Charting an Aquaculture Future for the Caribbean

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# Abstract

The development of 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. However, when located close to shore, aquaculture’s environmental impacts can jeopardize valuable habitats (e.g., mangroves, coral reefs, seagrass beds) and competition for coastal space can lead to conflicts with fisheries, tourism, and other uses. Farming further offshore is a possible option for alleviating these stresses. Using high-resolution environmental and economic data, we develop a spatial bio-economic model to identify suitable areas throughout the Caribbean for offshore finfish aquaculture, parameterized based on a species with considerable market potential, cobia (*Rachycentron canadum*). We estimate potential outcomes in terms of yields and profits under different market scenarios. We find that 50,373 km2 (1.7%) of marine space in the Caribbean is technically feasible for cobia aquaculture, with the potential to produce a total of 80.5 million metric tons (MMT) of seafood annually, an amount roughly equal to the total global production from capture fisheries (~80 MMT). Of this area, 43,120 km2 (1.45%) is economically viable given our estimates of current production costs, with the potential to produce 0.4 MMT of cobia annually. Areas associated with the highest relative economic potential were Jamaica, Trinidad and Tobago, and Haiti. The variability of farm-scale production and value, and thus the importance of site selection, differed across countries. Offshore aquaculture is a capital-intensive activity mediated by socioeconomic conditions, such as foreign investment risk and market dynamics. Accounting for these risk factors considerably lowered production in our analysis and may help explain the current lack of commercial offshore aquaculture in the Caribbean despite favorable conditions. The results of this research can be used to help prioritize areas in the Caribbean for offshore cobia aquaculture development and serve as a framework for identifying priority areas for offshore aquaculture of other species.

# Introduction

Global seafood production is expected to exceed 151 million tons by 2030 to meet growing demands, a 10% increase over current levels (Kobayashi et al. 2015; FAO 2016). The vast majority of new production must come from aquaculture given only modest potential increases from capture fisheries (Costello et al. 2016). Aquaculture seems poised to meet this challenge as the fastest growing food production sector globally, surpassing wild fisheries production for the first time in 2014 (FAO 2016). Marine aquaculture, or mariculture, is seen as having particularly strong growth potential (Merino et al. 2012). 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 m (Froehlich et al. 2017), is expected to increase (FAO 2016). By moving to deeper waters further from the coast, offshore aquaculture could be a viable strategy to minimize aquaculture’s adverse environmental and socioeconomic consequences (**???**; Froehlich et al. 2017). Additionally, production potential in the offshore realm far exceeds seafood demand for the foreseeable future (Kapetsky, Aguilar-Manjarrez, and Jenness 2013; Gentry, Froehlich, et al. 2017). 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 a regional level, 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 development (Van Wyk and Davis 2006; Creswell 5AD–2007; CRFM 2014; Pérez-Ramírez 2017). In 2014, the Caribbean produced 330,704 MT of seafood, 90% of which came from capture fisheries. Currently, over 88% of seafood consumed in the Caribbean is from wild capture fisheries (FAO 2016). To meet seafood demand in the region, over 144,000 MT of seafood, valued at over 196 million $USD, is imported annually (Nguyen and Jolly 2010; FAO 2016). Furthermore, seafood consumption per capita in the Caribbean is projected to increase rapidly over the next decade (22%)(FAO 2016). Wild fisheries production in the region is unlikely to play a meaningful role in decreasing exports or meeting growth in demand because of overfishing, degradation of coral ecosystems, and climate change (Burke et al. 2011; Pérez-Ramírez 2017). 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 residents (Hernández-Rodríguez et al. 2001), and promote a seafood industry that is more resilient to the effects of climate change (Pérez-Ramírez 2017).

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*) (Lovatelli et al. 2013). 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 resources (Alvarez-Lajonchère and Ibarra-Castro 2013). 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 areas (Gentry, Lester, et al. 2017). For example, coastal aquaculture can harm mangroves and coral reefs by increasing nutrient loads and causing physical damage to the habitat from farm infrastructure (Benetti et al. 2006; Gentry, Lester, et al. 2017), with cascading effects on marine-based tourism, the backbone of many Caribbean island economies (Benetti et al. 2006). Offshore aquaculture could be a promising alternative (D. D. Benetti, Benetti, et al. 2010; Gentry, Froehlich, et al. 2017), and recently developed submersible cages will allow aquaculture to be developed in areas that were previously considered unsuitable due to waves, water depths and/or high risk of damage from large storms and hurricanes (D. D. Benetti, Benetti, et al. (2010)).

Environmental conditions in the Caribbean such as relatively small seasonal fluctuations in ocean temperature 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 Rico (D. D. Benetti, O’Hanlon, et al. 2010). 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 temperature (Alvarez-Lajonchère and Ibarra-Castro 2013; D. D. Benetti, O’Hanlon, et al. 2010; Estrada et al. 2016). The largest open ocean mariculture farm in the world, Open Blue, has been successfully culturing cobia off the Caribbean coast of Panama since 2007.

The global potential for aquaculutre is large in terms of suitable area (Gentry, Froehlich, et al. 2017) and careful marine spatial planning can improve outcomes across multiple economic and environmental objectives (Lester et al. 2018). 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, as a case study. 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 amount of seafood 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., biophysical conditions, regulatory environment, capital investment, expertise, etc.). Our approach could be applied to other farmed species or applied to other regions, and our results can help to chart a course for a sustainable and economically prosperous offshore mariculture industry in the Caribbean.

# Methods

## Study Region and Overview

Our study domain includes the territorial waters and 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 for the 28 island countries in our study are are defined using data from Flanders Marine Institute (2011) 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 biomass (*t*) and Net Present Value (NPV), for offshore cobia mariculture in the Caribbean region. The first steps of our analysis are to identify 1 km2 sites throughout the study region that may be suitable for mariculture development and create a hypothetical farm design to apply to all suitable sites. Next, we apply a thermal performance curve (TPC) to predict temperature-dependent growth and thus production of cobia at each farm. We establish supply curves to determine national and Caribbean-wide cobia production that would be achieved under several scenarios of cobia price, production costs, and investment risk. Finally, we use our production model and estimated economic parameters to calculate NPV over a 10 year time horizon and examine production and revenue outcomes under the assumption that only farms that have a positive NPV will be developed.

## Suitability Assessment

We identified 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 (Table S1). We defined suitable thresholds for each factor and used 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.

We use physical specifications listed by the original manufacture of SeaStation cages to define our thresholds for areas that are technically feasible for offshore maricuture. SeaStation cages are submersible, self-tensioned, single rim cages and are currently the most widely used offshore mariculture cages in the U.S. (Loverich 2010). The minimum site 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/s (OceanSpar 2013). 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 (Kapetsky, Aguilar-Manjarrez, and Jenness 2013). We use spatial bathymetry data from Becker et al (2009) to identify areas within a suitable depth range and determine the absolute maximum zonal and meridional current velcocities using data on daily averages over a 10-year period (2005 - 2015) from ESR (2009) 15to identify areas that are technically feasible for offshore maricuture development.

Offshore mariculture farms can be associated with increased nutrient levels in the water column and along the benthos from fish waste in the vicinity of the cages (Lovatelli et al. 2013). Nutrient pollution from fish farms can be associated with algal blooms, reduced water quality and clarity, and low oxygen conditions, all of which can be damaging to coral reef ecosystems (Holmer 2010). Using data from (2010) on locations of coral reef habitat, we excluded these areas from offshore mariculture development. Additionally, we excluded areas within designated marine protected areas (MPAs) and conservation priority areas (IUCN and UNEP-WCMC 2017).

To account for potential conflicts with other ocean uses in offshore areas, we consider shipping, structures used for oil drilling, and areas licensed for deep sea mining exploration as potential offshore activities that may conflict with aquaculture development. We exclude areas that fall within 10% of the highest relative shipping activity locations and areas with benthic oil structures (data sources) using spatial data from Halpren (**???**), assuming they are not suitable for offshore mariculture development.

## Growth Model

Temperature is one of the primary abiotic factors controlling growth in ecotherms, including cobia (Brett 1979), and obviously cannot be easily controlled in offshore mariculture farms (Tidwell 2012). To reflect spatial differences in productivity across farms caused by temperature variations, we use 10 years of remotely-sensed sea surface temperature (SST) data (NASA Goddard Space Flight Center, Ocean Ecology Laboratory, and Ocean Biology Processing Group 2014) 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 site.

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-growth parameters for cobia are presented in Table SX and were adopted from (Klinger, Levin, and Watson 2017), who also used a TPC to model cobia growth.

Individual cobia growth at month for site () is estimated using the TPC for all 120 months in the SST time series. The 10 year () average individual growth () at site is then calculated for each calendar month :

We model offshore aquaculture potential in the Caribbean by coupling site specific estimates of average monthly cobia growth from the TPC model with a detailed farm design and economic model parameterized with values from the literature and technical reports. For each site, we calculate the projected net present value (NPV) over a 10 year period from the discounted stream of costs and revenues. We then limit our discussion of results to only include farms (1 km2 sites) with a positive NPV under the assumption that only profitable farm locations would be developed.

To estimate production, we assume a 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 cages (Fredriksson et al. 2004; Xu, Zhu, and Miao 2015). The cages are held in position by the mooring system at depths of 15-20 m below the surface(Loverich 2010). We develop a farm design for a 1 km2 area using the total cage volume to farm area ratio of offshore mariculture farms currently operating off the coast of Kona, Hawaii (Sims, n.d.) and the Gulf of Maine (Fredriksson et al. 2004). Our hypothetical farm has 16 SeaStation cages (each 6,400 m3) configured in two eight-cell grid mooring systems, for a total cage volume of 102,400 m3 per individual farm. The infrastructure of the farm has a footprint of ~0.48 km2, which meets the guidelines issued in NOAA’s Fishery Management Plan (FMP) 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 infrastructure (GMFMC (Gulf of Mexico Fishery Management Council) and NOAA (National Oceanic and Atmospheric Administration) 2009).

Individual cobia growth at month for site () is modeled using the previously calculated 10 year () average individual growth () at site for calendar month . Fingerlings are stocked at an initial weight of 15 grams and fish weight () in month at site 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 have estimated a total 12 month survival rate of 75% for cobia raised in offshore cages in the Caribbean (**???**; Huang et al. 2011). A cage at site is harvested when individual fish have grown to a harvestable size of 5 - 6 kg.

D. D. Benetti, O’Hanlon, et al. (2010) suggest as a target harvest density for sustainable offshore mariculture. Because growth rates vary across farm sites and all sites are assumed to experience an instantaneous mortality rate of 0.024, we calculate the optimal initial number of stocked fingerlings ().The number of fingerlings stocked in each cage is optimized at the level that achieves the target harvest density () at the time fish reach the final harvest weight of 5 kg, or 19,200 fish per cage.

The optimal stocking number () for each site is estimated using the historical SST timeseries. The number of hypothetical completed grow out cycles (), wherein a cobia is raised from an initial stocking weight of 0.15 g to a final harvest weight of 5 kg, is calculated for each site by first dividing the cumulative individual growth over the 120 month timeseries by the target harvest weight.

The average number of months per grow out cycle () is then calculated as . Given and the target harvest of 19,200 5 kg fish, the optimal number of fingerlings () to stock can be estimated for each site as follows:

Total site biomass in each month () is a function of the number of stocked cages , initial stocking number , and the instantaneous mortality rate:

Where is the number of stocked cages at site , is the weight of individual fish in cage in month , and is the initial number of fish stocked per cage at site .

## 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 S3a) while others are a function of EEZ (Table S3b) and/or vary by site within an EEZ. Costs of aquaculture infrastructure and installation increase with depth and distance from shore (Nations and United 2007). Start-up costs, which include initial capital expenditures () and installation costs (), were varied as a function 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 equitment required for installing the culture system. A 10% increase in cage and installation costs are assigned to sites with depths greater than 50 m to account for a more complex and time consuming installation procedure in deeper water (Lester et al. 2018). 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 () at site in month are modeled as follows:

Where 2,720 is the total monthly labor hours required at 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 fingerlings stocked in month () plus the total cost of feed. Feed cost is based on a feed price of $1.68/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 cobia, which we assume to be 5 kg. Thus, farms only earn revenue in months where individual fish weight () reaches 5 kg. In these months, farm revenue is a function of harvest biomass (, kg) and cobia price (), , otherwise . 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 comparing with national statistics, NPV is annualized by calculating the corresponding annuity payment:

Production and annuity values for each EEZ are examined under two main scenarios: 1. “Suitable”, where farms are developed in all areas that are technically suitable, and 2. “Profitable”, where only farms with a positive 10-year NPV at the current price of cobia are developed.

Defining appropriate discount rates in bioeconomic models is often difficult and depends on many factors, particularly the cost of capital and project risk (Stanley 1990). As a result, we also examine two different discount rate assumptions. First, we assume a fixed discount rate of 10% across all farms, which is based on the average discount rate of 10.6% found in a meta-analysis of published bioeconomic models for aquaculture from the last 25 years (Ruiz Campo and Zuniga-Jara 2018). However, lack of foreign investment due to perceived financial risk has been identfied as a major barrier to aquaculture development in the Caribbean (**???**). 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 indicators (Bhalla 1983). We applied the Foreign Investment Risk Matrix (FIRM) developed by Bhalla (1983) and modified by McGowan Jr and Moeller (2009), which utilizes three political and three economic continuous risk variables that are readily available for most countries (Table S2b). Risk scores were then used to scale EEZ-specific discount rates (Table 1) ranging from 10% to 25%, which aligns with the range of discount rates found in the literature of bioeconomic modelling of aquaculture (Ruiz Campo and Zuniga-Jara 2018).

# Results

## Suitability

Accounting for technical, environmental and use conflict constraints, we identified 50,373 km2 of ocean space (1.7% our study region) potentially suitable for the development of offshore mariculture (Figure 1). Depth was the largest constraining factor in the suitability analysis, as 97.85% of our study area fell outside the depth range (25 - 100 m) that we considered technically feasible for offshore farm infrastructure. By comparison, our second largest constraining factor was shipping activity, which only excluded 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 next largest 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 (Table 2; Figure 1). Overall, Trinidad and Tobago had the largest percentage of their EEZ identified as suitable (13.3%), followed by Saba (11.1%). Suitable areas accounted for < 5% of total EEZ area for all other Caribbean islands and no suitable areas were found in Martinque, St. Martin, and Guadeloupe because of the conservation status of otherwise suitable sites (Table 2).

## Cobia production

Ignoring economic constraints, the Caribbean’s potential to produce cobia from mariculture is extremely large, with an approximate annual production from all suitable sites of 0.4 MMT. The median cobia farm occupying a 1-km2 site in the Caribbean yields an annual supply and value (annuity) of 2,879,746 MT and $2,879,746, respectively. 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, these countries do not neccessarily have the most productive farms (Figure 2). Cobia growth is a function of temperature and growth rates (kg/month) vary across EEZs, showing a clear seasonal pattern (Figure 3). As a result, the most productive farm sites lie 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). Interstingly, 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 complete 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. 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 (REF). FCRs of cobia farms in our analysis ranged from 1.9078052 to 9.9733948, with a median FCR of 2.4606309. These findings accord with the literature, in which FCRs for cobia range from 1.5-3 . 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 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 0.4 MMT when only considering supply from profitable farm sites. In terms of value, farms in most countries were profitable and this result was robust to the discount rate (Figure 4). Only the Bahamas and Cuba contained a considerable number of unprofitable farm sites, with the median Bahamian farm unprofitable if assessed with a 10% discount rate. Farm annuity value is tightly clustered around $3 million for many countries, suggesting site selection is less of a concern in these areas. However, farms in Turks and Caicos, Jamaica, the Dominican Republic, Cuba, the Bahamas, and Aruba vary considerably in value and site selection is thus a critical factor for prospective cobia farms (Figure 4).

# Discussion

The potential for mariculture development in the Caribbean region has not previously been systematically and thoroughly assessed (CRFM 2014). Previous studies have examined the production potential of mariculture at large spatial scale in terms of suitable space using biological and environmental data (@Kapetsky2013; @Gentry2017), or estimated economic potential of offshore mariculture at the farm level using bioeconomic models [@Kam2003; @Shamshak2009; @Kaiser2010; @Bezerra2016;]. Our study presents a framework for incorporating biological, environmental, economic, and political data to estimate production and economic potential at a regional scale. Our results highlight the large economic and production potential for offshore mariculture in the Caribbean and the importance of spatial planning to achieve optimal economic results, and here we discuss factors that are potentially currently limiting mariculture development in the region.

The total annual production of 0.4 MMT possible from all suitable areas in the Caribbean is two orders of magnitude larger than total current seafood production in the region (~300,000 MT) and approximately equal to the total annual harvest from the world’s capture fisheries (~80 MMT). Impressively, this output requires just 1.7% of the Caribbean’s marine space, a result similar to that of (2017) who estimated that current total landings could be produced from 0.015% of global ocean area. In fact, the Caribbean could match its current seafood production using just 178.8 km2 (0.006%) of its marine space.

1) estimate the offshore mariculture production capacity of the Caribbean region (in terms of amount of seafood 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., biophysical conditions, regulatory environment, capital investment, expertise, etc.).

Our results indicate that space for offshore development in the Caribbean is not a limiting factor, however, once economics are incorporated, the placement of farms can have a large impact on profitabilty, highlighting the importance of strategic spatial planning. EEZs with highest total production are not necessarily the most profitable, and profitability varies significantly across, and in some cases, within EEZs. This is particularly true for the Bahamas, which is associated with the highest potential in terms of production to large areas of suitable space, the EEZ as a whole experiences negative profits when economics are in are considered due to the longer harvest cycle length associated with cooler temperatures, which translates to higher costs associated with feed and mortality. The large variability in profitability across EEZs highlights the importance of spatial planning for mariculture development at the regional level. Strategic site selection for mariculture development is particularly important in EEZs that show high variability in farm level profitatbility such as Cuba, Bahamas, Aruba, and the Dominican Republic.

EEZs with more farm to farm variability in outcomes represent countries where strategic site selection is particularly important.

* We should then return to the three questions posed at the end of the intro and maybe spend a paragraph talking about each, particularly in the context of “charting an aquaculture future for the Caribbean.” The last question is about barriers to development, which is where we could spend some time talking about Bess results. We still may want to consider integrating her work into the methods and results as well, unless you think the paper is better and tighter as is.
* Other topics we could cover: o Model/analysis caveats: things we could have done better; where we are most uncertain about assumptions or parameter values o Applicability of model to other species or other locations o How our results could be used to guide policy and investment in the region

# Figures

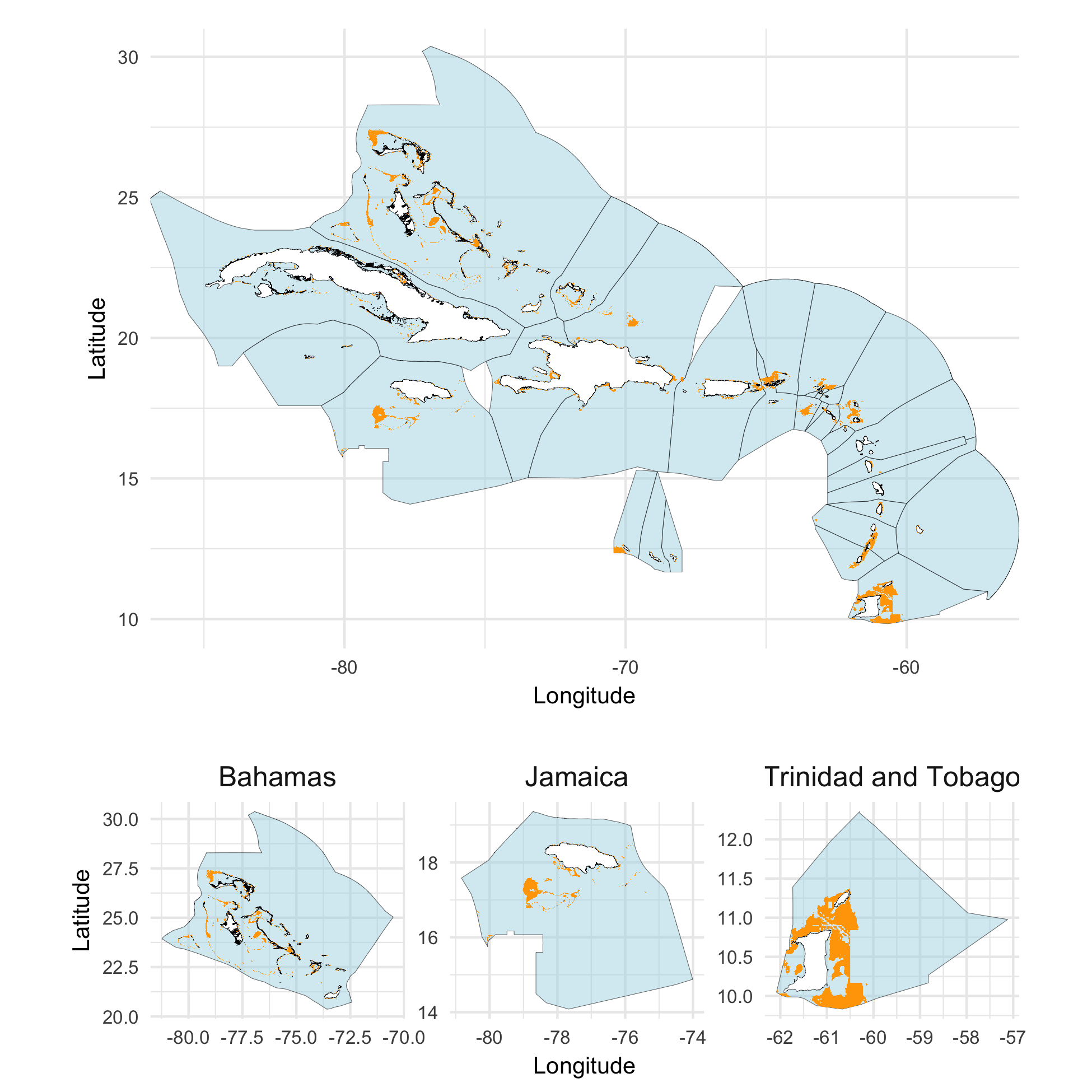


Figure 1. Suitable areas (orange) for offshore cobia mariculture in the Caribbean.

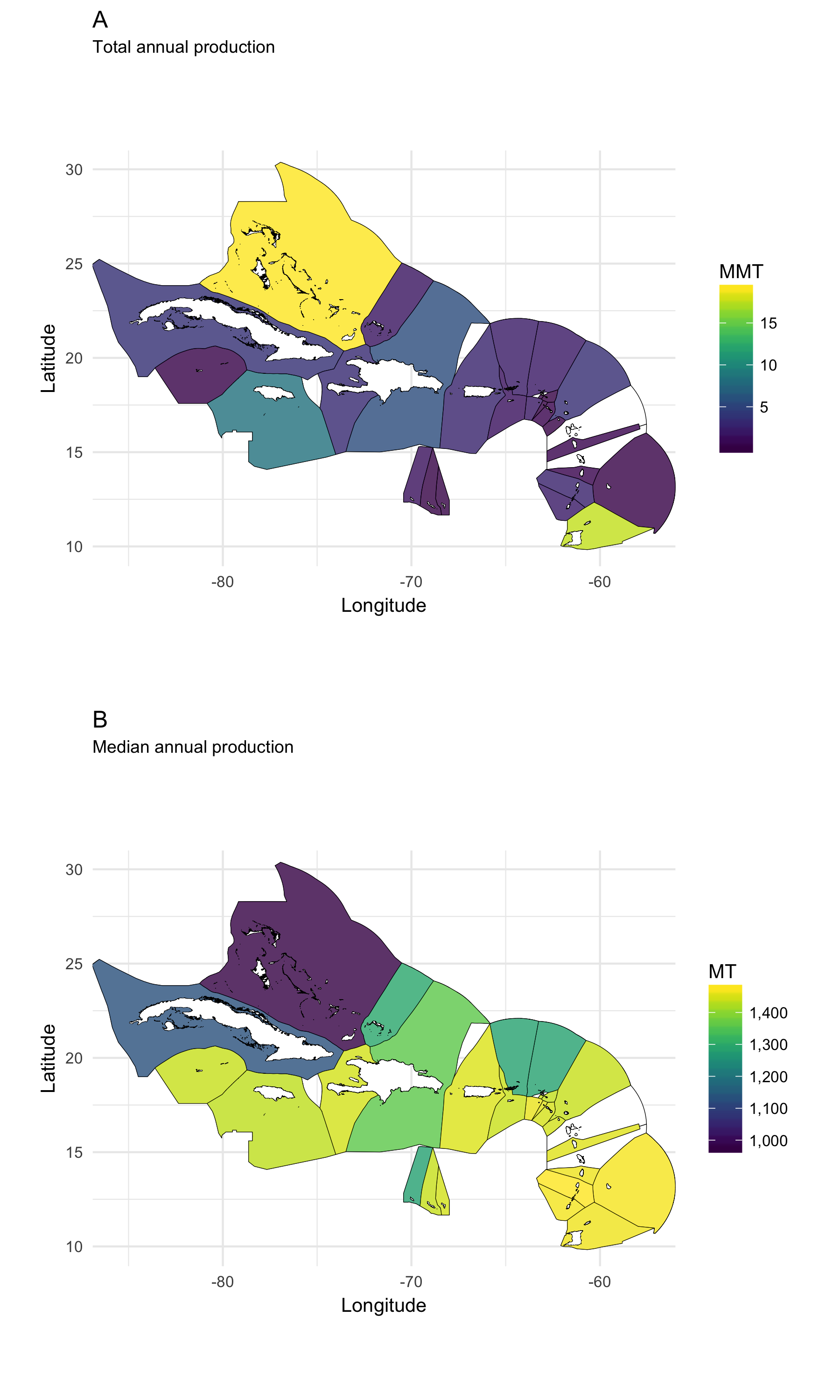


Figure 2. Estimated total annual production of cobia from all suitable farm sites (panel A) and median production from only profitable farm sites (panel B)

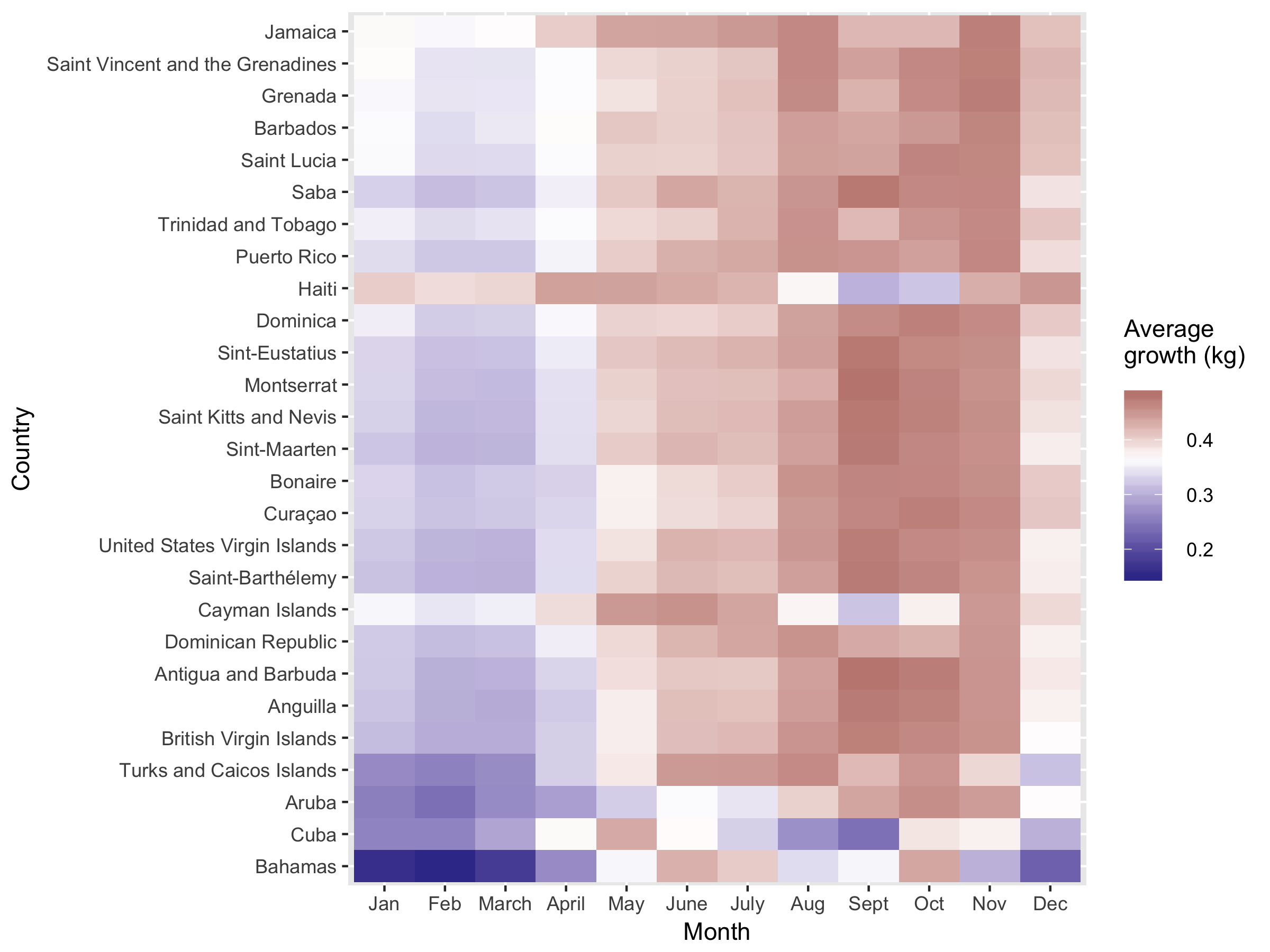


Figure 3: Average cobia growth rates per month by EEZ

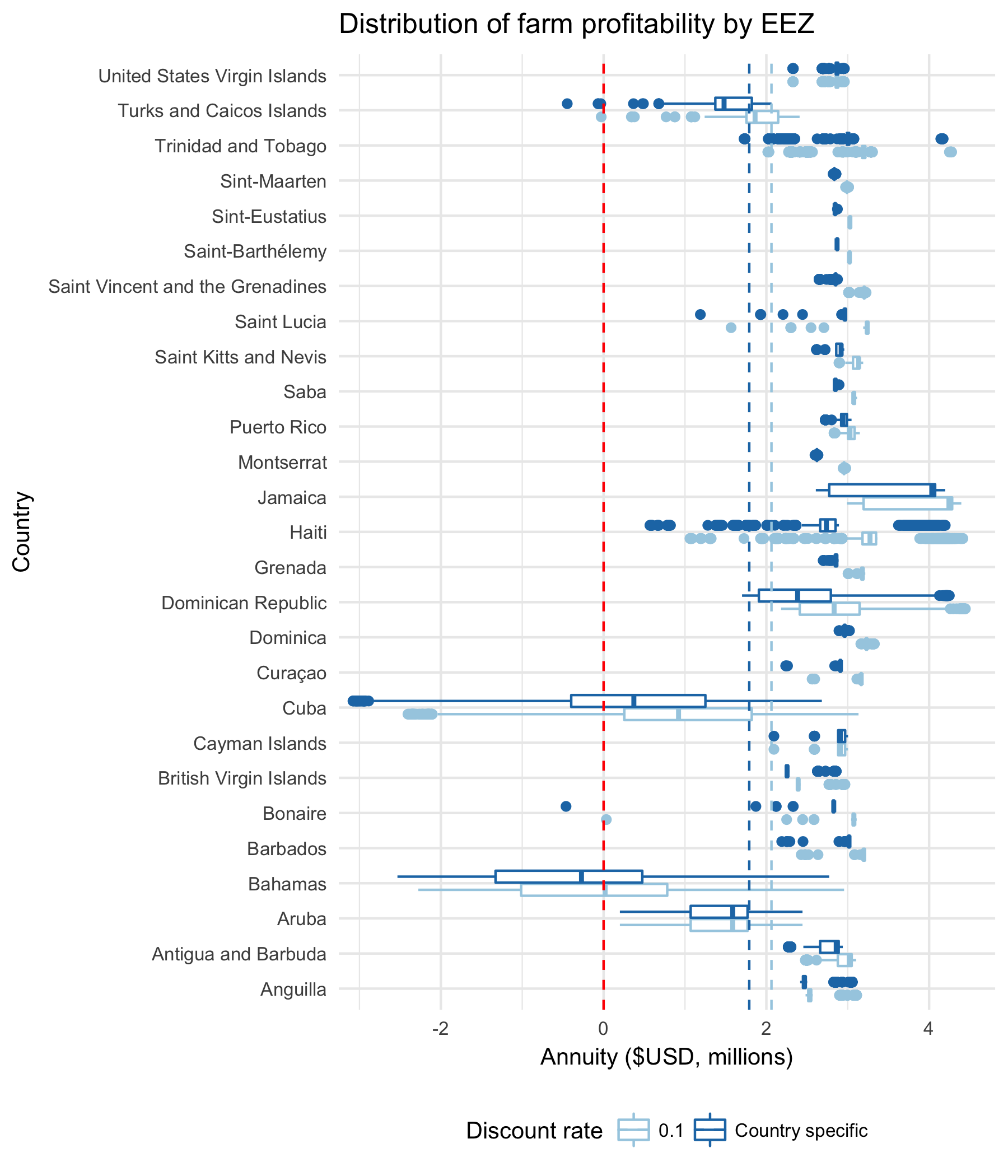


Figure 4: Annualized profits per cobia aquaculture farm by Caribbean EEZ

# 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 4. Supply (mt) and annuity under 4 different scenarios

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| country | supply\_all | supply\_main | supply\_cntry | supply\_diff | annuity\_all | annuity\_main | annuity\_cntry | supply\_diff\_perc |
| Bahamas | 1.9e+08 | 1.1e+08 | 8.5e+07 | 8e+07 | 8.5e+08 | 8.6e+09 | 6.1e+09 | 42 |
| Trinidad and Tobago | 1.8e+08 | 1.8e+08 | 1.8e+08 | 0 | 3.8e+10 | 3.8e+10 | 3.6e+10 | 0 |
| Jamaica | 8.4e+07 | 8.4e+07 | 8.4e+07 | 0 | 2.3e+10 | 2.3e+10 | 2.1e+10 | 0 |
| Dominican Republic | 5.6e+07 | 5.6e+07 | 5.6e+07 | 0 | 1.1e+10 | 1.1e+10 | 9.7e+09 | 0 |
| Cuba | 3.5e+07 | 3e+07 | 2.3e+07 | 4465341 | 2.4e+09 | 3.2e+09 | 2e+09 | 13 |
| Antigua and Barbuda | 3.4e+07 | 3.4e+07 | 3.4e+07 | 0 | 7e+09 | 7e+09 | 6.5e+09 | 0 |
| Haiti | 3.1e+07 | 3.1e+07 | 3.1e+07 | 3114 | 7.3e+09 | 7.3e+09 | 6.3e+09 | 0.01 |
| Puerto Rico | 2.7e+07 | 2.7e+07 | 2.7e+07 | 0 | 5.7e+09 | 5.7e+09 | 5.5e+09 | 0 |
| Saint Vincent and the Grenadines | 2.5e+07 | 2.5e+07 | 2.5e+07 | 0 | 5.4e+09 | 5.4e+09 | 4.8e+09 | 0 |
| British Virgin Islands | 2e+07 | 2e+07 | 2e+07 | 0 | 3.9e+09 | 3.9e+09 | 3.6e+09 | 0 |
| Grenada | 2e+07 | 2e+07 | 2e+07 | 0 | 4.3e+09 | 4.3e+09 | 3.9e+09 | 0 |
| Anguilla | 2e+07 | 2e+07 | 2e+07 | 0 | 3.9e+09 | 3.9e+09 | 3.8e+09 | 0 |
| Saba | 1.9e+07 | 1.9e+07 | 1.9e+07 | 0 | 4e+09 | 4e+09 | 3.7e+09 | 0 |
| Turks and Caicos Islands | 1.7e+07 | 1.7e+07 | 1.7e+07 | 9568 | 2.5e+09 | 2.5e+09 | 2e+09 | 0.057 |
| United States Virgin Islands | 1.4e+07 | 1.4e+07 | 1.4e+07 | 0 | 2.9e+09 | 2.9e+09 | 2.9e+09 | 0 |
| Aruba | 1.4e+07 | 1.4e+07 | 1.4e+07 | 0 | 1.6e+09 | 1.6e+09 | 1.6e+09 | 0 |
| Saint Lucia | 5e+06 | 5e+06 | 5e+06 | 0 | 1.1e+09 | 1.1e+09 | 1e+09 | 0 |
| Saint Kitts and Nevis | 4541259 | 4541259 | 4541259 | 0 | 9.8e+08 | 9.8e+08 | 9.1e+08 | 0 |
| Dominica | 4278602 | 4278602 | 4278602 | 0 | 9.5e+08 | 9.5e+08 | 8.7e+08 | 0 |
| Cayman Islands | 2e+06 | 2e+06 | 2e+06 | 0 | 4.1e+08 | 4.1e+08 | 4.1e+08 | 0 |
| Barbados | 1473676 | 1473676 | 1473676 | 0 | 3.2e+08 | 3.2e+08 | 3e+08 | 0 |
| Montserrat | 1301882 | 1301882 | 1301882 | 0 | 2.7e+08 | 2.7e+08 | 2.4e+08 | 0 |
| Curaçao | 1217992 | 1217992 | 1217992 | 0 | 2.7e+08 | 2.7e+08 | 2.5e+08 | 0 |
| Sint-Eustatius | 1163127 | 1163127 | 1163127 | 0 | 2.4e+08 | 2.4e+08 | 2.3e+08 | 0 |
| Bonaire | 724492 | 724492 | 714900 | 0 | 1.5e+08 | 1.5e+08 | 1.4e+08 | 0 |
| Sint-Maarten | 345763 | 345763 | 345763 | 0 | 7.2e+07 | 7.2e+07 | 6.8e+07 | 0 |
| Saint-Barthélemy | 129263 | 129263 | 129263 | 0 | 2.7e+07 | 2.7e+07 | 2.6e+07 | 0 |

# 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. Bhalla (1983) 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 Moeller (2009) 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 Moeller (2009) 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 Moeller (2009). 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.

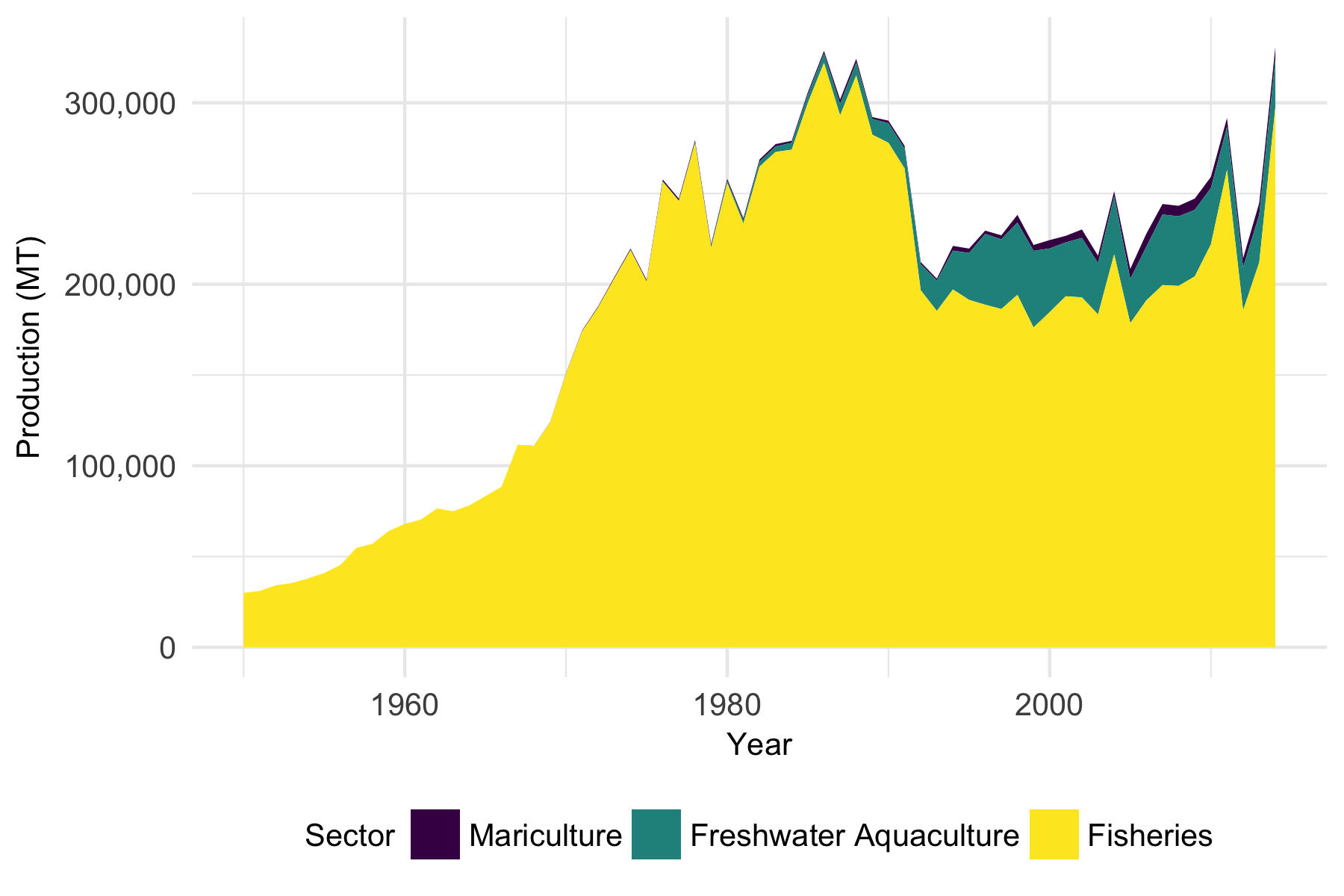


Figure S1. Seafood production in the Caribbean from 1950 - 2016 (data from: FAO 2016)

, and

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 S2a. 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 expentiture 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 S2b. 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-Barth\_lemy | 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 S2c. 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 S3. Suitable area available for potential offshore mariculture development for each spaital 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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