

Governance and mariculture in the Caribbean

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ABSTRACT

Despite overall global growth of marine and coastal aquaculture (i.e., mariculture), there is substantial regional heterogeneity in production. Biophysical growing conditions do not explain variation in production, indicating that other economic, social, and political drivers are likely influencing geographic patterns of industry development. The Caribbean is one such region where mariculture has considerable potential, but current production is very low. This is particularly surprising because the region relies heavily on seafood products and has experienced substantial declines in capture fisheries. Given the discrepancy between potential and realized production, this paper evaluates governance mechanisms (e.g., policies, laws, and regulations) related to current and future mariculture production in the Caribbean. We review literature examining the development and governance of several emerging industries, which we use to inform a Mariculture Governance Index that we assess for each Caribbean country and interpret relative to their current and potential mariculture production. Further, we seek to provide insight into the dynamic relationship between governance and mariculture development through country-specific case studies by exploring the timelines of mariculture growth relative to the timing of mariculture policy and legislation for select countries. This work develops a method for better understanding the role of governance in mariculture development and is applicable across regions, providing valuable context for identifying opportunities and barriers to mariculture expansion.

1. Introduction

As capture fishery yields have plateaued worldwide, the world has become increasingly reliant on aquaculture to meet growing global demand for fish protein, with production expected to increase by 62% by 2030 [1]. In 2014, aquaculture surpassed wild fisheries as the largest supplier of fish for human consumption, a significant milestone for aquatic food production. While this achievement appears promising, scarce land and freshwater resources complicate the expansion of freshwater aquaculture, indicating that this industry growth could stagnate in the near future [2]. As such, a shift towards aquaculture in the marine realm, where there is massive production potential [3], is essential to further expand cultured seafood production and support growing demand. Collectively referred to as mariculture, marine and coastal aquaculture currently represent just 36% of aquaculture's total seafood production. However, marine species are being domesticated at a rapid pace and culture technologies are advancing, increasing viable culture areas, diversifying product offerings, and expanding the range of market prices for consumers [4,5].

Despite the global expansion of commercial mariculture, industry development has been highly variable in space around the world.

Mariculture in parts of Asia (especially China) and Scandinavia has expanded considerably, yet regions like Africa and South America (excluding Chile) have experienced relatively limited development. Mariculture production is highly dependent on biophysical growth conditions; however, variance in these parameters does little to explain regional heterogeneity. For example, countries such as Argentina and Indonesia have considerable offshore production potential [3], but minimal offshore production at present [6]. This stark difference between current and potential production suggests the influence of other, non-ecological factors such as economics, social and cultural dynamics, and governance, on the location of mariculture development. Our study focuses on governance and specifically on how policy, legislation, and government infrastructure can provide a framework to support mariculture activities.

Governance attributes have been shown to play a substantial role in aquaculture development [4,7] as they can influence investment decisions and the commercial success of aquaculture operations [8]. While the term “governance” can encapsulate a breadth of meanings, for the purposes of this paper, we define governance as the formal governing institution of a country and the system of laws, policies, and regulations that the institution implements and enforces. For the most part, coastal

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nations have full sovereignty to establish, protect, regulate, and manage mariculture operations within their exclusive economic zones (EEZs). However, varying priorities and capacities of coastal nations have led to patchwork regulatory systems, and few countries have legislation explicitly focused on mariculture, especially catered towards offshore operations [9].

The scholarly literature presents conflicting findings regarding the relationship between governance and the development of various freshwater and marine aquaculture operations; while governance can serve as an enabling force for mariculture development, it can also hinder growth through too many regulations and complex permitting processes. For example, Norway and the United States have extensive political and regulatory infrastructure for offshore mariculture operations; yet, Norway's production growth has far exceeded that of the United States, despite the United States' higher estimated ecological potential [3,10]. Evidence suggests that this is due to the centralized governance of offshore mariculture activities in Norway [7,10], while U.S. offshore mariculture is governed by multiple federal and state agencies across a broad suite of complex regulations [10–12]. While Norway's mariculture production has thrived under strong, centralized governance, Abate et al. [13] found in their cross-country analysis of both freshwater aquaculture and mariculture operations that countries with fewer environmental regulations related to aquaculture have higher development rates relative to countries with more stringent regulations. Similarly, weak or nonexistent environmental and food safety regulations, coupled with government support and an expedited permitting process, facilitated the rapid expansion of freshwater aquaculture practices in Asia [14,15]. While fewer regulations might facilitate mariculture development, many regions are now dealing with the repercussions of lax environmental oversight. Poorly regulated coastal aquaculture development worldwide has led to vast destruction of mangrove ecosystems [15–17]. Although most existing research has focused on freshwater aquaculture, the varying dynamics described above between a country's governance infrastructure and aquaculture production suggest the need for a more detailed study of the role of governance on mariculture development. This paper seeks to broaden the scope of the current literature by examining both the facilitating and inhibiting influence of a country's governance climate on mariculture development.

The Caribbean provides a useful context for evaluating these policy drivers of mariculture development as the 30 island nations and territories that we examined all are located within a single Large Marine Ecosystem (LME) (NOAA [52]), but with notable political, economic, and social heterogeneity across islands. A LME is characterized by having relatively consistent bathymetry, hydrography, productivity, and trophic relationships. As such, we are able to compare a broad sample of distinct national/territorial governments and identify legislative and regulatory trends that are relatively independent of environmental conditions. Data compiled by the Food and Agriculture Organization of the United Nations (FAO) estimated region-wide production at around 7000 metric tons (MT) in 2016. However, Thomas et al. [18] estimated that mariculture for a single species, cobia (*Rachycentron canadum*), could profitably produce over 34 million MT of seafood in the Caribbean. While achieving this level of production capacity is likely not feasible due to operational and market variables such as feed availability and consumer demand, the vast disparity between this estimated potential and current production indicates there is considerable room for mariculture growth.

This work synthesizes the extensive literature on aquaculture and mariculture governance, as well as drawing from literature examining analogous industries such as capture fisheries and agriculture, to inform the development of a Mariculture Governance Index (MGI). When combined with data on current and potential production, the MGI allows us to evaluate the relationship between governance mechanisms and mariculture development. These insights can inform policy recommendations for Caribbean countries looking to expand their

mariculture production. Many islands have developed initiatives to encourage “blue” economic growth, turning to the ocean as a means of diversifying and strengthening their economies, increasing local food production, and providing employment opportunities [19]. While mariculture expansion comes with valid concerns regarding disease, potential ecosystem degradation, and overall sustainability [20–22], many countries worldwide have a growing interest in developing the industry as a means of diversifying their economies and building food security [19]. Thus, understanding the mechanisms that drive mariculture development can facilitate its contribution to the economies and food systems of Caribbean islands. Understanding the barriers or enablers to mariculture expansion in the Caribbean is especially relevant given the rising interest among small island developing states (SIDS) to advance their “blue economies”, with the development of mariculture industries featuring prominently in many of these initiatives [19]. Considering that our study includes 25 SIDS, the Caribbean merits additional attention to understand the influence of governance dynamics on mariculture development which can better inform future blue economy initiatives (United Nations [54]).

2. Methods

2.1. Study sites

This study focuses on 30 island nations and territories of the insular Caribbean (Fig. 1). Of these countries, 13 are independent nations, 12 are overseas territories, and 5 are administrative divisions (Table S1, Supp. Info.). Overseas territories maintain some level of autonomy regarding internal affairs, whereas administrative divisions are directly administered by the sovereign country as an extension of the territory and, as such, are subject to the policies of that governing nation unless otherwise adjudicated.

The most recently available data on seafood production in the Caribbean were sourced from FAO [6] and filtered to include only marine and brackish water aquaculture production (excluding all capture fisheries and freshwater aquaculture production) to define “current” mariculture production volume in the Caribbean. Potential cobia production data are from Thomas et al. [18].

2.2. Index development

2.2.1. Mariculture Governance Index table

The construction of our Mariculture Governance Index (MGI) was based on our review of the literature of emerging industries and the key



Fig. 1. Study Area. Map of the 30 countries, shown in green, included in our study. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

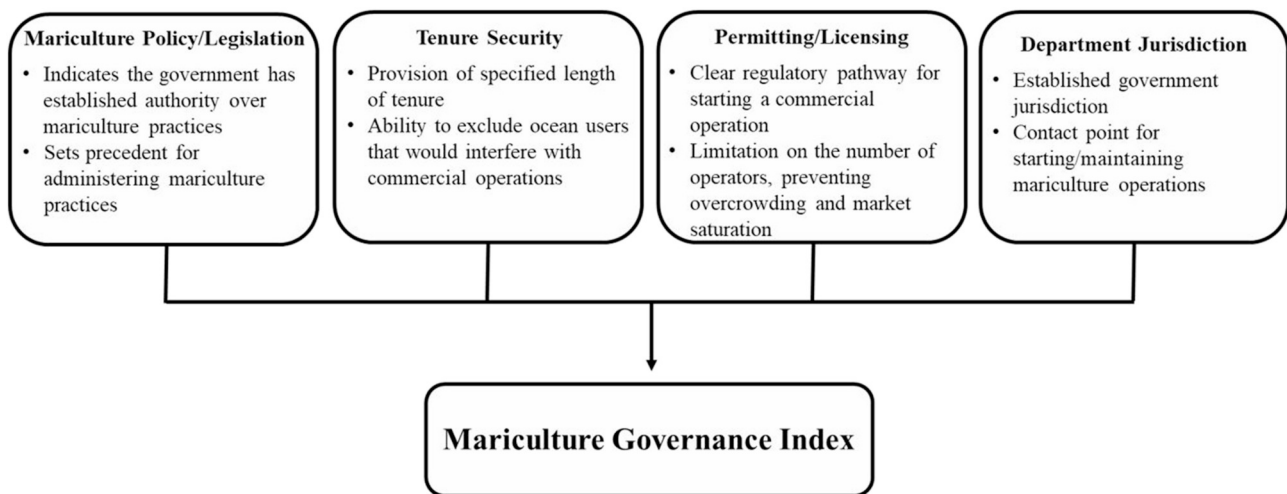


Fig. 2. Mariculture Governance Index Framework. The four categories of the Mariculture Governance Index were derived from an extensive literature review of governance in both the freshwater aquaculture and mariculture industries as well as in analogous industries such as renewable energy and agriculture.

factors that support their development. We constrained our literature search to “sustainable” industries, such as renewable energy and organic farming, as the development dynamics of these industries are the most analogous to mariculture. For example, renewable energy is a burgeoning industry that seeks to provide a long-term solution to using finite resources to power the world; mariculture seeks to provide a long-term solution to shrinking wild fish populations and growing global seafood demand. The MGI includes four categories: mariculture policy and legislation, tenure security, permitting/licensing, and department jurisdiction (Fig. 2). Each of these categories is scored on a binary scale and is awarded a point (1) if it is a feature of a given country's governance infrastructure. A combined Index score of 0 indicates no mariculture governance while a score of 4 represents substantial governance infrastructure for mariculture.

Our review of the literature informed the selection of each of the categories in the MGI (see sections 2.2.1.1 through 2.2.1.4). We chose categories that describe mariculture governance and government support for development and/or production. In other words, we selected categories that we hypothesized, based on existing evidence in the literature, would help facilitate aquaculture development and did not include aspects of governance that are more likely to discourage development (e.g., very strict assessment and monitoring requirements via an Environmental Impact Assessment). We also focused on categories that could be readily assessed on a binary scale to facilitate objective comparison across countries. Finally, given that we intend for the MGI to be applicable to other regions, we chose categories for which data would generally be available and that are relevant to assessing governance dynamics regardless of geographic location.

2.2.1.1. Mariculture policy and legislation. Policy tends to establish a desired objective and outlines a strategy for achieving specified goals and leveraging public support and funding; legislation is often the outcome of established policy and refers to a body of laws, rules, and/or regulations that establish legal boundaries. The inclusion of mariculture in policy and legislative documents indicates that the mariculture industry exists in a country or, at the very least, that mariculture has been identified as a possible new industry. It also establishes precedent for the government to oversee mariculture practices, and provides clarity and certainty to potential investors and developers.

Both policy and legislation substantially impact industry development. For example, China's renewables sector saw rapid progress after the implementation of their 2005 Renewable Energy Law [23], and policy measures supporting wind power have led to domestic development of the industry in several countries, resulting in internationally

competitive businesses [24]. Further, international and national climate legislation led to the drastic expansion of the clean energy industry [25].

References to mariculture legislation were wide-ranging, with some pieces of legislation grouping mariculture and aquaculture under one provision and others having mariculture-specific policy prescriptions. Given this breadth, the category was scored positively based on any mention of mariculture or aquaculture carried out in marine areas in formal legislative or policy documents.

2.2.1.2. Tenure security. Concepts of public trust and common pool resources in regards to marine resources create conflicts across human uses of the ocean space [26]. These dynamics can greatly inhibit the ability of mariculture operators to protect their investments as they cannot guarantee the exclusion of other ocean users that could interfere with commercial operations [27,28]. Tenure rights, the strength of which can positively correlate with development, provide a legal means of excluding certain activities from a given space [27]. In addition to spatial exclusion, a key aspect of tenure rights is the length of tenure, as a sufficient length of time is required for firms to be able to generate a return on their investment [28]. Clearly defined tenure rights provide transparency regarding the expectations of both the operator and the government. A potential operator gains security knowing they can exclude other users from a specified space for a prescribed length of time and the administration has a contract that restricts the development within spatial and legal parameters [28]. For example, many Asian countries that have committed to growing their freshwater aquaculture industries have provided long-term leases to give security to investors and lenders [15].

For our study, provisions for leasing of the foreshore (the part of the shore between high- and low-water marks), the seabed, or the water column, found either in official legislative documents or on government websites, served as a proxy for tenure security. The constitutions of most of the countries in this study generically ensure legal authority over property/land. However, given that mariculture is a nascent industry in the Caribbean and private use of ocean space is often contentious, we decided only property rights that applied directly to mariculture production were sufficient for a country to score positively in this category.

2.2.1.3. Permitting/licensing. A permitting process presents a specified pathway for potential developers to get operational plans approved. Although permitting and licensing can have a financial cost and add more time to the development process, they also create more certainty about the parameters of operating legally within the country and the

regulatory hurdles that must be passed [29]. The process details the requirements prescribed by the issuing agency as well as specifies a fee, which discourages operators who are not financially committed from applying. The administrative office can also keep track of the number of permit holders and limit the number of operators. Policy provisions for permitting and licensing were found in official policy and legislative documents as well as on government websites, and a country scored positively in this category if these sources outlined the cost and/or process for applying for a permit or license.

2.2.1.4. Department jurisdiction. Having a specified government department that oversees aquaculture activities provides operators with a clear point of contact for starting and maintaining aquaculture ventures and establishes a clear jurisdiction within the government for authority to develop policies, implement laws, and enforce regulations [10]. Without a lead department or agency, navigating permitting and licensing can be confusing and burdensome for a developer. For example, in the United States, the division of authority across multiple agencies seems to have hindered nationwide growth in the mariculture industry [10–12].

A country scored positively in this category if it had a single or lead department appointed to oversee mariculture activities. Jurisdiction had to be held by a department of that island's territorial government (not the country's sovereign nation, when applicable) to qualify. For example, Puerto Rico and the U.S. Virgin Islands are governed by U.S. mariculture policy, but there is no department specific to either island that administers mariculture operations and, therefore, it did not score positively in this category.

2.3. Data and analysis

2.3.1. MGI data

For each country, mariculture-related policy documents were

collected through the FAO's legislative and policy database (FAOLEX). We applied the advanced search options to narrow our results to the 30 countries in our study and to documents containing the keywords “mariculture” or “aquaculture” (n = 53). This approach was supplemented by visiting the government websites of each country for relevant information, as well as conducting a systematic web search (Table S2, Supp. Info.) using the Google search engine. The scope of the search was broad, including any policy or legislative documents that related to marine activities (especially fisheries), environmental regulations, and marine spatial planning. Given the breadth of our search, only verified state documents and websites as well as official gray literature were used. After locating these documents, we reviewed each of them for mentions of aquaculture or mariculture through automated searches of these key terms and reading through documents that were not search compatible. Twelve countries in our study use a language other than English for their government documents; therefore, we translated search terms used for English-speaking countries into both French and Spanish. Documents from these countries were translated using Google Translate's document translation feature and then verified by a native speaker. While our search for documents was extensive, it is possible that some countries have relevant policies or legislation that are not published online. The lead author was the primary scorer for the index. The remaining co-authors would have been consulted to form a consensus-based assessment if information was confusing or required challenging subjective decisions, but we did not encounter any such cases. Table S3 in the Supplementary Information provides a comprehensive list of the sources from which we extracted information for the MGI.

Mariculture is a highly localized activity. As such, even though administrative divisions are generally subject to the laws and policies of their sovereignties, we deemed that legislation or policies regarding mariculture would need to be administered by local officials and, therefore, should be specific to each administrative division. However,

Table 1

Mariculture Governance Index Scores. Index scores reflect the extent of each country's mariculture governance framework. A country scored positively (1) in a category if it met the criteria outlined in the methods section. The number of categories scored positively were summed into the total score for each country.

Country	Mariculture Policy/Legislation	Permit/License Required	Tenure Security	Department Jurisdiction	Index Score
Anguilla					0
Aruba					0
Bonaire					0
British Virgin Islands					0
Cayman Islands					0
Curacao					0
Haiti					0
Montserrat					0
Saba					0
Sint Eustasius					0
Sint Maarten					0
Guadeloupe	1				1
St. Barthélemy	1				1
St. Martin	1				1
Barbados	1			1	2
Martinique	1			1	2
Trinidad and Tobago	1			1	2
Turks and Caicos	1	1			2
Bahamas	1	1		1	3
Dominica	1		1	1	3
Grenada	1		1	1	3
Dominican Republic	1	1		1	3
Jamaica	1	1		1	3
Puerto Rico	1	1	1		3
St. Lucia	1		1	1	3
St. Vincent and the Grenadines	1		1	1	3
US Virgin Islands	1	1	1		3
Antigua and Barbuda	1	1	1	1	4
Cuba	1	1	1	1	4
St. Kitts and Nevis	1	1	1	1	4

2016 Production

Mariculture Governance Index Score	Non-producers		Producers
Low (0-1)	• Anguilla • Aruba • Bonaire • British Virgin Islands • Cayman Islands • Curaçao	• Haiti • Montserrat • Saba • St. Barthélemy • St. Eustatius • St. Martin • Sint Maarten	• Guadeloupe (19MT)
Medium (2-3)	• Barbados • Dominica • Grenada • Jamaica • Puerto Rico • St. Vincent & the Grenadines	• Trinidad & Tobago • Turks & Caicos • U.S. Virgin Islands	• Bahamas (8MT) • Dominican Republic (750MT) • Martinique (36MT) • St. Lucia (5.3MT)
High (4)	• Antigua & Barbuda		• Cuba (6,157MT) • St. Kitts and Nevis (1MT)

Fig. 3. Governance-production matrix. Mariculture Governance Index versus production data [6]. Annual production from 2016 is shown in parentheses for each producer country, and non-producers had no reported mariculture production in 2016. Index scores were categorized into “low” (0 or 1), “medium” (2 or 3), and “high” (4).

the sovereign authority could be the driving force behind any mariculture-related laws as long as they were prescribed specifically for one of the Caribbean countries in this study. For example, France's *Décret No. 2011-866* outlines the means by which mariculture development should be pursued and planned by some of its administrative divisions, including St. Barthelemy and St. Martin [30]. Therefore, *Décret No. 2011-888* counted as mariculture policy for both countries. Regarding overseas territories, they maintain general authority over their internal affairs and, therefore, were treated the same as sovereign nations.

2.3.2. Governance-production matrix

Using the scores from the Mariculture Governance Index, a governance-production matrix was developed to assess the possible linkages between governance infrastructure and mariculture development. Mariculture governance index scores were categorized into groups: low (scores of 0 or 1), medium (scores of 2 or 3), and high (score of 4). Countries were also categorized as “producers” or “non-producers” based on current mariculture production, with “producer” countries producing from 1 MT to 6157 MT in 2016, with a median value of ~19 MT [6].

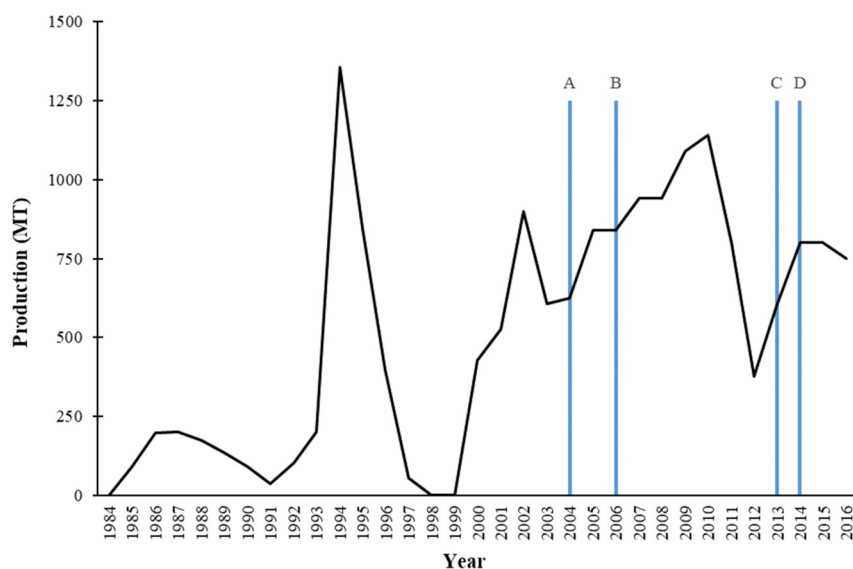


Fig. 4. Mariculture Production and Governance in the Dominican Republic. Mariculture production in the Dominican Republic from 1984 to 2016 (black line; [6]). Vertical blue lines indicate years of policy or legislation implementation: (A) *Law creating the Dominican Council of Fisheries and Aquaculture (CODOPESCA)*, 2004. (B) *Presidential Decree for Sustainable Development of Fisheries and Aquaculture*, 2006. (C) *Presidential Decree Creating Fund for Development of Fisheries and Aquaculture*, 2013. (D) *Resolution approving the Cooperation Agreement on Fisheries Maritime and Aquaculture*, 2014. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3. Results and discussion

The Mariculture Governance Index (Table 1) reveals considerable variation across Caribbean countries, with three countries scoring high (MGI = 4), thirteen countries scoring in the medium range, and fourteen scoring in the low range. Mariculture policy and legislation was the most common governance attribute ($n = 19$ countries), followed by department jurisdiction ($n = 13$), mariculture permitting/licensing ($n = 9$), and tenure security ($n = 9$).

Based on the governance-production matrix (Fig. 3), there appears to be a positive association between mariculture production and a medium or high MGI score. Given the small sample size of our data, we employed a Fisher's exact test to further assess the relationship between governance and mariculture production. The Fisher's test indicates that the presence of mariculture production is significantly associated with the level of mariculture governance ($N = 30$; $p = 0.05$). However, the seven countries with 2016 mariculture production have a range of MGI scores, suggesting that not all of the included index categories are requisites for mariculture development. On the other hand, we did find that all seven producing countries had, at a minimum, some form of mariculture policy or legislation, indicating the need for at least a basic governance infrastructure for industry development.

3.1. Governance insights

3.1.1. Producers with high index scores

Examining the islands that have active mariculture allowed us to assess some of the likely governance drivers of mariculture production in the region. For one, Cuba has the highest mariculture production in the region and a Mariculture Governance Index score of 4. Cuba's aquaculture industry arose out of state-sponsored research, investment, and technical infrastructure provided by the National Aquaculture Enterprise (Empresa Nacional de Acuicultura) [31]. Cuba's mariculture legislation includes specific technical standards for species production and a provision for the hygienic production of aquatic organisms, among others, and concessions for the establishment of aquaculture activities have a minimum tenure of five years [32]. Authorization for all aquaculture activities and related concessions, licenses, and permits are issued by the same authority, the Ministry for the Food Industry [32]. State-sponsored aquaculture development was not a component of our Mariculture Governance Index, and such government-run industry is likely rare outside of communist governments, but it does suggest a pathway for advancing mariculture development and circumventing investor risk. In particular, submitting to all of the

regulatory requirements for mariculture production as well as the acquisition of permits and leases is a much simpler and cheaper process when the administrator and the applicant are the same entity. While full government sponsorship of the mariculture industry is unlikely in other Caribbean countries, Cuba exemplifies how an extensive governance framework for the development and operation of mariculture ventures, as well as consolidated management under a single governing agency, can facilitate industry expansion.

The Dominican Republic's mariculture industry was the second highest producer in 2016 with 750 MT and a MGI score of 3. However, the timeline of mariculture production relative to the timeline of key governance developments indicates a more complex interplay between the two (Fig. 4). The Dominican Republic created the Dominican Council of Fisheries and Aquaculture (CODOPESCA) in 2004 (Law No. 307-4 [47]) to oversee industry development, issued a presidential decree (Presidential Decree No. 513-06 [48]) in 2006 for the sustainable development of fisheries and aquaculture, and, in 2013, established a national fund for the sustainable development of fisheries and aquaculture, declaring it a national priority (Presidential Decree No. 40-13 [49]). However, production in the country existed 20 years prior to the first legislative action in 2004, though it was quite volatile. Production increased exponentially from 1991 to 1994 before crashing precipitously, likely due in part to back-to-back tropical storms (Debby and Gordon in the fall of 1994), which caused extreme flooding and damage to the country's infrastructure [33]. The industry had started to recover in 2000 prior to the creation of CODOPESCA. However, mariculture production again experienced a steep decline between 2010 and 2011 for reasons we were not able to identify. This decline was not as dramatic as in 1994, and the industry has had relatively positive growth since 2012.

These dynamics indicate that mariculture development can sometimes precede any policy or legislation or even be the catalyst for creating formal industry regulations. However, a strong governance structure may provide the necessary support to build the industry back up after extreme events, such as hurricanes. Although the initial development of the Dominican Republic's mariculture industry does not appear to be associated with a strong governance framework, the quick recovery of the industry after the 2011 decline, especially in comparison to the 1994 crash, could be connected to the creation of CODOPESCA as well as the subsequent presidential decrees that have prioritized the mariculture industry through designated government funding and support.

St. Kitts and Nevis provides an example of a country with a high governance score (MGI = 4) and a very small amount of production

(1 MT in 2016). While it might appear that the country's comprehensive governance framework has negatively impacted industry development, most of their regulations and policies are quite recent, and we would not expect these elements to have had a major impact on aquaculture production yet. If the *Fisheries, Aquaculture, and Marine Resources Act* (2016), which governs every phase of mariculture operations including permit fees and fines for operation violations, fish hatchery standards, and the construction of aquaculture structures, does impact development, it could take several years or more for production statistics to reflect these dynamics [34].

3.1.2. Non-producers with high index scores

Understanding the governance dynamics of mariculture production in the Caribbean is critical for future development of the industry, particularly in countries with high production potential. Acknowledging that there is a difference between simply having governance related to mariculture and having governance that effectively facilitates the industry, we selected several countries with MGI scores of 3 or 4 and no current production and evaluated potential barriers to development not captured by the Index.

Puerto Rico and the U.S. Virgin Islands both have an index score of 3. The U.S. Virgin Islands has never recorded mariculture production and there has been no production in Puerto Rico since 2010. Because both are U.S. overseas territories, the benefits of their high governance scores are likely undermined by the same decentralized and complex policy and legislative framework that is attributed to the lack of mariculture growth in the United States, which is subject to twenty federal laws administered by seven different agencies [35]. One offshore cobia farm in Puerto Rico waited on permits from various federal agencies for five years before shutting down and moving operations to Panama where regulations were less stringent [36].

Of the three countries with an MGI score of 4, Antigua and Barbuda is the only one without any current production, despite considerable estimated potential for cobia [18]. The twin-island nation has never reported mariculture production and several attempts at land-based aquaculture have not been successful due to high operational costs and limited local market interest [37]. While land-based aquaculture and mariculture are subject to their own unique development hurdles, they may face similar issues with operational expenses and local market demand. For example, both land-based aquaculture and mariculture projects are required to conduct an Environmental Impact Assessment (EIA) in order to obtain a license for developing and operating facilities [38]. Negative environmental impacts from mariculture development, from disease outbreaks [20,39] to changes in ecosystem dynamics

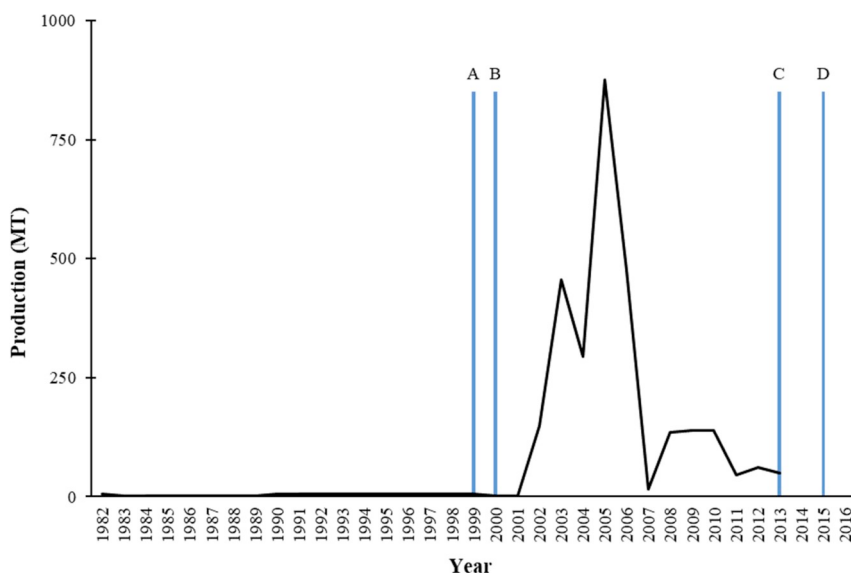


Fig. 5. Mariculture Production and Governance in Jamaica. Mariculture production from 1982 to 2013 (black line; [6]). No production data have been reported since 2013. Vertical blue lines indicate years of policy or legislation implementation. (A) *The Aquaculture, Inland and Marine Products and By-Products (Inspection, Licensing and Export) Act*, 1999. (B) *Updated Aquaculture, Inland and Marine Products and By-Products (Inspection, Licensing and Export) Act*, 2000. (C) *Updated Aquaculture, Inland and Marine Products and By-Products (Inspection, Licensing and Export) Act*, 2013. (D) Ministry paper "Aquaculture Development Initiatives", 2015. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

[40,41], have been well-documented, and requiring an EIA is indicative of a government's commitment to sustainable, long-term development. However, the EIA process can be cumbersome, time-consuming, and expensive (especially if dealing with corruption and calls for bribery) [42], which can deter potential producers. Individuals seeking to develop mariculture operations within Antigua and Barbuda's EEZ might view the cost of an EIA as a prohibitive risk to their investment, especially given the historical lack of demand for land-based aquaculture products. Of the 30 countries in our analysis, nine had EIA requirements for mariculture operations, and, of those, only three have current mariculture production, despite substantial production potential for some of them, e.g. Trinidad and Tobago [18]. Cuba, the Dominican Republic, and St. Kitts and Nevis's EIA requirements were implemented decades after mariculture production had been established in the countries, which likely meant existing businesses had already generated revenues and were able to afford the costs of the EIA process or were grandfathered in to the system. Further, new mariculture operations in these countries, especially Cuba and the Dominican Republic, can justify the time and expense of an EIA since demand for mariculture products is well-established.

Jamaica has a MGI score of 3, yet no current mariculture production. Historically, Jamaica has had some production, peaking at 875 MT in 2005 before a stark decline to 50 MT by 2013 (Fig. 5). This spike occurred closely after the implementation of the country's *Aquaculture, Inland and Marine Products and By-Products Act* in 1999 and its updated version in 2000, which governs the inspection, licensing, and export of aquaculture and mariculture products [43]. Beginning in 2002, a rapid increase in production volume occurred until 2007 when Hurricane Dean inflicted over US\$36,000 of damage on shrimp farms [44]. While there seems to have been a small level of recovery afterward, though not nearly on the same level as prior, Jamaica has not reported any production data since 2013.

A 2015 *Aquaculture Development Initiatives* paper, produced by the Ministry of Agriculture, Labour and Social Security [50], outlined two major challenges to mariculture development in the country. First, increasing coastal development has negatively impacted nearshore water quality with sewage contamination threatening current and future mariculture operations. Second, the existing regulatory framework cannot grant mariculture operators exclusive access to the foreshore, seafloor, and water column, leaving them at risk from damage and theft. As discussed in Section 2.2.1.2, a lack of tenure rights creates a risky investment environment which can discourage funding and development [27,28].

3.2. Factors beyond governance

In lieu of an extensive governance framework and proactive government backing, it appears that mariculture production can be fostered through alternative sources of support, such as training programs, professional organizations, and financing institutions. Guadeloupe, an administrative division of France, has a MGI score of 1 but, in 2016, produced 19 MT of mariculture products. While the country's mariculture legislation is dictated by France, mariculture operations within Guadeloupe are aided by the Union of Aquaculture Producers of Guadeloupe (SYPAGUA), which offers training, technical supervision, product promotion, and overall support to all fish farmers in the country, including a mariculture farm that produces red drum (*Sciaenops ocellata*). Further mariculture-specific support is provided by the Comité Régional des Pêches Maritimes et des Elevages Marins (CRPMEM), or Regional Committee for Maritime Fisheries and Marine Farming. The CRPMEM represents and promotes the interests of mariculture producers at the regional level, as well as provides scientific and technical support. Recognizing the potential fostered by the support of SYPAGUA and CRPMEM, the Conseil Régional de la Guadeloupe adopted a Regional Marine Aquaculture Development Plan (SRDAM) in 2013 [45]. Inclusive of all relevant stakeholders, the SRDAM

emphasizes mariculture training and conversion of suitable marine sites (~500 ha) to marine fish farms.

Martinique, with a Mariculture Governance Index score of 2 and 36 MT of mariculture production in 2016, has an even more extensive network of professional organizations to support mariculture activities. The organization and objectives of the Association pour la Défense des Producteurs Aquacoles Martiniquais (ADEPAM) are very similar to those of SYPAGUA in Guadeloupe. In addition to several broader aquaculture organizations, Martinique has its own CRPMEM that performs similar functions to its namesake in Guadeloupe [46]. The island is also home to an aquaculture training school, the Ecole de la Formation Professionnelle aux métiers Maritimes et Aquacoles (EFPMA), and Crédit Maritime offers credit and banking services to aquaculture professionals on the island [46].

There are multiple factors other than a country's governance infrastructure that can impact mariculture development that are beyond the scope of our study. As mentioned previously, hurricanes can have detrimental impacts on existing mariculture infrastructure. These extreme natural events can introduce substantial risk to development which might deter potential investment. Furthermore, local seafood demand, cultural attitudes towards mariculture, and access to supplies and inputs are all potential variables influencing whether a country pursues mariculture production. Funding mechanisms, including foreign direct investment and subsidies, also likely have a role in industry development. However, given limited public information on some of these inputs for many countries, it is difficult to distill such information into an indicator for the MGI. Further consideration should also be given to the lag effect of new policies and legislation on production, as it takes time for governance changes to impact industry.

Spatial conflicts with other industries or management objectives, such as tourism, which is especially relevant to the Caribbean, might also limit mariculture development, specifically in coastal areas where most human activities take place. However, offshore aquaculture presents a lower probability of conflict as these operations take place further away from shore, and presumably no aquaculture operation would be located over or adjacent to a coral reef [18], limiting most conflicts with snorkel and SCUBA activities. On the other hand, there are possible synergies between mariculture development and tourism. For example, islands with high levels of tourism might want to prioritize local seafood production as a sustainable food source for both locals and tourists. Also, mariculture farms can serve as a tourism activity, as evidenced by the Caicos Conch Farm on Providenciales, Turks and Caicos (recently closed in 2018), and the land-based La Parc Aquacole in Point Noire, Guadeloupe, where tourists can catch their own fish and have it cleaned and cooked for them on site.

While the MGI is intended to be applicable to regions around the world, we acknowledge that this broad outlook results in a loss of depth and specificity in our assessment of individual countries within the Caribbean as well as for other regions to which it might be applied. For example, the MGI does not capture the presence of any small-scale, informal governance regimes that might influence mariculture development within local communities. Further, the binary assessment of each category fails to account for nuances across the MGI indicators and the amount of influence a national government exerts over mariculture development. To illustrate, some of the countries in our study have extensive policies or pieces of legislation dedicated to mariculture, while others have only a brief paragraph about a specific regulation of the mariculture industry within a broader policy or legislation document regarding, for example, wild fisheries. The difference between extensive versus cursory policy or legislation and the impact on mariculture development is not reflected in the binary outcomes of the MGI. In specific regards to tenure security, the MGI does not account for the length of leases provided for mariculture development, a factor that would likely influence investment in mariculture operations. Further, we found that all countries that did reference tenure rights did so for the foreshore and/or seabed, and not for the water column, possibly

indicating uncertainty over the legality of water column lease rights in many countries. The MGI also does not include governance characteristics indirectly applicable to mariculture operations. For example, trade agreements and tariffs likely influence if and where a country participates in export markets, affecting the level of demand for mariculture products and possibly the level of investment in mariculture production. While not designed to glean these finer details, the MGI provides an overview of mariculture governance dynamics across countries, highlighting areas of investigation, like those mentioned previously, that should be pursued further.

4. Conclusion

With its favorable growing conditions and close proximity to large importing markets in North and South America, the Caribbean is poised to be a key player in global mariculture production [3,18]. Our findings indicate that governance infrastructure for mariculture can be a critical enabling force for development but that the industry can still grow in the absence of key governance categories. Specifically, all seven current mariculture producers in the Caribbean have some form of mariculture policy or legislation, and all but one has a specified department for overseeing mariculture operations. Beyond the governance categories included in our index, training programs, professional organizations, and financial resources appear to play a positive role in mariculture development, particularly in countries with limited governance. It is critical to elucidate the drivers of mariculture development for countries interested in strategic and efficient policies to foster industry investment and growth. The analysis is focused on the Caribbean; however, it is anchored by concepts that can be employed in other regions. Our extensive literature review of governance related to mariculture, development of a systematic index to assess this governance infrastructure, and application of it to the diverse island nations in the Caribbean provides a transferable knowledge base that can be applied to other regions seeking to expand seafood production.

Conflicts of interest

The authors declare no competing financial interests.

Contributions

E.R. and S.L. designed research; E.R. and T.C. performed research; E.R., R.G., T.C., L.T., and S.L. interpreted results; T.C. and L.T. provided Caribbean mariculture data; E.R., R.G., and S.L. wrote the paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpol.2019.103565>.

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