |
| Grenada | 2.87 | 23.7 |
| Jamaica | 2.92 | 24.2 |
| Dominican Republic | 2.98 | 24.8 |
| Montserrat | 3.28 | 25 |
| Saint Vincent and the Grenadines | 3.69 | 25 |
| Cuba | 3.85 | 25 |
| Haiti | 4.03 | 25 |

Table 2. Estimated suitable area (km2 by EEZ)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Country | EEZ area (km2) | Suitable area (km2) | % suitable | Profitable area (km2) | % profitable |
| Bahamas | 615,628 | 14,311 | 2.32 | 7,487 | 1.22 |
| Cuba | 350,483 | 2,474 | 0.71 | 2,046 | 0.58 |
| Dominican Republic | 349,786 | 3,290 | 0.94 | 3,290 | 0.94 |
| Jamaica | 256,647 | 4,720 | 1.84 | 4,720 | 1.84 |
| Barbados | 184,865 | 84 | 0.05 | 84 | 0.05 |
| Puerto Rico | 154,335 | 1,515 | 0.98 | 1,515 | 0.98 |
| Cayman Islands | 118,125 | 114 | 0.10 | 114 | 0.10 |
| Antigua and Barbuda | 111,358 | 1,949 | 1.75 | 1,949 | 1.75 |
| Haiti | 102,801 | 1,779 | 1.73 | 1,778 | 1.73 |
| Turks and Caicos Islands | 90,765 | 1,028 | 1.13 | 1,027 | 1.13 |
| Anguilla | 90,017 | 1,221 | 1.36 | 1,221 | 1.36 |
| British Virgin Islands | 81,383 | 1,271 | 1.56 | 1,271 | 1.56 |
| Trinidad and Tobago | 76,273 | 10,186 | 13.35 | 10,186 | 13.35 |
| United States Virgin Islands | 38,130 | 814 | 2.13 | 814 | 2.13 |
| Saint Vincent and the Grenadines | 36,132 | 1,415 | 3.92 | 1,415 | 3.92 |
| Aruba | 29,898 | 946 | 3.16 | 946 | 3.16 |
| Dominica | 28,495 | 242 | 0.85 | 242 | 0.85 |
| Grenada | 25,492 | 1,142 | 4.48 | 1,142 | 4.48 |
| Curaçao | 25,315 | 71 | 0.28 | 71 | 0.28 |
| Saint Lucia | 15,354 | 285 | 1.86 | 285 | 1.86 |
| Bonaire | 12,955 | 43 | 0.33 | 43 | 0.33 |
| Saba | 9,472 | 1,050 | 11.08 | 1,050 | 11.08 |
| Saint Kitts and Nevis | 9,450 | 256 | 2.71 | 256 | 2.71 |
| Montserrat | 7,172 | 74 | 1.03 | 74 | 1.03 |
| Saint-Barthélemy | 4,147 | 7 | 0.18 | 7 | 0.18 |
| Sint-Eustatius | 2,166 | 65 | 3.01 | 65 | 3.01 |
| Sint-Maarten | 452 | 20 | 4.32 | 20 | 4.32 |

Table 3. Supply (MT) and annuity under 4 different scenarios

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Country | Supply (suitable) | Supply (profitable, 10%) | Supply (profitable, country %) | Annuity (suitable) | Annuity (profitable, 10%) | Annuity (profitable, country %) |
| Bahamas | 190.5 | 110.8 | 84.5 | 0.85 | 8.57 | 6.11 |
| Trinidad and Tobago | 175.8 | 175.8 | 175.8 | 37.98 | 37.98 | 35.56 |
| Jamaica | 83.6 | 83.6 | 83.6 | 22.76 | 22.76 | 21.22 |
| Dominican Republic | 56.1 | 56.1 | 56.1 | 11.44 | 11.44 | 9.68 |
| Cuba | 34.9 | 30.5 | 22.9 | 2.37 | 3.2 | 2.01 |
| Antigua and Barbuda | 34 | 34 | 34 | 6.99 | 6.99 | 6.55 |
| Haiti | 31.2 | 31.2 | 31.2 | 7.27 | 7.28 | 6.32 |
| Puerto Rico | 27.2 | 27.2 | 27.2 | 5.68 | 5.68 | 5.51 |
| Saint Vincent and the Grenadines | 25 | 25 | 25 | 5.43 | 5.43 | 4.83 |
| British Virgin Islands | 20.5 | 20.5 | 20.5 | 3.86 | 3.86 | 3.65 |
| Grenada | 20 | 20 | 20 | 4.34 | 4.34 | 3.9 |
| Anguilla | 19.8 | 19.8 | 19.8 | 3.94 | 3.94 | 3.84 |
| Saba | 18.8 | 18.8 | 18.8 | 3.96 | 3.96 | 3.67 |
| Turks and Caicos Islands | 16.7 | 16.6 | 16.6 | 2.51 | 2.51 | 2.04 |
| United States Virgin Islands | 14.4 | 14.4 | 14.4 | 2.85 | 2.85 | 2.85 |
| Aruba | 13.9 | 13.9 | 13.9 | 1.62 | 1.62 | 1.62 |
| Saint Lucia | 5 | 5 | 5 | 1.11 | 1.11 | 1.01 |
| Saint Kitts and Nevis | 4.5 | 4.5 | 4.5 | 0.98 | 0.98 | 0.91 |
| Dominica | 4.3 | 4.3 | 4.3 | 0.95 | 0.95 | 0.87 |
| Cayman Islands | 2 | 2 | 2 | 0.41 | 0.41 | 0.41 |
| Barbados | 1.5 | 1.5 | 1.5 | 0.32 | 0.32 | 0.3 |
| Montserrat | 1.3 | 1.3 | 1.3 | 0.27 | 0.27 | 0.24 |
| Curaçao | 1.2 | 1.2 | 1.2 | 0.27 | 0.27 | 0.25 |
| Sint-Eustatius | 1.2 | 1.2 | 1.2 | 0.24 | 0.24 | 0.23 |
| Bonaire | 0.7 | 0.7 | 0.7 | 0.15 | 0.15 | 0.14 |
| Sint-Maarten | 0.3 | 0.3 | 0.3 | 0.07 | 0.07 | 0.07 |
| Saint-Barthélemy | 0.1 | 0.1 | 0.1 | 0.03 | 0.03 | 0.03 |

# Supplementary Information

#### Risk Adjusted Discount Rate

We modify previously published methodologies to quantify a country’s relative investment risk in the Caribbean, where limited data on economic and political conditions are available. 56 developed the Foreign Investment Risk Matrix (FIRM) to assist investors in classifying the political and economic risks associated with investing in different countries using discrete risk categories. An expanded version of FIRM was developed by McGowan and Moeller57 that utilizes three political and three economic continuous risk variables that are readily available for most countries.

Limited data were available for the risk variables described by McGowan and Moeller57 for Caribbean island countries. Only three countries in our study have data available for the “conflict” variable and only nine have data available for all five of the other McGowan and Moeller risk variables. Therefore, to calculate risk scores for the island countries in our region, we identify comparable, substitute risk variables for each of McGowan and Moeller’s risk variables. We then calculate Pearson’s correlation coefficients and significance vales between McGowan and Moeller’s risk variables and our selected substitute variables using countries with data available for both sets to validate our substitute variables (Table XX). Although there are not enough data for the conflict variable in the Caribbean to calculate a correlation coefficient, we assume WRI’s political stability score to be a logical substitute.

Averages of political and economic variables are calculated by removing any variables for which data are not available for that country. In some cases this means that the only data available to calculate a final relative risk score is GDP per capita. Bhalla (1983) states that GDP per capita is one of the most important variables determining both political and economic risk because income per capita reflects both the underlying economy and the effectiveness of political management. For the 14 countries with data available for all variables, we find GDP to be a significant (r = 0.88, *p*-value = < 0.001) predictor of the final risk score, providing further support for this approach (Figure 1).

For each variable, a country’s rating is determined by transforming the data for that variable to a scale of 1 (low risk) to 5 (high risk) and multiplying by the specified weight to determine the variable’s final score (R x W) (Table 3). Political and economic risk scores are calculated by taking the sum of final scores for all three variables, and the total risk score is calculated by multiplying the political and economic risk scores by the specified weight and summing the values (Table 3). The weights shown in Table 3 were arbitrarily chosen by McGowan and Moeller57. In practice, they recommend weighting variables according to relevance and importance to the particular project that is being assessed. For this analysis, all political and economic variables are given equal weight.

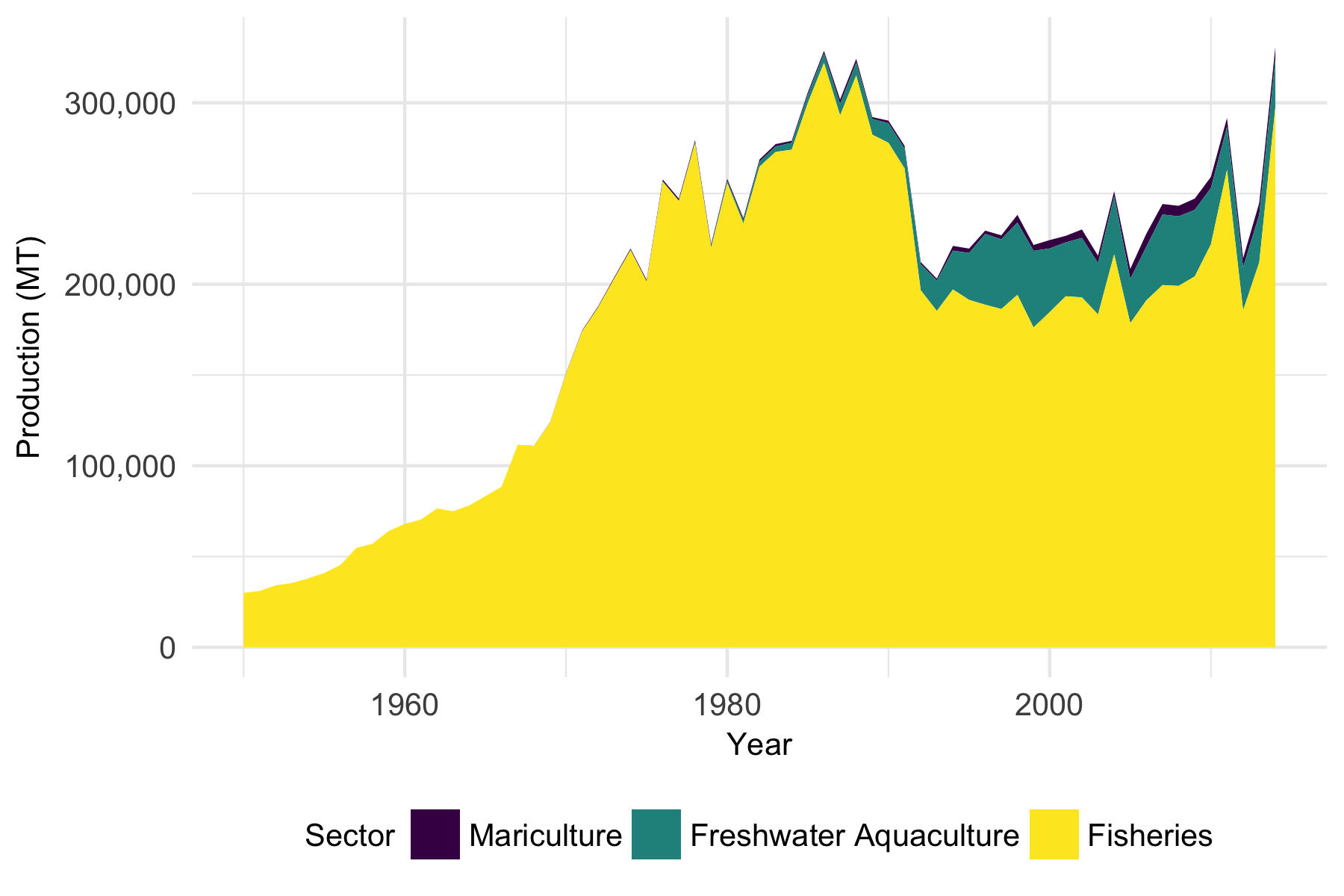


Figure S1. Seafood production in the Caribbean from 1950 - 2016 (data from: FAO 2016)

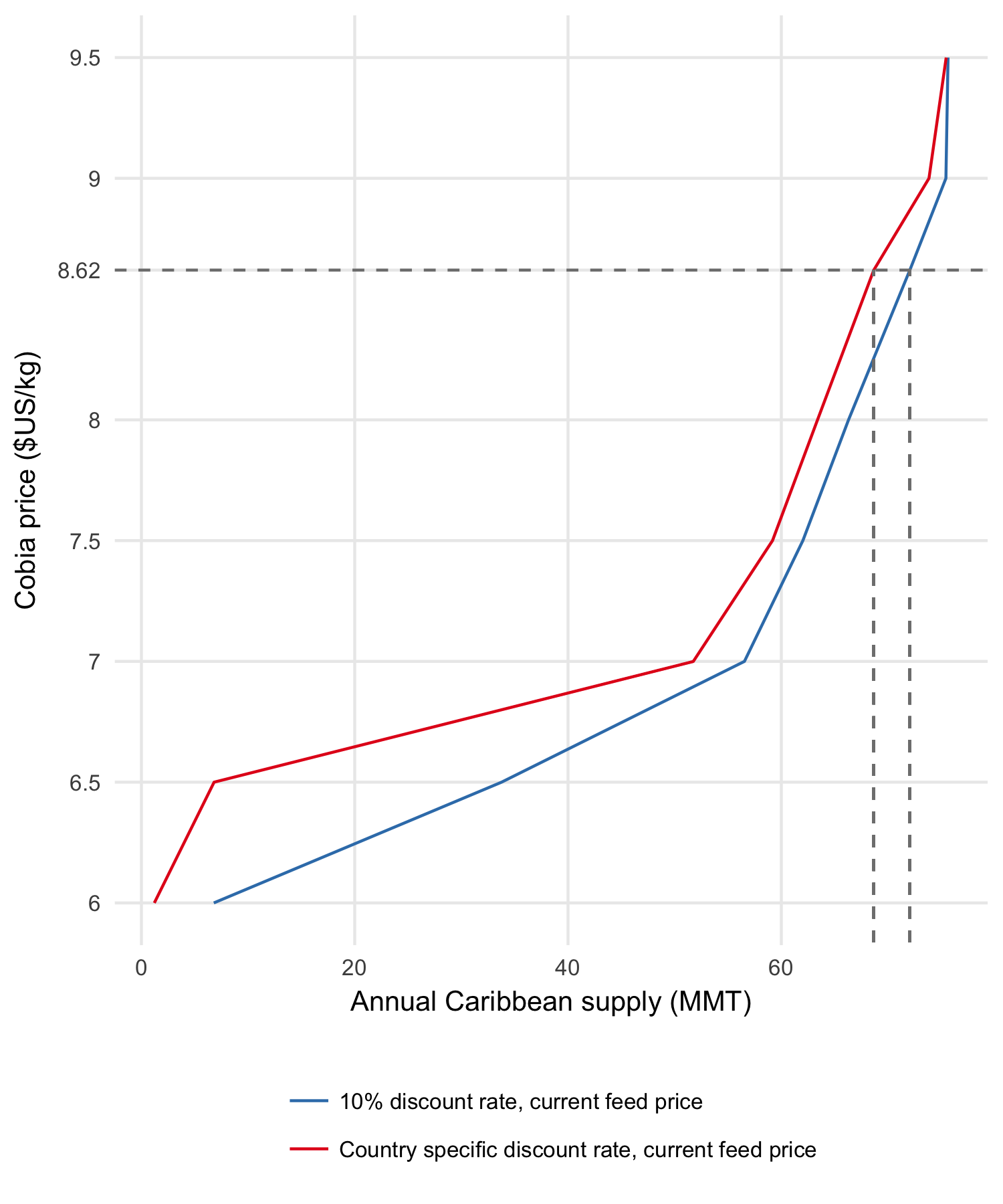


Figure S3. Cobia supply curves under current feed costs ($1.65/kg) and a 10% reduction in feed cost.

Table S1. Description of spatial data layers and criteria used to identify cells suitable for development of offshore aquaculture in the Caribbean

|  |  |  |  |
| --- | --- | --- | --- |
| Layer | Year | Criteria | Source |
| Marine Protected Areas | 2016 | Not an established, designated or proposed Marine Protected Area | IUCN and UNEP-WCMC 2016 |
| Oil Rigs | 2003 | No existing benthic oil structures | Halpern et al. 2008 |
| Shipping | 2005 | Not included in the top 10% of relative shipping activity in the Caribbean | Halpern et al. 2008 |
| Coral Reefs | 2010 | No coral reefs are present in the 1 km2 area | UNEP-WCMC, WorldFish Centre,\_WRI,\_TNC\_2010 |
| Depth | 2009 | Depths >=25 and < = 100 | Kapetsky et al. 2013 |
| Current Velocity | 2005-2015 | Maximum average monthly zonal or meridional current velocity < 1 | ESR 2009 |

Table S2. Model parameters and values for the Thermal Performance Curve, and economic model

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Description | Input | Parameter | Value | Source |
| Thermal performance curve | Minimum temperature for cobia growth | Tmin | 22 ℃ | Klinger et al. 2017 |
| Thermal performance curve | Optimal temperature for cobia growth | To | 29 ℃ | Klinger et al. 2017 |
| Thermal performance curve | Maximum temperature for cobia growth | Tmax | 32 ℃ | Klinger et al. 2017 |
| Thermal performance curve | Average monthly temperature in each cell | Tt,i | Variable | Calculated in study using data from NASA 2014 |
| Thermal performance curve | Individual growth of cobia | G | Variable | Calculated in study |
| Thermal performance curve | slope parameter | a1 | 0.017 kg/month/℃ | Klinger et al. 2017 |
| Thermal performance curve | slope parameter | a2 | -0.17 kg/month/℃ | Klinger et al. 2017 |
| Thermal performance curve | intercept parameter | b1 | -1.6 kg/month | Klinger et al. 2017 |
| Thermal performance curve | intercept parameter | b2 | 5.3 kg/month | Klinger et al. 2017 |
| Growth Model | mothly individual fish weight at each farm | wi,t | Variable | Calculated in study |
| Growth Model | Number of hypothetical growout cycles over 10 years at each farm | gi | Variable | Calculated in study |
| Growth Model | Optimal stocking density | n\* | Variable | Calculated in study |
| Growth Model | Number of stocked cages | Ci | Variable | Calculated in study |
| Growth Model | Total monthly biomass at each farm | Bi,t | Variable | Calculated in study |
| Economic Model | Initial capital expenditures | Ei | $4,473,547.00 | Calculated based on average farm depth and capital expenditure costs in Lipton and Kim 2007 and Bezerra et al. 2016 |
| Economic Model | Installation costs | Ii | $52,563 | Calculated based on average farm depth and installation costs from Bezerra et al. 2016 |
| Economic Model | Permit/Least price | P | $3,265.00/km2 | Bezerra et al. 2016 |
| Economic Model | fuel efficiency |  | 3.219 km/g | Lester et al. 2018 |
| Economic Model | Fingerling price | F | $2.58/fingerling | Bezerra et al. 2016 |
| Economic Model | Feed price | F | $1.68/kg | Bezerra et al. 2016 |
| Economic Model | EEZ specific hourly wage of farm workers | sz | Variable | See Table S3b |
| Economic Model | EEZ specific fuel price | gz | Variable | See Table S3b |
| Economic Model | Total costs for each farm | Ti | Variable | Calculated in study |
| Economic Model | Start up costs for each farm | SCi | Variable | Calculated in study |
| Economic Model | Initial capital expenditures for each farm | Ei | Variable | Calculated in study |
| Economic Model | Monthly operating cost for each farm | Oci,t | Variable | Calculated in study |
| Economic Model | Monthly labor and maintenance costs for each farm | Li,t | Variable | Calculated in study |
| Economic Model | Farm distance from shore | di | Variable | Calculated in study |
| Economic Model | Cobia price | p | $8.64/kg | Bezerra et al. 2016 |
| Economic Model | Fixed discount rate | d | 10.60% | Ruiz-Campo et al. 2018 |
| Economic Model | EEZ specific disount rate | dEEZ | Variable | See Table S3b |
| Economic Model | Monthly farm revenue | Ri,t | Variable | Calculated in study |
| Economic Model | Total farm profit | i | Variable | Calculated in study |
| Economic Model | Net Present Value | NPVi | Variable | Calculated in study |

Table S3a. EEZ specific economic model parameters

|  |  |  |
| --- | --- | --- |
| Country | Cost Model Parameters |  |
|  | Fuel price (US$/g) | Wage (US $/hr) |
| Anguilla | 1.27 | 1.5 |
| Antigua and Barbuda | 1.02 | 3.04 |
| Aruba | 0.99 | 5.4 |
| Bahamas | 1.12 | 5.25 |
| Barbados | 1.39 | 3.13 |
| Bonaire | 1 | 4.7 |
| British Virgin Islands | 0.89 | 6 |
| Cayman Islands | 1.16 | 7.32 |
| Collectivity of Saint Martin | 0.86 | 0.05 |
| Cuba | 1.34 | 4.58 |
| Curacao | 0.85 | 1.5 |
| Dominica | 0.93 | 0.41 |
| Dominican Republic | 1.19 | 1.67 |
| Grenada | 1.17 | 3.63 |
| Guadeloupe | 1.44 | 0.31 |
| Haiti | 0.77 | 1.33 |
| Jamaica | 0.92 | 3.63 |
| Martinique | 1.49 | 2.78 |
| Montserrat | 1.61 | 7.25 |
| Puerto Rico | 0.7 | 5.09 |
| Saba | 1.06 | 2.96 |
| Saint Kitts and Nevis | 0.95 | 1.85 |
| Saint Lucia | 0.89 | 1.54 |
| Saint Vincent and the Grenadines | 0.86 | 3.63 |
| Saint-Barthlemy | 1.06 | 3.63 |
| Sint-Eustatius | 1.06 | 5.14 |
| Sint-Maarten | 1.08 | 4.9 |
| Trinidad and Tobago | 0.53 | 2.21 |
| Turks and Caicos Islands | 1.28 | 6.25 |
| United States Virgin Islands | 0.88 | 8.35 |

Table S3b. Sources of EEZ specific economic model parameters

|  |  |  |
| --- | --- | --- |
| Country | Fuel Price Source | Wage Source |
| Anguilla | <https://www.expatistan.com/cost-of-living/the-valley-anguilla?currency=USD> | <https://books.google.com/books?id=fsB3DAAAQBAJ&pg=PA27&lpg=PA27&dq=anguilla+minimum+wage&source=bl&ots=6sDxkXKjDB&sig=gsUjbVP0mRBiQng5auLjv4VAqnU&hl=en&sa=X&ved=0ahUKEwjs6sza3uDRAhVH3mMKHfdiCh04ChDoAQgZMAA#v=onepage&q=anguilla%20minimum%20wage&f=false> |
| Antigua and Barbuda | <http://www.globalpetrolprices.com/Antigua-and-Barbuda/gasoline_prices/> | <http://antiguaobserver.com/minimum-wage-increase-takes-effect-in-november/> |
| Aruba | <http://www.globalpetrolprices.com/Aruba/gasoline_prices/> | <http://www.loc.gov/law/foreign-news/article/aruba-increased-minimum-wage-and-wage-limit-for-benefits/> |
| Bahamas | <http://www.globalpetrolprices.com/Bahamas/gasoline_prices/> | <http://www.jamaicaobserver.com/latestnews/Bahamas-Gov-t-increases-minimum-daily-wages> |
| Barbados | <http://www.globalpetrolprices.com/Barbados/gasoline_prices/> | <https://www.state.gov/j/drl/rls/hrrpt/humanrightsreport/index.htm#wrapper> |
| Bonaire | <http://www.curoil.com/main/index.aspx> | <http://www.doingbusinessdutchcaribbean.com/bonaire/employment/minimum-wages> |
| British Virgin Islands | <http://www.globalpetrolprices.com/British-Virgin-Islands/gasoline_prices/> | <http://www.bvi.gov.vg/media-centre/minimum-wage-increase-effective-october-1> |
| Cayman Islands | <http://www.globalpetrolprices.com/Cayman-Islands/gasoline_prices/> | <https://caymannewsservice.com/2016/02/cabinet-rubber-stamps-minimum-wage/> |
| Collectivity of Saint Martin | <http://www.sint-maarten.net/St-Maarten-IslandInfo/stmaarten_IslandInfo.html> | <http://www.ecotripsos.com/lowestminimumwage/> |
| Cuba | <http://www.globalpetrolprices.com/Cuba/gasoline_prices/> | <http://curacaochronicle.com/local/minimum-wages-adjusted/> |
| Curacao | <http://www.curoil.com/main/index.aspx> | <http://dominicanewsonline.com/news/homepage/news/business/dominicas-minimum-wage-lowest-in-oecs-report/> |
| Dominica | <http://dominicanewsonline.com/news/homepage/news/business/gasoline-price-drops-below-10-biggest-fuel-price-drop-in-five-years/> | <https://www.state.gov/j/drl/rls/hrrpt/humanrightsreport/index.htm#wrapper> |
| Dominican Republic | <http://www.globalpetrolprices.com/Dominican-Republic/gasoline_prices/> | <https://www.state.gov/j/drl/rls/hrrpt/humanrightsreport/index.htm#wrapper> |
| Grenada | <http://www.globalpetrolprices.com/Grenada/gasoline_prices/> | Average wage across all EEZs |
| Guadeloupe | <http://www.guadeloupe.pref.gouv.fr/Actualites/Revision-des-prix-des-produits-petroliers-en-Guadeloupe-novembre-2016> | <http://www.haitilibre.com/en/news-10972-haiti-economy-everything-you-need-to-know-about-the-new-minimum-wage.html> |
| Haiti | <http://www.globalpetrolprices.com/Haiti/gasoline_prices/> | <http://jis.gov.jm/minimum-wage-rates-effective-march-1/> |
| Jamaica | <http://www.globalpetrolprices.com/Jamaica/gasoline_prices/> | Average wage across all EEZs |
| Martinique | <http://martinique.dieccte.gouv.fr/Derniere-revision-mensuelle> | <http://www.caribank.org/uploads/2012/12/Montserrat-2009-vol-1_v7.pdf> |
| Montserrat | <https://www.stlucianewsonline.com/govt-announce-adjustment-in-fuel-prices/> | <http://money.cnn.com/2016/03/31/investing/puerto-rico-congress-bill/> |
| Puerto Rico | <http://www.globalpetrolprices.com/Puerto-Rico/gasoline_prices/> | <http://www.doingbusinessdutchcaribbean.com/saba/employment/minimum-wages> |
| Saba | Average fuel price across all EEZs | <https://www.stlucianewsonline.com/st-kitts-and-nevis-minimum-wage-highest-in-the-oecs-st-lucia-at-4/> |
| Saint Kitts and Nevis | <http://www.globalpetrolprices.com/Saint-Kitts-and-Nevis/gasoline_prices/> | <https://www.stlucianewsonline.com/st-kitts-and-nevis-minimum-wage-highest-in-the-oecs-st-lucia-at-4/> |
| Saint Lucia | <http://www.globalpetrolprices.com/Saint-Lucia/gasoline_prices/> | <https://www.stlucianewsonline.com/st-kitts-and-nevis-minimum-wage-highest-in-the-oecs-st-lucia-at-4/> |
| Saint Vincent and the Grenadines | <http://www.globalpetrolprices.com/Saint-Vincent-and-the-Grenadines/gasoline_prices/> | Average wage across all EEZs |
| Saint-Barth\_lemy | Average fuel price across all EEZs | Average wage across all EEZs |
| Sint-Eustatius | Average fuel price across all EEZs | <http://www.doingbusinessdutchcaribbean.com/st-eustatius/employment/minimum-wages> |
| Sint-Maarten | <http://smn-news.com/st-maarten-st-martin-news/18471-fuel-price-changed.html> | <http://www.doingbusinessdutchcaribbean.com/st-maarten/employment/minimum-wages> |
| Trinidad and Tobago | <http://www.globalpetrolprices.com/Trinidad-and-Tobago/gasoline_prices/> | <http://www.newsday.co.tt/news/0,204964.html> |
| Turks and Caicos Islands | <https://activecaptain.com/fuelLists/fuelIndexROW.php?co=TC&sort=gas> | <http://magneticmediatv.com/2015/05/minimum-wage-in-effect-for-turks-and-caicos/> |
| United States Virgin Islands | <https://secure.dlca.vi.gov/license/Asps/NewsSurvey/RenderDoc.aspx?id=%20147&ftype=PDF#toolbar=1&navpanes=1&scrollbar=0> | <http://viconsortium.com/breaking-news/minimum-wage-increase-8-35-takes-effect-u-s-virgin-islands/> |

Table S4. Suitable area available for potential offshore mariculture development for each spatial data layer used in our suitability analysis

|  |  |  |  |
| --- | --- | --- | --- |
| X | Layer | Suitable.Area..km.2. | X..of.Study.Area |
| 1 | Study area | 3e+06 | 100 |
| 2 | Oil platform presence | 3e+06 | 100 |
| 3 | Coral presence | 3e+06 | 100 |
| 4 | Current speed | 2811562 | 95 |
| 5 | MPA presence | 2779548 | 94 |
| 6 | High shipping activity | 2641628 | 89 |
| 7 | Depth | 63753 | 2.1 |
| 8 | Final suitable area | 50381 | 1.7 |

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