Aquaculture 516 (2020) 734600

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

A multimetric investor index for aquaculture: Application to the European Union and Norway

Rui Gomes Ferreira[a], Joao G. Ferreira[b,*], Frans-Joost Boogert[a], Richard A. Corner[a], Joao Pedro Nunes[c], Jon Grant[d], Johan Johansen[e], William F. Dewey[f]

[a] Longline Environment Ltd, 63, St. Mary Axe, London, W1G 8TB, United Kingdom
[b] DCEA, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Quinta da Torre, 2829-516, Monte de Caparica, Portugal
[c] CE3C – Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências, Universidade de Lisboa, 1749-016, Lisboa, Portugal
[d] Department of Oceanography, Dalhousie University, Halifax, NS, B3H 4J1, Canada
[e] Salten Havbrukspark as, Sundsfjord, Nygårdssjøen, N-8120, Norway
[f] Taylor Shellfish, 130 SE Lynch RD, Shelton, WA, 98584, USA

ARTICLE INFO

Keywords:
Aquaculture
Investors
Multimetric index
Europe
Smartphone application

ABSTRACT

An aquaculture investor (AQI) index was developed in order to provide a broad view of the relative attractiveness of 29 different European countries to aquaculture investors. AQI is based on five complementary categories: Market, Production, Regulatory, Environment, and Social, with each category containing four indicators. The attraction of investment into aquaculture depends on the viability of developing aquaculture for each country, and these five categories account for the connectivity in the aquaculture industry. The index benchmarks and tracks countries' progress by producing a quantitative and scalable tool for stakeholders to assess and monitor aquaculture attractiveness, and is designed to rank aquaculture competitiveness for each country. Index scores calculated for Europe range from moderate to good, on a heuristic five-class scale. Countries in Northern Europe with well-established aquaculture sectors score better than countries in Southern Europe. Countries with developing aquaculture sectors tend to score moderately. While high scores within single categories can be achieved, the index rewards countries with high scores across the five categories, to provide a more useful tool for stakeholders. No countries within Europe rank below the middle of the moderate range. The index identifies several countries with high scores that do not have significant aquaculture industries (e.g. Sweden and Finland), and further research is warranted to identify why aquaculture has not been developed. It is expected that as AQI is expanded to lower income countries spanning other geographic regions, countries with lower quality indicator scores will have lower overall scores. The index provides a broad-scale approach across a wide range of categories, and should be interpreted in that context, since it is designed to provide high-level guidance of the general attractiveness for aquaculture in each country. Appropriate due diligence for specific circumstances is warranted by all stakeholders requiring further knowledge to assist decision-making.

To ensure a wide dissemination and maximum visual appeal to both investors and the public, the AQI index was deployed as a smartphone application (AquaInvestor), freely available on the Google Play Store, together with a companion website, and to our knowledge provides the first country-wide comparative assessment of aquaculture potential, available to investors and the general public in eight European languages and Chinese.

1. Introduction

There has been a significant increase in worldwide consumption of aquatic products, from 9.9 kg per capita per year fifty years ago, to the current peak of 20 kg per capita y^{-1} in 2014 (Carlucci et al., 2015; FAO, 2016). Over the next thirty years, humanity faces the huge challenge of providing safe and adequate nutrition to a world population estimated to reach 9.7 billion by 2050 (Cressey, 2009; FAO, 2016; Godfray et al., 2012); in 2025, worldwide seafood consumption is predicted to reach 21.8 kg per capita which will require an additional 31 X 10^6 t y^{-1} of aquatic products (FAO, 2016).

Capture fisheries have declined worldwide since the late 1970s, with many species exceeding maximum sustainable yield (e.g. Boonstra et al., 2018; Ehlers, 2016; Shannon et al., 2014), whereas aquaculture

* Corresponding author.
E-mail address: joao@hoomi.com (J.G. Ferreira).

https://doi.org/10.1016/j.aquaculture.2019.734600
Received 16 July 2018; Received in revised form 7 October 2019; Accepted 14 October 2019
Available online 19 October 2019

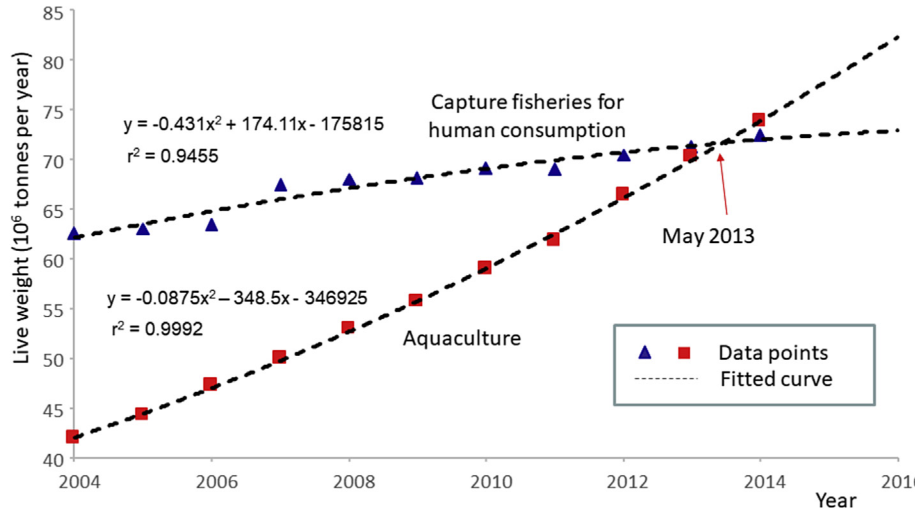

Fig. 1. Worldwide production of capture fisheries for direct human use, and of aquaculture, over the period 2004–2014 (Lopes et al., 2017).

has grown at an annualized percentage rate (APR) of 6%, and in May 2013, world aquaculture production overtook capture fisheries for human consumption (Fig. 1). In 2014, 73.8 X 10^6 t of fish were farmed, representing 44% of total aquatic production (FAO, 2016); wild catch includes 21 X 10^6 t not directly used for human food—some of this harvest is used for animal feeds in both agriculture and aquaculture (Merino et al., 2012; Naylor et al., 2000).

By contrast with world growth of aquaculture, production in the European Union is stagnant or falling. In 2012, European aquaculture produced 2.88 x 10^6 t, representing 4.3% of world supply, down from 12.2% in 1990 (FAO, 2014). For the European Union, those numbers are substantially worse, down from 7.9% in 1990 to 1.9% in 2012. The difference between Europe and the EU is largely explained by a substantial increase in Norwegian salmonid aquaculture.

Over the next 15–20 years, European aquaculture faces several significant challenges. A report commissioned by the EU Directorate-General for Internal Policies (Lane et al., 2014) proposes minimum increases of 100% in marine culture and 40% in freshwater culture by 2030. The Common Fisheries Policy (CFP), supported through the European Maritime and Fisheries Fund (EMFF), National Aquaculture Plans, and the EC Strategic Guidelines for Sustainable Aquaculture Development (European Commission, 2013), document the imperative for sustainable increases in aquaculture production to provide economic growth, increased employment, and to reduce the EU's trade deficit in aquatic products, which 2015, stood at €16.7 billion (European Commission, 2016a).

Nevertheless, the projected growth of EU aquaculture to 2030, based on the EMFF aquaculture development plans submitted by EU Member-States (Fig. 2), will result only in an overall growth of 51.4% (Lopes et al., 2017).

Overall, the national plans thus fall short of the 2030 target by 50%, and there is a further concern that almost no information is provided to lend credibility to these projections. There are no data concerning which species will be responsible for this extra growth, where and how cultivation will increase, or on market tendencies and global trade, which will undoubtedly condition investment and business success.

Given the strategic importance of aquaculture in the European Union Blue Growth Initiative (see e.g. European Commission, 2015; European Commission, 2016b), aquaculture development requires new analytical approaches to guide sector investments and achieve an efficient allocation of resources.

Multimetric indices (e.g. OECD, 2008; Schoolmaster Jr. et al., 2013) have been applied in a variety of contexts, from broad-scale health assessment of the global ocean (Halpern et al., 2012) to more specific ecosystem analyses focusing on e.g. eutrophication (Bricker et al., 2003; Xiao et al., 2007), habitat integrity (Shi et al., 2016), phytoplankton diversity (Laplace-Treyture & Feret, 2016), freshwater wetlands (Miller et al., 2016), and sea-level rise (Raposa et al., 2016). However, very little work has been carried out on the application of this type of index to aquaculture (but see Valenti et al., 2018), and the existing literature mainly focuses on the impact of aquaculture on the environment, either in general terms, such as environmental pressures (e.g. Borja et al., 2011), or with respect to specific aspects such as benthic shellfish cultivation (Wang et al., 2017).

Aquaculture investors are faced with decisions under conditions of uncertainty and require analytical solutions to find a balance among multiple competing factors such as regulation, markets, and environmental conditions, that drive the due diligence[1] of aquaculture investment, rather than relying on diffuse individual indicators to measure the potential of success for aquaculture development.

This work aims to provide an integrated analytical approach to support investment decisions for growth of aquaculture in Europe and elsewhere, by developing a multimetric aquaculture investor index that is easily understood and allows a rapid assessment of the relative competitive advantages of different nations.

Four objectives were considered:

1. To identify major categories for an investor index for aquaculture, and their respective indicators, and to develop methodologies for (a) obtaining suitable data; (b) aggregating the component categories into a meaningful final score, i.e. an index that translates the investor appeal of different nations for aquaculture development;
2. To apply this index to European countries, in order to obtain a general ranking based on a broad set of complementary categories;
3. To identify knowledge gaps and help define priorities for use of resources by policy-makers, with the aim of promoting improved management of the aquaculture sector;
4. To promote widespread access to the index through the delivery of a multilingual smartphone application oriented towards industry and investors, and to increase public awareness by means of a dedicated website.

[1] "An investigation or audit of a potential investment or product to confirm all facts, that might include the review of financial records" (Investopedia, https://www.investopedia.com/terms/d/duediligence.asp).

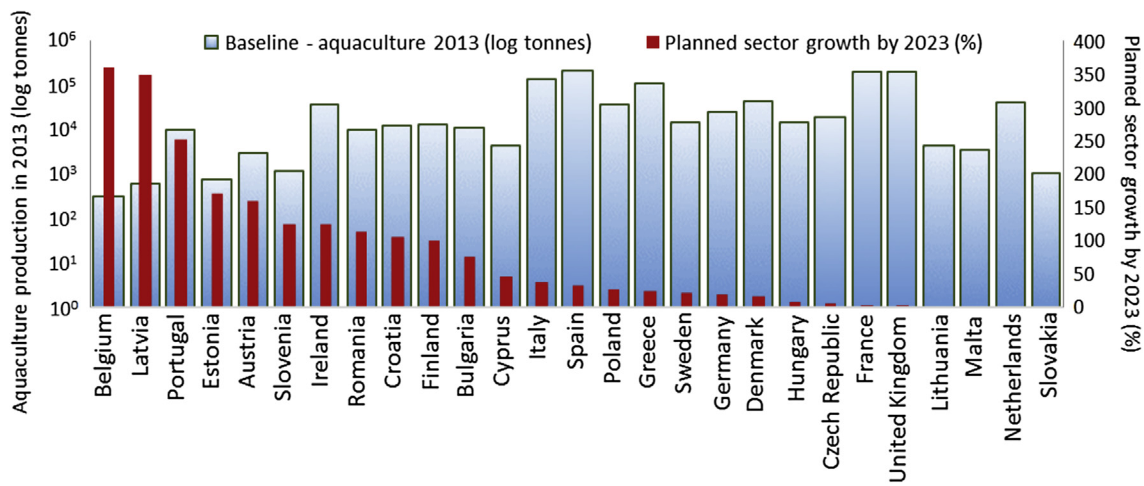

Fig. 2. Summary of national aquaculture development plans for the decade between 2013 and 2023 submitted to the EMFF - note log scale for production data (Lopes et al., 2017).

2. Methods

2.1. Overview

The AQI Index ranks country performance based on indicators that influence aquaculture investment in Europe and identifies where the best conditions to develop aquaculture exist, based on a set of five broad categories, each of which composed of four indicators, considered the most relevant for providing detailed assessment of each category. The combination of categories addresses a set of goals that account for the numerous considerations that make up the aquaculture framework. AQI recognises the linkages that exist in the aquaculture industry, accounts for upstream and downstream elements, and ensures that an ecosystem approach to aquaculture (Soto et al., 2008) is considered. Each of these categories can be considered separately or aggregated into an overall score. The index provides a rating of the current appeal for aquaculture investment in European countries; it is not intended to predict future trends in aquaculture development, but to give a general indication of the current state for each country.

Fig. 3 illustrates the steps used in the conceptualisation, development, and deployment of the AQI index.

2.2. Categories and indicators

The AQI index measures the scores of categories that influence aquaculture investment. Output measures (e.g. hatchery production) are used rather than input measures (e.g. hatchery feed) to avoid double counting. The index is calculated on the basis of the following categories (Fig. 4): Market, Production, Regulatory, Environmental, and Social. Data were grouped at the national level, using quantitative and qualitative assessments to determine individual category and overall country scores.

The rationale for category determination is to define the foundations of a successful aquaculture industry. The market, production, regulatory, environment, and social categories, when combined, provide an assessment framework for decisions about resource allocation in the aquaculture industry. Category selection highlights the diverse linkages between human, societal, and environmental systems, and emphasises the benefits of addressing goals in an integrated manner.

The indicators span a wide range of thematic areas at country level, requiring substantial data sets to capture variations. Categories can be combined into a final score once appropriate data have been collected.

The four indicators in each category (Fig. 4) make up the individual classifications used to calculate the categorical scores. These indicators were selected to reflect the primary concerns to investors across the

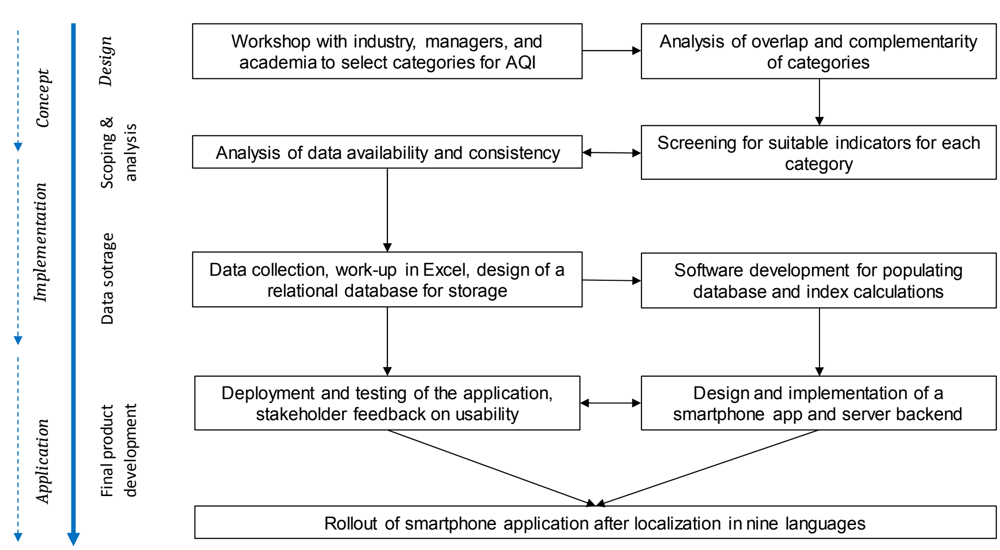

Fig. 3. Workflow for the Aquaculture Investor (AQI) Index product development.

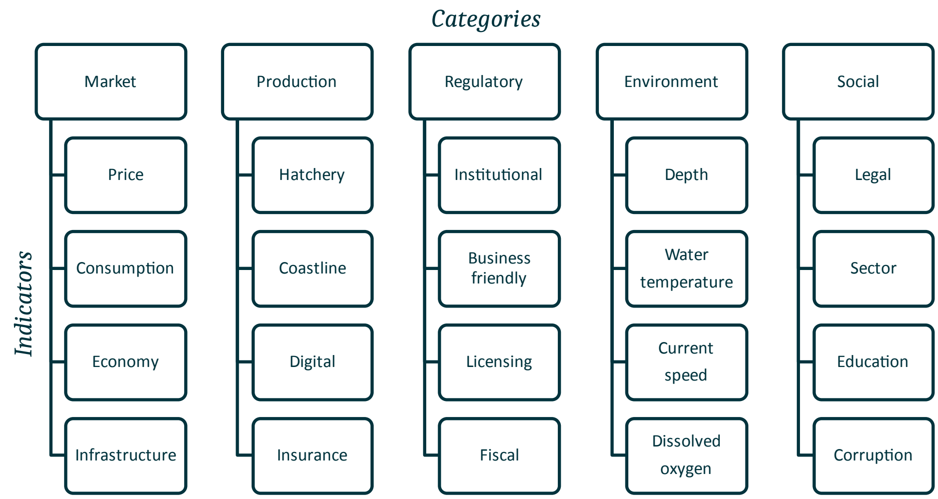

Fig. 4. Aquaculture Investor (AQI) Index categories and indicators.

categories, identified through consultation within the AquaSpace[2] consortium and with external stakeholders (see e.g. Corner et al., 2018).

The indicators for each category in the index are shown in Table 1, together with a description of the data types and methods used. Data accuracy and completion are prioritised for each indicator to ensure that each country has data points, or valid proxies, making use of datasets with the highest possible resolution and confidence.

2.3. Data sources, integrity, and reliability

AQI provides flexibility by accommodating additions or changes in the types of data used for score calculations. All indicator units must follow a standard numeric format and value, and data points are mandatory for all the indicators. The datasets were obtained from a variety of sources and were required to possess sufficient resolution to be included for indicator calculation. The selection of indicators was materially influenced by the availability of comprehensive datasets (Table 1). As new data become available, the indicator framework is subject to modifications to improve the accuracy of the index. European data is presented and published with a high degree of homogeneity, as data collection efforts are coordinated centrally through the regional and European agencies. Expansion of the index to other geographical areas will present challenges related to data resolution and quality, both spatially and temporally, as well as variability in the data collection methodologies. The need for consistent datasets both regionally and nationally is warranted to obtain valid comparisons across countries.

2.4. Model setup

The AQI index is evaluated through a score (σ), where σ is the linear-weighted sum of the scores for each of the categories (σ_1 to σ_n), weighted equally; φ_i is the final score for the ith category; n (=5) is the number of categories (Table 2, Eq. 1).

AQI weights scores equally to avoid introducing a bias with respect to societal preferences for one category over another. The index recognises that different investors will place individual weightings on different categories, but rather than providing pre-established unequal weighting to approximate the outcome of different preferences, the AquaInvestor smartphone application provides user-defined weighting which oscillates between 0.5 and 1.5. φ_i is the category weight for the ith category (Table 2, Eq. 2).

2.4.1. Description of categorical indicators

A description is provided only for a subset of five indicators (one selected from each category), to exemplify the core approach. A comprehensive description for the full indicator list is given in http://www.aquaspace-h2020.eu/wp-content/uploads/2017/10/Smartphone-%E2%80%98Investor-Appeal%E2%80%99-application.pdf (2016).

2.4.2. Market category

The *Price* indicator was chosen as an example for the *Market* category because it is one of the more complex calculations developed for AQI, to encompass the diversity of species and production volumes in every European country. The seven-step algorithm is described below.

2.5. M1 – Price indicator

Price is a leading indicator that signals production and market decisions. Import and export time-series data were compiled for the European Union and Norway and weighted for the percentage price deviation in each country from the European mean. In addition, a double weighting of the percentage price deviation was executed to account for production volumes in each country and ranked from 1 (lowest) to 5 (highest). The price component considers the top eight species grown in Europe[3] by tonnage: Atlantic salmon (*Salmo salar*; 1,423,030 t y^{-1}), Rainbow trout (*Oncorhynchus mykiss*; 360,940 t y^{-1}), gilthead seabream (*Sparus aurata*; 139,768 t y^{-1}), European seabass (*Dicentrarchus labrax*; 161,418 t y^{-1}), common carp (*Cyprinus carpio*; 71,277 t y^{-1}), Mediterranean mussel (*Mytilus galloprovincialis*; 306,864 t y^{-1}), blue mussel (*Mytilus edulis*; 122,579 t y^{-1}), and Pacific oyster (*Magallana gigas*; 75,395 t y^{-1}).

1 - Production matrix - The implementation of a production matrix applies a binary approach to determine whether a country (C) produces (P) one of the top eight species produced in Europe (Table 2, Eqs. 3 and 4).

The presence of species-specific aquaculture scoring is binary, with 1 meaning that a country cultivates that species, and 0 that it does not.

2 - Mean time-series price data - Time-series price data was obtained from the European Market Observatory for Fisheries and Aquaculture (EUMOFA) from 2006-2015, for first sale price and

[2] The EU Horizon 2020 funded AquaSpace project was executed by a consortium that included European, North American, and Chinese partners. The EU and North American parties cooperated under the scope of the Galway Statement (http://www.atlanticresource.org/aora/).

[3] Data from Eurostat for 2016; includes production data for Turkey where applicable.

Table 1
Indicators, metrics, approach, and primary data sources for each category.

Category: Market

Indicator	*Metric*	*Rationale/approach*	*Primary data source*
Price	Historical import/export prices from 2007-2015	Double weighted (production and proportion) percent price deviation. Reflects country's capacity to compete	EUMOFA, FAOSTAT
Consumption	Fish consumption per capita	Time-series per kilogram consumption of fish per capita. Reflects relevance of internal market, and product acceptance	FAOSTAT, 2016
Economy	GDP per capita & current account balance	Measure of economic performance	International Monetary Fund, World Economic Outlook Database, April 2010
Infrastructure	Rail lines per km^2, Air transport, registered carrier departures, and Container port traffic (20 foot-equivalent units)	Tiered systems measuring rail, air, and port movements. Reflects capacity to distribute goods internally and for export	World Bank

Category: Production

Indicator	*Metric*	*Notes*	
Hatchery & nursery	Production of hatcheries and nurseries at eggs stage in life cycle (millions) and at juvenile stage in life cycle (millions)	Normalised hatchery/total production and nursery/total production. Reflects dependency on external sources	Eurostat, 2016
Coastline	Ratio of World Resource Institute coastline length measured against Google Earth values	The larger the ratio, the greater the discrepancy in measurement indicating potentially suitable sites for aquaculture	World Resource Institute, Google Earth
Digital capacity	Mobile phone subscriptions and internet users (per 100 people)	Digital coverage increases the access to information	World Bank
Insurance	Heuristic assessment and/or surveys of the principal insurance markets	Categorization of the tiers of insurance penetration per country, important for industry growth	Lloyds aquaculture underwriters

Category: Regulation

Indicator	*Metric*	*Notes*	
Institutional	Matrix comparing the percentile rank of government effectiveness, political stability, regulatory quality, voice and accountability (% percentile rank)	Assessment to determine rankings of institutional frameworks, reflects the solidity of investment decisions	www.govindicators.org. WGI from Natural Resource Governance Institute and Brookings Institution (Kaufmann) & World Bank Development Research Group (Kraay)
Business-friendly	Matrix comparing the time to start a new business (days), cost of starting a new business (% of GNI per capita), and burden of customs procedure	Assessment to determine the ease of starting a new business	World Bank, Doing Business project (http://www.doingbusiness.org/)
Licensing	Length of time required to obtain an aquaculture licence (0–6, 6–12, 12–18, 18–30, 30 + months)	Tiered scoring per months for aquaculture licensing, accounting for marine, freshwater aquaculture	Interviews with aquaculture managers and industry
Fiscal	Fiscal burden through tax revenue (% of GBP) and labour tax and contributions (% of commercial profits)	Relative fiscal burden faced by private enterprise in each country	World Bank, Doing Business project (http://www.doingbusiness.org/)

Category: Environment

Indicator	*Metric*	*Notes*	
Depth	Area and proportion of a country's EEZ that falls into different classes Depth classes: 0–10 m > 300 m 10–40 m 150–300 m 40–150 m	Categorization of depth classes ranging from desirable to undesirable, important for decisions on moorings, and on availability of marine space	GEBCO bathymetry (1 km^2 resolution)
Temperature	Months during minimum and maximum species temperatures (SST) ranges in a country's EEZ) 6–15 °C 12 months (salmon) – CAT1 11–26 °C 12 months (bream) – CAT2 8–22 °C 12 months (bass) – CAT3	Categorization of water temperature ranges in the Exclusive Economic Zones (per country) for salmon, sea bream, and sea bass, key for animal growth For each range if the country's annual water temperatures fall outside of the range, for every 2 months off the range, a point is withdrawn, so for CAT1: 6–15 °C 10 months: score 4 6–15 °C 8 months: score 3 6–15 °C 6 months: score 2 6–15 °C 4 months or less: score	Copernicus marine services: GLOBAL OCEAN PHYSICS REANALYSIS GLORYS2V3 product
Current speed	Current speed Area and proportion of a country's EEZ that falls into different classes Current speed classes:	Categorization of current speeds ranging from desirable to undesirable. Reflects physiological performance, potential issues with escapees and introgression, and mooring stability	Copernicus marine services: GLOBAL OCEAN PHYSICS REANALYSIS GLORYS2V3 product

(*continued on next page*)

Table 1 (*continued*)

Category: Market			
Indicator	*Metric*	*Rationale/approach*	*Primary data source*
	0–3 cm s^{-1} 50–80 cm s^{-1} 25–50 cm s^{-1} 3–10 cm s^{-1} 10–25 cm s^{-1}		
Dissolved oxygen	Dissolved oxygen Area and proportion of a country's EEZ that falls into different classes Dissolved oxygen classes: ≤2 mg L^{-1} 2–5 mg L^{-1} 5–7 mg L^{-1} > 7 mg L^{-1}	Categorization of dissolved oxygen ranging from desirable to undesirable. Key parameter for survival of cultivated organisms, and a general indicator both for choice of species, and of water quality in relation to anthropogenic activities	Copernicus marine services: GLOBAL OCEAN BIOCHEMISTRY NON ASSIMILATIVE HINDCAST GLORYS2V3 product
Category: Social			
Indicator	*Metric*	*Notes*	
Legal	Rule of law (percentile rank)	Rule of law captures perceptions of the extent to which agents have confidence in and abide by the rules of society	www.govindicators.org
Sectoral	Value of domestic aquaculture as a percentage of aquaculture, first sale and landings, and import/export seafood	Social licence. This is a key aspect, and in Europe, often a significant barrier to entry for development of new facilities, and a limiting factor in expansion	EUMOFA
Education and training	Grants and other revenue (% of revenue) and gross enrolment ratio in tertiary education	A proxy for the degree of labour force sophistication, and reflects the capacity of the workforce e.g. to properly address biosecurity, incorporate emerging technologies, and meet standards e.g. for fish welfare	World Bank
Corruption	Control of corruption (percentile ranking)	The extent of which public power is exercised for private gain, which can affect processes such as licensing, and numerous aspects of day-to-day operation	www.govindicators.org

import/export prices. The data are compiled from numerous sources, including national and EU institutional sources, as detailed at https://www.eumofa.eu/historical-time-series.

The data for import/export prices have a greater resolution when compared to first sale price, because customs authorities declare and publish all movement to EUMOFA. The mean time-series import/export price (V) per species (S) across all European countries was calculated for each nation (Table 2, Eq. 5).

3 - Country output – The production output per species per country was determined to balance discrepancies in price through weighting, correcting for countries where production is negligible, to avoid skewing the competitiveness of a country that has good prices because of a negligible production due to absence of aquaculture for a specific species (Table 2, Eqs. 6 and 7).

4 – Mean percent price deviation – The mean percent price deviation per species was calculated for each European country. The mean deviation is a measure of dispersion, computed by taking the arithmetic mean of the absolute values of the deviations from the average values. This deviation provides an initial indicator to determine, in relative terms, the competitiveness of a species price in each country, when compared to the mean European price per kilogram (Table 2, Eq. 8).

5 – Europe-wide production-weighted percent price deviation – The production-weighted mean price deviation per species for each European country takes into account country prices. The mean price deviation determines the price deviation per species for each country compared to the European average. The percent price deviation for each species is multiplied by each country's production and expressed out of the total European species production. The production-weighted percent price deviation does not allow countries with small productions and good prices to influence their overall score (Table 2, Eq. 9).

6 - Double-weighted (production and proportion) percent price deviation – The double-weighted percent price deviation accounts for production and proportion. The percent deviation of the production-weighted price is multiplied by the species production per country and expressed out of total country production for all species, showing the relative representativeness of each species by production and proportion (Table 2, Eq. 10).

7 - Sum of country double-weighted percent price deviation – In the last step, the sum of the country double-weighted percent price deviations is computed to determine the final score for each country, accounting for weighted production and price in Europe (Table 2, Eq. 11).

A worked example of the application the seven-step algorithm, using generic data, is given in Table 3.

2.5.1. Production category

The availability of space along the coastline was selected as an example indicator in this category, although indicators such as *Hatchery & Nursery* (P1), or *Digital Capacity*, i.e. communication infrastructure and internet access (P3), are also interesting metrics supporting production.

2.6. P2 – Coastline indicator

The coastline paradox states that the length of a country's coastline varies depending on the resolution of the measurement due to inlets, bays, fjords, estuaries, and other coastal features. Coastline

Table 2
Equations used in the Aquaculture Investor (AQI) index.

Category and indicator	Equations for calculation of AQI	List of symbols
Final scores and weighting	$\sigma = \sum_{i=1}^{n} \frac{\varphi_i}{n}$ (Eq. 1) $\sigma = \sum_{i=1}^{n} \left(\frac{\varphi_i \omega_i}{\sum_{i=1}^{n} \omega_i} \right)$ (Eq. 2)	σE− AQI score φQ− Score for category i ωc− weighting coefficient for category i n – number of categories
M1 – Prices	$\lvert P_c = 0, \quad \alpha = 0 \rvert$(Eq. 3) $\lvert P_c > 0, \quad \alpha = 1 \rvert$(Eq. 4) $V_{s=} \frac{1}{c} \sum_{i=c}^{i=1} V_{i,s}$(Eq. 5) $T_c = \sum_{i=1}^{s} C_{s,i}$(Eq. 6) $T_s = \sum_{i=1}^{c} S_{c,i}$(Eq. 7) $W_{c,s} = \frac{V_{c,s} - V_S}{V_S} * 100$(Eq. 8) $M_{c,s} = \frac{W_{c,s} * B_{c,s}}{T_S}$(Eq. 9) $Q_{c,s} = \frac{M_{c,s} * B_{c,s}}{T_C}$(Eq. 10) $Q_c = \sum_{i=1}^{i=s} Q_{c,i}$(Eq. 11)	P_c – production of species by country α – binary flag V – average EU species price (value) B – aquatic production (biomass) T – total aquatic production (biomass) W – % price deviation from mean (weighted) M – production-weighted EU percent price deviation Q - double-weighted (production and proportion) percent price deviation c = country s = species <u>Seven-step algorithm</u> 1) Binary production matrix 2) EU arithmetic species price average 3) Sum of country production 4) % species price deviation from EU average 5) Production-weighted % species price deviation from EU average 6) Double-weighted (production and proportion) % price deviation 7) Sum of country double-weighted % price deviation
M2 – Consumption	$F_{Y,L} = \frac{1}{Y} \sum_{i=1}^{i=Y} F_{Y,L}$ (Eq. 12)	F = consumption per capita y = year L = class The time-series average sum of consumption per capita across all classes of fish (freshwater, demersal, pelagic, marine, crustacean, cephalopod, mollusc, and others) per EU country and Norway
M3 – Economy	$F(GDP)_{y,c} = \frac{1}{Y} \sum_{i=1}^{i=y} F_{y,c}$ (Eq. 13) $F(CUR)_{y,c} = \frac{1}{Y} \sum_{i=1}^{i=y} F_{y,c}$ (Eq. 14)	F(GDP) = result F(CUR) = result y = year c = country The time-series average sum of GDP per capita and current account balance per EU country and Norway
M4 – Infrastructure	$T_{y,c} = \frac{1}{Y} \sum_{i=1}^{i=y} T_{y,c}$(Eq. 15) $V(RAIL) = \frac{T_c}{T_{max}}$(Eq. 16) $V(CAR) = \frac{T_c}{T_{max}}$(Eq. 17) $V(AIR) = \frac{T_c}{T_{max}}$(Eq. 18)	T = mean annual values V(RAIL) = value V(CAR) = value V(AIR) = value c = country y = year The mean annual value for rail lines, air transport, and container port traffic per EU country and Norway, followed by value of each country as a proportion of the maximum value
P1 – Hatchery and nursery	$T_{Y,C} = \frac{1}{Y} \sum_{i=1}^{i=Y} T_{Y,C}$(Eq. 19) $V(HAT) = \frac{T_c}{T_{max}}$(Eq. 20) $V(NUR) = \frac{T_c}{T_{max}}$(Eq. 21)	T = mean annual values V(HAT) = hatchery value V(NUR) = nursery value C = country Y = year The mean annual value for hatchery and nursery production per EU country and Norway, followed by value of each country as a proportion of the maximum value
P2 – Coastline	$R_C = \frac{A_c}{M_c}$(Eq. 22) $S_c = \frac{R_c}{R_{max}} * 100$(Eq. 23)	S = normalised score R = ratio of absolute vs measured A = absolute coastline M = measured coastline c = country The ratio of the absolute coastline against the measured coastline, followed by the value for each country as a proportion of the maximum value
P3 – Digital capacity	$T_{y,c} = \frac{1}{Y} \sum_{i=1}^{i=y} T_{y,c}$ (Eq. 24)	T = mean annual values c = country y = year The mean annual value for mobile subscription and internet users (per 100 people) per EU country and Norway, capped at a value of 100.
P4 – Insurance		Heuristic survey from aquaculture underwriters about the perception of the availability of aquaculture insurance per EU country and Norway
R1 – Institutional	$T_{Y,C} = \frac{1}{Y} \sum_{i=1}^{i=Y} T_{Y,C}$ (Eq. 25)	T = mean annual values c = country Y = year The mean annual value for government effectiveness, political stability, regulatory quality, voice and accountability per EU country and Norway
R2 – Business-friendly	$V(TIME) = \frac{T_c}{T_{max}}$(Eq. 26) $V(COST) = \frac{T_c}{T_{max}}$(Eq. 27) $V(BURDEN) = \frac{T_c}{T_{max}}$(Eq. 28)	T = mean annual values V(TIME) = Time to start a new business V(COST) = Cost of business start-up V(BURD) = Burden of customs procedure c = country Y = year The average yearly value for the time to start a new business, cost of business start-up, and burden of customs per EU country and Norway, followed by value of each country as a proportion of the maximum value.
R3 – Licensing	–	Heuristic survey from various aquaculture regulators about the licensing time per EU country and Norway
R4 – Fiscal	$T_{Y,C} = \frac{1}{Y} \sum_{i=1}^{i=Y} T_{Y,C}$ (Eq. 29)	T = mean annual values C = country Y = year The mean annual value for tax revenue (% of GDP), and Labour tax and contributions per EU country and Norway

(*continued on next page*)

Table 2 (*continued*)

Category and indicator	Equations for calculation of AQI	List of symbols
E1 – Water depth	$E_d = \sum_{i=1}^{i=N_d} \frac{D_c D_s}{100}$ (Eq. 30)	E_d = Environmental depth indicator score D_c = EEZ area in depth class (%) N_d = Number of depth classes Depth class scores (D_s) 0–10 m 1 > 300 m 2 > 10–40 m 3 150–300 m 4 > 40–150 m 5
E2 – Water temperature	$E_{t,s} = \sum_{i=1}^{i=N_t} \frac{T_{c,s} D_{c,s}}{100}$ (Eq. 31) $E_{t,b} = \sum_{i=1}^{i=N_t} \frac{T_{c,b} D_{c,b}}{100}$ (Eq. 32) $E_{t,g} = \sum_{i=1}^{i=N_t} \frac{T_{c,g} D_{c,g}}{100}$ (Eq. 33) $E_t = max(E_{t,s}, E_{t,b}, E_{t,g})$ (Eq. 34)	$E_{t,s}$ = Temperature score (salmon) $E_{t,b}$ = Temperature score (seabass) $E_{t,g}$ = Temperature score (gilthead) $T_{c,s}$ = EEZ area in temperature class salmon (%) $T_{c,g}$ = EEZ area in temperature class gilthead (%) $T_{c,b}$ = EEZ area in temperature class bass (%) N_t = Number of temperature classes E_t = Environmental temperature indicator score Temperature indicator ranges per species (inclusive) - score 5 for 12 months: 6–15 °C ($D_{c,s}$: salmon) 11–26 °C ($D_{c,g}$: gilthead bream) 8–22 °C ($D_{c,b}$: bass) If compliant period is: 4 months or less 1 6 months 2 8 months 3 10 months 4
E3 – Current speed	$E_s = \sum_{i=1}^{i=N_S} \frac{S_c S_S}{100}$ (Eq. 35)	E_s = Environmental current speed indicator score S_c = EEZ area in current speed class (%) N_s = Number of current speed classes Current speed class scores (S_s): 0–3 cm s^{-1} 1 > 50–80 cm s^{-1} 2 > 25–50 cm s^{-1} 3 > 3–10 cm s^{-1} 4 > 10–25 cm s^{-1} 5 The typical maximum current speed (percentile 90) is used for calculation
E4 – Dissolved oxygen	$E_o = \sum_{i=1}^{i=N_O} \frac{O_c O_s}{100}$ (Eq. 36)	E_o = Environmental oxygen indicator score O_c = EEZ area in depth class N_o = number of depth classes Dissolved oxygen class scores (O_s) – *note there is no score 3* ≤ 2 mg L^{-1} 1 > 2–5 mg L^{-1} 2 > 5–7 mg L^{-1} 4 > 7 mg L^{-1} 5 The typical minimum current speed (percentile 10) is used for calculation
S1 – Legal	$T_{Y,C} = \frac{1}{Y} \sum_{i=1}^{i=Y} T_{Y,C}$ (Eq. 37)	T = mean annual values c = country y = year The mean annual value the rule of law (percentile rank) per EU country and Norway
S2 – Sectoral importance	$T_{A,\,C,Y} = \sum_{i=1}^{i=Y} A_{C,i}$ (Eq. 38) $T_{F,\,C,Y} = \sum_{i=1}^{i=Y} F_{C,i}$ (Eq. 39) $T_{W,\,C,Y} = \sum_{i=1}^{i=Y} W_{C,i}$ (Eq. 40) $T_{total} = \sum T_A, T_F, T_W$ (Eq. 41) $R = \frac{T_A}{T_{total}}$ (Eq. 42)	R – ratio value T – Total value A – aquaculture value F – first landings sale W – import and export values c = country y = year The sectoral importance of aquaculture is calculated by summing the annual value of aquaculture, first sale of landings, and export/import per EU country and Norway, and dividing the total values of aquaculture against the total value of seafood to obtain a proportion
S3 – Education	$T_{y,c} = \frac{1}{Y} \sum_{i=1}^{i=y} T_{y,c}$ (Eq. 43) $E_c = \frac{T_c}{T_{max}}$ (Eq. 44)	T = mean annual values c = country y = year E = Enrolment value The mean annual value for grants and other revenue, gross enrolment ratio (tertiary sector) per EU country and Norway, and the mean annual number of technicians in research and development as a proportion of the maximum value
S4 – Corruption	$T_{y,c} = \frac{1}{Y} \sum_{i=1}^{i=y} T_{y,c}$ (Eq. 45)	T = average of annual values c = country y = year The mean annual value for control of corruption per EU country and Norway

measurement from the World Resource Institute was used, in addition to a manual measurement of all the European coastlines using Google Earth. The World Resource Institute coastline length is divided by the Google Earth coastline length to obtain a ratio. The larger the ratio, the greater the discrepancy between the World Resources Institute and Google Earth measurement, meaning that the coastline has a greater number of coastal features such as sheltered areas that could indicate increased suitability for aquaculture (Table 2, Eqs. 22 & 23).

Table 3
Worked example for the Market – Price (M1) indicator using a 7-step algorithm (see text and Table 2 for equations).

Country/Species	Portugal	United Kingdom	Norway	Mean or Total
Step 1: Boolean existence matrix				
Bass	1	1	0	
Bream	1	0	0	
Salmon	0	1	1	
Manila clam	1	1	0	
Step 2: Average price over 10 years (€ kg^{-1})				
Bass	6	12		9
Bream	5			5
Salmon		5	6	5.5
Manila clam	10	2		6
Step 3: Production volume (tonnes)				
Species				
Bass	20000	15000		35000
Bream	12000			12000
Salmon		150000	1200000	1350000
Manila clam	5000	2000		7000
Total	37000	167000	1200000	
Step 4: Percent price deviation from mean				
Bass	−33.33	33.33		
Bream	0.00			
Salmon		−9.09	9.09	
Manila clam	66.67	−66.67		
Step 5: Europe-wide production-weighted percent price deviation				
Bass	−19.05	14.29		
Bream	0.00			
Salmon		−1.01	8.08	
Manila clam	47.62	−19.05		
Step 6: Double-weighted (production and proportion) percent price deviation				
Bass	−10.30	1.28		
Bream	0.00			
Salmon		−0.91	8.08	
Manila clam	6.44	−0.23		
Step 7: Integration				
Total	−3.86	0.15	8.08	

2.6.1. Regulatory category

The methodology detailed below illustrates the calculation of how business-friendly each country considered in the AQI is.

2.7. R2 – Business-friendly indicator

The institutional indicators aim to measure the quality of the institutions in the European Union and Norway, and include the time to start a new business, the cost of business start-up procedures and burden of customs procedure. Data were obtained from the World Bank and expressed annually as a percentile rank from 2005 to 2014. The annual means for each component were taken and averaged again to obtain a final score ranging between 1 (lowest) and 5 (highest).

Entrepreneurs around the world face a range of challenges. One of them is inefficient regulation. This indicator measures the procedures, time, cost, and paid-in minimum capital required for a small or medium-size limited liability company to start up and formally operate. Data are collected by the World Bank with a standardized survey that uses a simple business case to ensure comparability across economies and over time, with assumptions about the legal form of the business, its size, location, and nature of operation (Doing Business methodology, The World Bank Doing Business, 2018). Surveys are administered through more than 9000 local experts, including lawyers, business consultants, accountants, freight forwarders, government officials, and other professionals who routinely administer or advise on legal and regulatory requirements.

Entrepreneurs may not be aware of all required procedures or may avoid legally required procedures altogether—but where regulation is particularly onerous, levels of informality are higher, which comes at a cost: firms in the informal economy usually grow more slowly, have less access to credit, and employ fewer workers - and those workers remain outside the protections of labour law. This indicator can therefore help policy-makers understand the business environment in a country.

Time needed to start a new business – The number of calendar days needed to complete all required procedures to legally operate a commercial or industrial firm are recorded by this indicator. Requirements may include obtaining necessary licenses and permits as well as completing any required notifications, verifications, and inscriptions for the company and its employees with relevant authorities. This indicator captures the median duration that incorporation lawyers indicate is necessary to complete each procedure. If a procedure can be speeded up at additional cost, the fastest procedure, independent of cost, is chosen (Table 2, Eq. 26).

The economic health of a country is measured not only in macroeconomic terms but also by other factors that shape daily economic activity such as laws, regulations, and institutional arrangements. The data measure business regulation, gauge regulatory outcomes, and evaluate the extent of legal protection of property, the flexibility of employment regulation, and the tax burden on businesses.

The fundamental premise of these data is that economic activity requires good rules and regulations that are efficient, accessible to all who need to use them, and simple to implement. Thus, sometimes there is more emphasis on more regulation, such as stricter disclosure requirements in related-party transactions, and other times emphasis is on simplified regulations, such as a one-stop-shop for completing business start-up formalities. In the specific case of aquaculture, licensing for coastal farms is often burdened by lack of transparency about the attribution process, and/or the jurisdiction of different agencies on different areas such as water usage, pollution, production, and biosecurity.

Cost of business start-up procedures – Cost to register a business is normalised by presenting it as a percentage of gross national income (GNI) per capita (Table 2, Eq. 27).

Burden of customs procedures – Burden of Customs Procedure measures business executives' perceptions of their country's efficiency of customs procedures. The rating ranges from 1 to 7, with a higher score indicating greater efficiency. Data are from the World Economic Forum's Executive Opinion Survey, conducted for 30 years in collaboration with 150 partner institutes. The 2009 round included more than 13,000 respondents from 133 countries. Sampling follows a dual stratification based on company size and the sector of activity. Data are collected online or through in-person interviews, and responses are aggregated using sector-weighted averaging. The data for the latest year are combined with the data for the previous year to create a two-year moving average. The lowest score (1) rates the customs procedure as extremely inefficient, and the highest score (7) as extremely efficient (Table 2, Eq. 28).

The World Economic Forum's annual Global Competitiveness Reports have studied and benchmarked the many factors underpinning national competitiveness. The goal has been to provide insight and stimulate discussion among all stakeholders on the best strategies and policies to help countries overcome the obstacles to improving competitiveness. It serves as a critical reminder of the importance of structural economic fundamentals for sustained growth.

2.7.1. Environment category

In the present version of AQI, the environmental indicators were applied only to the marine environment. A Geographic Information System (GIS) analysis was implemented to determine the environmental conditions available in each country's Exclusive Economic Zone (EEZ). Layers were created for bathymetry, water temperature, current speed, and dissolved oxygen at the resolution of 1 km^2. The overlay of these data layers was combined with data on species thresholds (Ferreira et al., 2017) to provide a baseline identification of suitability for aquaculture in Europe. All data were obtained from publicly available sources (Table 1). The approach taken for the *Water Temperature* indicator is described below.

2.8. E2 – Water temperature indicator

Water temperature is a primary consideration for aquaculture, key both to establish suitability for a particular species and to determine the time required to grow a species to market size.

Water temperature in marine systems was acquired through Copernicus. Temperature was then reclassified into four classes, where the highest (4) corresponds to ten or more months with suitable temperatures, based on the temperature thresholds available for target species (Atlantic salmon, gilthead bream, and European seabass, depending on the region). Class 3 corresponds to 6–8 months within thresholds, class 2 to 4–6 months, and the lowest class (1) to four or less months with suitable temperatures, (Table 1). The country scores were calculated through the summation of the water temperature class (N_t) for each country, multiplied by the temperature category values per species (e.g. $T_{c,s}$ $D_{c,s}$) divided by 100 (Table 2, Eqs. 31, 32, 33, 34). The reclassified data (Fig. 5) show the scores of all the European EEZs.

Temperature for lakes and reservoirs was calculated using the MODIS land surface temperature product but is not presently used. For the five landlocked countries (Austria, Czech Republic, Hungary, Luxembourg, and Slovakia) included in AQI, the final score is calculated by weighting the four other categories (Market, Production, Regulatory, and Social) and removing the Coastline indicator from the Production category.

2.8.1. Social category

Finally, one example is detailed for the Social category.

2.9. S3 – Education & training indicator

Grants and other revenue – Grants and other revenue, as provided by the World Bank, include grants from other foreign governments, international organizations, and other government units; interest; dividends; rent; requited, nonrepayable receipts for public purposes such as fines, administrative fees, and entrepreneurial income from government ownership of property; and voluntary, unrequited, nonrepayable receipts other than grants (Table 2, Eq. 43).

Gross enrolment ratio – Gross enrolment ratio is the ratio of total enrolment, regardless of age, to the population of the age group that officially corresponds to the level of education shown. Tertiary education, whether or not it leads to an advanced research qualification, normally requires, as a minimum condition of admission, the successful completion of education at the secondary level.

Gross enrolment ratios indicate the capacity of each level of the education system, but a high ratio may mean that the number of overage children enrolled in each grade because of repetition or late entry, rather than a successful education system, is likely to be substantial. The net enrolment rate excludes overage and underage students and more accurately captures the system's coverage and internal efficiency. Differences between the gross and net enrolment rates show the incidence of overage and underage enrolment (Table 2, Eq. 44).

3. Results and discussion

3.1. Weighting criteria

The weighting criteria that apply to each category of AQI are considered to be equal due to the absence of statistical or empirical preference data, despite the knowledge that the interests and motivations for aquaculture stakeholders differ. Given the complexity of assuming stakeholder preferences, instead of applying a scenario analysis with pre-defined weighting permutations, the AQI app gives users the ability to establish their own weighting criteria, based on individual interest per category, to recalculate the final country scores.

The ability to allow stakeholders to choose between a weighting range of 0.5 to 1.5 allows the index to be representative, rather than prescriptive. An individual-stakeholder-preference-based approach

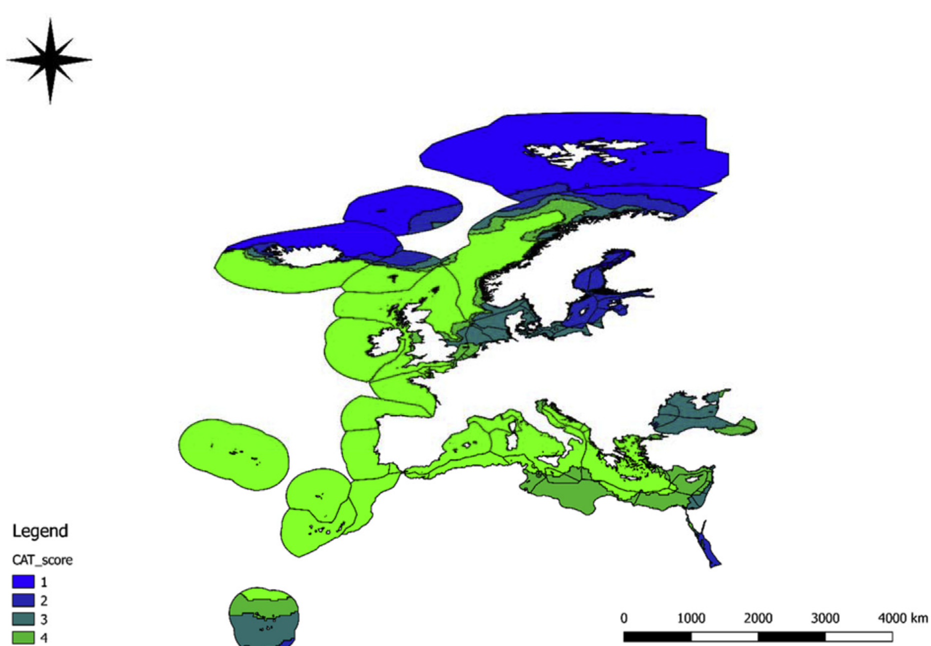

Fig. 5. Reclassified water temperature data for European country EEZ using GIS.

Table 4
Categorical and aggregate scores of the Aquaculture Investor (AQI) index (landlocked countries in italics).

Country	Total	Market	Production[a]	Regulatory	Environmental[b]	Social
Austria	69.33	15.17	10.50	12.00	–	14.33
Belgium	60.50	15.33	10.67	11.00	12.00	11.50
Bulgaria	52.50	9.67	11.50	9.00	14.00	8.33
Croatia	58.17	9.67	12.83	12.00	17.00	6.67
Cyprus	64.50	12.50	9.83	13.00	13.00	16.17
Czech Republic	61.56	13.50	10.33	11.00	–	11.33
Denmark	76.50	16.00	17.17	16.00	13.00	14.33
Estonia	61.67	13.33	10.67	13.00	14.00	10.67
Finland	77.17	16.17	16.33	16.00	14.00	14.67
France	74.67	14.33	16.00	13.00	16.00	15.33
Germany	68.33	17.17	12.67	12.00	13.00	13.50
Greece	57.83	10.50	13.83	11.00	13.00	9.50
Hungary	56.67	8.50	8.67	13.00	–	12.33
Ireland	69.17	11.17	15.33	14.00	14.00	14.67
Italy	59.17	14.33	14.33	8.00	14.00	8.50
Latvia	57.17	13.33	10.50	10.00	14.00	9.33
Lithuania	60.33	14.33	10.67	10.00	16.00	9.33
Luxembourg	68.00	15.00	9.67	12.00	–	14.33
Malta	69.33	12.50	11.83	13.00	15.00	17.00
Netherlands	70.33	18.00	12.67	14.00	13.00	12.67
Norway	78.50	12.00	18.17	17.00	13.00	18.33
Poland	57.33	14.50	14.17	8.00	14.00	6.67
Portugal	61.00	12.67	11.83	11.00	14.00	11.50
Romania	47.83	10.67	12.50	8.00	12.00	4.67
Slovakia	54.89	12.50	9.50	10.00	–	9.17
Slovenia	60.50	12.33	8.83	13.00	15.00	11.33
Spain	68.00	16.50	16.17	8.00	14.00	13.33
Sweden	76.00	17.00	13.67	15.00	16.00	14.33
United Kingdom	78.83	17.33	17.17	13.00	16.00	15.33

[a] 'Coastline' indicator omitted for landlocked countries, see text for explanation.
[b] Category omitted for landlocked countries, see text for explanation.

removes the need to derive pre-defined weightings empirically, allowing for the score calculation of all preferences within the weighting ranges. Using mobile technology to capture user choices lends value to the index through its flexibility, enabling mainstream and long-tail preferences to be accounted for, thereby increasing the usefulness of the index for the end-user.

3.2. Scores

The AQI indicator and category scores are given in Table 4, providing a comparison across European countries. The highest scoring countries are the United Kingdom (78.83), Norway (78.50), and Finland (77.17). The lowest scoring countries are Slovakia (54.89), Bulgaria (52.50), and Romania (47.83).

A breakdown of the highest and lowest-ranked countries analysed by category is provided below.

- Top three performing countries in the market category: Netherlands (18.00), the United Kingdom (17.33), and Germany (17.17). The three lowest performing countries were Hungary (8.50), Bulgaria (9.67), and Croatia (9.67);
- Top three performing countries in the production category: Norway (18.17), Denmark (17.17), and the United Kingdom (17.17). The three lowest performing countries[4] were Latvia (10.8), Cyprus (9.83), and Slovenia (8.83);
- Top three performing countries in the regulatory category: Norway, Denmark, and Finland (17.00). The lowest performing countries were Italy, Poland, Romania, and Spain (8.00).
- Top performing countries in the environment category: Croatia (17.00), France, Lithuania, Sweden, and the United Kingdom (16.00). The lowest performing countries were Latvia, Poland, Bulgaria (14.00), and Romania (12.00);
- Top performing countries in the social category: Norway (18.83), Malta (17.00), and Cyprus (16.17). The lowest performing countries were Romania (4.67), Croatia (6.67), and Poland (6.67).

An analysis of these results shows that Norway and the UK appear most consistently in the highest-ranked three countries, whereas Poland and Romania are mainly in the lower part of the range of 29 countries. Cyprus and Croatia appear in the top three in one category, but in the bottom three for another. These results illustrate the within-country variance of scores for some nations and show that no category has an identical set of highest- or lowest-scoring countries.

A sensitivity analysis performed with respect to the weighting factors shows that the index can change by up to ± 8% for a particular country, but generally the change varies between ± 1–4%. As an example, setting the categorical weights to Market = 0.5, Production = 1.5, Regulatory = 0.5, Environment = 0.5, and Social = 1.0, results in higher scores for both Norway (82.23) and the United Kingdom (80.31), with Norway scoring highest out of all 29 countries.

The competitiveness of different European countries is summarized in Fig. 6. The colour coding system was attributed heuristically and corresponds to the following ranges: High (90–100), Good (70–90), Moderate (30–70), Poor (10–30), and Bad (0-10).

The ranges defined for the five classes follow a typical Gaussian distribution: the *Moderate* band, at the centre of the distribution, is broadest, followed by narrower ranges of *Good* and *Poor* on either side, and finally by narrower ranges of *High* and *Bad*. The nomenclature is taken from the Water Framework Directive (WFD - 2000/60/EC, European Commission, 2000), which itself considers this kind of distribution as a potential ranking order for Biological Quality Elements (*sensu* WFD).

The highest scoring nations are in the upper band of the *Good*

[4] The Czech Republic, Luxembourg, Slovakia, and Hungary were excluded because although their scores are among the lowest in this category, the *Coastline* indicator is not used.

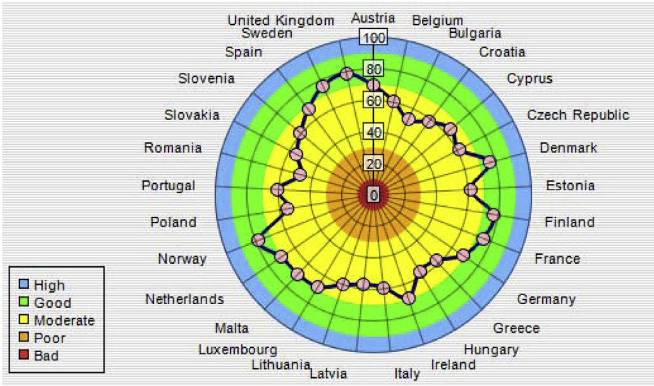

Fig. 6. Aquaculture Investor (AQI) Index results.

classification, and the lowest scores fall into the *Moderate* category, i.e. no countries in Europe fall into the lower two classification bands.

The index scores calculated for Europe range from Moderate to Good. Countries with well-established aquaculture sectors in northern Europe score well, whereas countries in southern Europe tend to score moderately. Countries with developing aquaculture sectors tend to score moderately. High scores within single categories can be achieved, however to provide the highest appeal for stakeholders, the index rewards countries with high scores across the five categories. No countries within Europe rank below the middle of the moderate range.

The index identifies several countries with high scores that do not have significant aquaculture industries (e.g. Sweden and Finland), and further research is required to identify why aquaculture has not developed in these countries to any significant extent. It is expected that as the index is expanded to lower income countries spanning other geographic regions, nations with lower quality indicator scores, particularly with respect to the regulatory, environment, and social categories will have lower overall scores.

The lack of industry growth in the European Union cannot be explained solely by factors internal to Europe itself. While it is indisputable that lengthy and convoluted lease approval procedures in many EU countries, together with social license issues, are internal constraints that make Europe less competitive, it is clear that lack of growth must also be driven by other factors, particularly lack of price competitiveness, together with aspects such as cost structure.

A common attribute of aquaculture markets with sustainable competitive advantages is the tendency to have high combinatorial scores across the categories. While categories can be viewed as standalone assessments, i.e. as tools to address specific questions, the combination of category scores provides a more robust indication of the conditions for aquaculture development.

Very few studies exist for comparison with AQI. Valenti et al. (2018) defined a set of sustainability indicators for assessing aquaculture systems and applied these in a set of case studies in Brazil. Their work is oriented to the farm-scale, and does not combine indicators into an overall score, whereas AQI provides a broader overview, both in terms of scale and integration. Farm-scale sustainability assessment using indicator suites is well established for certification purposes (Bush, 2018; Tlusty et al., 2016; Vandergeest & Unno, 2012), and other sustainability assessment approaches such as dynamic modelling (see Ferreira et al., 2013, for a review) of production, environmental effects, and economic performance have been applied in many parts of the world, but this work is perhaps the first to provide a comparison across a number of countries using a range of complementary metrics.

3.3. Limitations and future work

The development and application of an index of this nature must strike a balance between an ideal conceptualisation and the number and quality of available data. The scale at which such an analysis should be performed is also a consideration, since micro- and macro-economic aspects are both important, and even sector-scale components are relevant. In this work, we focus mainly on 'macro' indicators (e.g. *infrastructure*, *digital capacity*, *corruption*), but include some 'meso' indicators more relevant at the sector scale, such as *hatchery & nursery*, *coastline*, and *mooring depths*.

Equally, we recognise that the index could be enhanced with dynamic components such as change in demand, although given the global nature of trade in aquatic products, country-scale trends might not prove useful.

Some indicators such as infrastructure and digital capacity may crosscut categories—this is inevitable, and such indicators were placed in the category considered most relevant.

The index considers existing data and will be updated as new data become available. No provisions are made to predict future improvement or deterioration of indicator scores, and it is possible that national statistics offices have failed to collect or report material facts and statistics that could influence national scores. The environment category currently accounts only for the marine (EEZ) environment in the GIS analysis—this is a priority area for future development of AQI, particularly when considering that 70% of aquaculture worldwide is land-based.

A major area where data are lacking is social license; because this is often based on perception and relates to objections about aspects such as visual impact, noise, increases in navigation, or land-based processing facilities, it is extremely challenging to evaluate on a country-wide scale (Young et al., 2019). Nevertheless, given the generally high scores achieved by most European countries, it may well be that public objections to siting, or competing claims which are often better established, are the dominant factors that constrain aquaculture expansion (see e.g. Billing, 2018).

AQI is designed to provide high-level guidance of the general attractiveness for aquaculture in each country, which justifies a broad-scale approach across a wide range of categories; the AQI scores must therefore be interpreted in this context. Appropriate due diligence for specific circumstances is therefore warranted by stakeholders to assist in decision-making. The requirements for such local-scale assessments are to some extent implicit in the regulatory component of AQI, reflecting the fact that different regions mandate application of specific models or tailored studies as a pre-condition for licensing.

The AquaInvestor smartphone app (Fig. 7) and its companion website were designed with scalability in mind. Multilingual capability is critical in order to address the target markets for this work, and the software implementation readily allows the addition of more languages—at installation, if a match is made between one of the nine languages of the app and a user's operating system language, AquaInvestor is installed in the appropriate language. The scores for all indicators are stored in the cloud, so that any updates are seamlessly made available to the user; this makes software maintenance and enhancement very straightforward—for instance, the addition of more countries, and score modification as more and/or better data are sourced, will not require a reinstall of the app.

4. Conclusions

The obstacles to development of aquaculture production in Europe, the United States, and Canada are multiple and diverse, but this is not the case with respect to consumption. The EU and US import the vast majority of aquatic products they consume, and despite vocal opposition by some consumer groups, European and US consumers place their trust in the supermarkets where they purchase their food. Any product inspection in European and North American outlets, including markets, stores, and restaurants, shows that about half the fish on offer are cultivated—this is unsurprising since over half of the global production of fish relies on aquaculture (FAO, 2016).

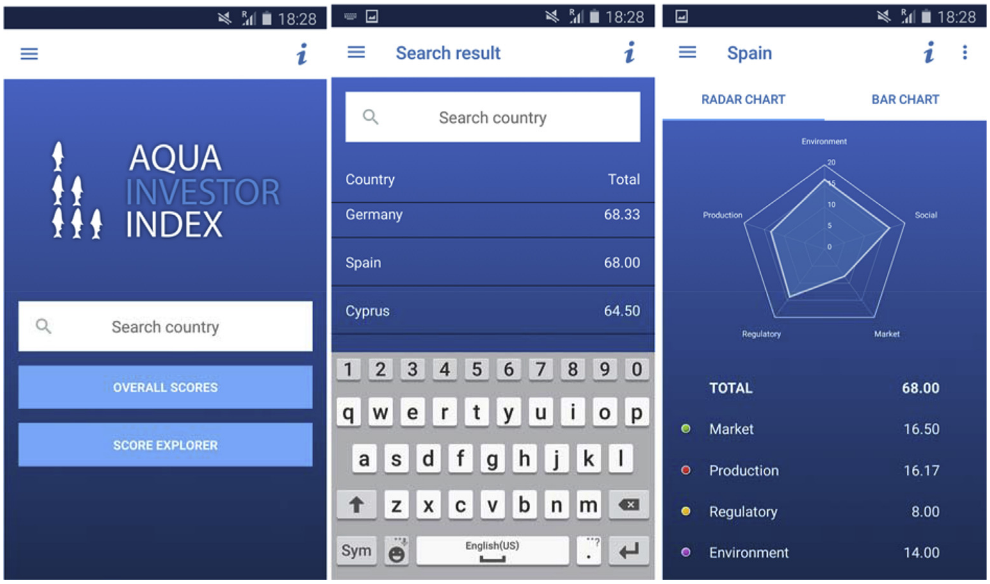

Fig. 7. Screenshots of the AquaInvestor smartphone application, available in nine languages on Google Play.

The lack of growth of this food production sector in developed countries is extremely worrying, mainly for reasons of food security and food safety, but also because of job creation. The European Union's Common Fisheries Policy has shown exponential growth in the size of its policy documents, but unfortunately this does not translate into sector growth (Pastoors, 2014).

As AQI is applied in other parts of the world, including emerging economies, a broader picture will emerge with respect to global competitiveness. The index can also be applied within countries, e.g. to compare individual states in the USA or Canada, which have different requirements for licensing.

The use of a range of criteria (categories), and the selection of appropriate indicators for these, makes it possible to examine what competitive advantages each country holds for attracting investment in aquaculture. It is also valuable to compare nations on an individual category basis. Our intention in developing the Aquaculture Investor Index was (i) to support investment decisions, by providing a sector overview; and (ii) help policy-makers understand which barriers to entry might be more significant in their country when compared to others, and therefore help to shape future decisions and promote growth of sustainable aquaculture.

Acknowledgements

The authors acknowledge funding from the EU Horizon 2020 AquaSpace project (H2020 Grant Agreement Nº 633476). J.P. Nunes is also funded by the Portuguese Foundation for Science and Technology (grant ref. IF/00586/2015), co-funded by the European Social Fund. Jon Grant is funded by the Natural Sciences and Engineering Research Council of Canada, and Cooke Aquaculture, as an Industrial Research Chair. The authors express their thanks to J. Lencart e Silva for support with the environmental analysis, and to three reviewers for comments on earlier drafts of this text.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aquaculture.2019.734600.

References

Billing, S.-L., 2018. Using public comments to gauge social licence to operate for finfish aquaculture: lessons from Scotland. Ocean Coast Manag. 165, 401–415.
Bricker, S.B., Ferreira, J.G., Simas, T., 2003. An integrated methodology for assessment of estuarine trophic status. Ecol. Model. 169 (1), 39–60.
Boonstra, W.J., Valman, M., Björkvik, E., 2018. A sea of many colours – how relevant is Blue Growth for capture fisheries in the Global North, and vice versa? Mar. Policy 87, 340–349.
Borja, A., Barbone, E., Basset, A., Borgersen, G., Brkljacic, M., Elliott, M., Garmendia, J.M., Marques, J.C., Mazik, K., Muxika, I., Neto, J.M., Norling, K., Rodríguez, J.G., Rosati, I., Rygg, B., Teixeira, H., Trayanova, A., 2011. Response of single benthic metrics and multi-metric methods to anthropogenic pressure gradients, in five distinct European coastal and transitional ecosystems. Mar. Pollut. Bull. 62 (3), 499–513.
Bush, S.R., 2018. Understanding the potential of eco-certification in salmon and shrimp aquaculture value chains. Aquaculture 493, 376–383.
Carlucci, D., Nocella, G., De Devitiis, B., Viscecchia, R., Bimbo, F., Nardone, G., 2015. Consumer purchasing behaviour towards fish and seafood products. Patterns and insights from a sample of international studies. Appetite 84, 212–227.
Corner, R.A., Aguilar-Manjarrez, J., Massa, F., Fezzardi, D., 2018. Multi-stakeholder Perspectives on Spatial Planning Processes for Mariculture in the Mediterranean and Black Sea. https://doi.org/10.1111/raq.12321. Reviews in Aquaculture.
Cressey, D., 2009. Future fish- News feature. Nature 458, 398–400.
Ehlers, P., 2016. Blue growth and ocean governance—how to balance the use and the protection of the seas. WMU J. Marit. Aff. 15 (2), 187–203.
European Commission, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community actions in the field of water policy. Official Journal of the European Communities L327, 1 22.12.2000.
European Commission, 2013. Strategic Guidelines for the Development of EU Aquaculture. COM (2013) 229 Final. European Commission, pp. 12.
European Commission, 2015. Implementation of the Rules on Finfish Aquaculture. European Commission, pp. 43.
European Commission, 2016a. Facts and Figures on the Common Fisheries Policy. European Commission, pp. 56.
European Commission, 2016b. On the Application of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) in Relation to Aquaculture. European Commission Working Document, pp. 36.
Eurostat, 2016. European Aquaculture Statistics. accessed via. https://www.longline.co.uk/meta.
FAO, 2014. The State of World Fisheries and Aquaculture. FAO Rome, pp. 243.
FAO, 2016. The State of World Fisheries and Aquaculture 2016. Contributing to Food Security and Nutrition for All. Rome. pp. 204.
Ferreira, J.G., Grant, J., Verner-Jeffreys, D., Taylor, N., 2013. Carrying capacity for aquaculture, modeling frameworks for determination of. In: Meyers, Robert A. (Ed.), Encyclopedia of Sustainability Science and Technology. Springer, 978-0387894690, pp. 1–32.
Ferreira, J.G., Boogert, F.J., Cubillo, A.M., Nunes, J.P., Lencart e Silva, J., Corner, R.A., Ferreira, R.G., 2017. Top-down Assessment of Aquaculture Expansion Potential in Europe. Aquaculture Canada and Sea Farmers 2017. Halifax, May 29-31st 2017. Invited Talk.
Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2012. The challenge of food security. Science 327, 812–818.
Halpern, B.S., Longo, C., Hardy, D., McLeod, K.L., Samhouri, J.F., Katona, S.K., Kleisner, K., Lester, S.E., O'Leary, J., Ranelletti, M., Rosenberg, A.A., Scarborough, C., Selig, E.R., Best, B.D., Brumbaugh, D.R., Chapin, F.S., Crowder, L.B., Daly, K.L., Doney,

S.C., Elfes, C., Fogarty, M.J., Gaines, S.D., Jacobsen, K.I., Karrer, L.B., Leslie, H.M., Neeley, E., Pauly, D., Polasky, S., Ris, B., St Martin, K., Stone, G.S., Sumaila, U.R., Zeller, D., 2012. An index to assess the health and benefits of the global ocean. Nature 488, 615–620.

Lane, A., Hough, C., Bostock, J., 2014. The Long-Term Economic and Ecologic Impact of Larger Sustainable Aquaculture. pp. 96 EU Parliament Study IP/B/PECH/IC/2013_162 Fisheries.

Laplace-Treyture, C., Feret, T., 2016. Performance of the Phytoplankton Index for Lakes (IPLAC): a multimetric phytoplankton index to assess the ecological status of water bodies in France. Ecol. Indicat. 69, 686–698.

Lopes, A.S., Ferreira, J.G., Vale, C., Johansen, J., 2017. The mass balance of production and consumption: supporting policy-makers for aquatic food security. Estuar. Coast Shelf Sci. 188, 212–223.

Merino, G., Barange, M., Blanchard, J.L., Harle, J., Holmes, R., Allen, I., Allison, E.H., Badjeck, M.C., Dulvy, N.K., Holt, J., Jennings, S., Mullon, C., Rodwell, L.D., 2012. Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? Glob. Environ. Chang. 22, 795–806.

Miller, K.M., Mitchell, B.R., McGill, B.J., 2016. Constructing multimetric indices and testing ability of landscape metrics to assess condition of freshwater wetlands in the Northeastern US. Ecol. Indicat. 66, 143–152.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies. Nature 405, 1017–1024.

Organisation for European Cooperation and Development (OECD), 2008. Handbook on Constructing Composite Indicators. Methodology and User Guide. pp. 162 OECD, JRC, EC 2008.

Pastoors, M.A., 2014. Exponential growth in the number of words used for the European Common Fisheries Policy (CFP): does better management require more text? Mar. Policy 46, 101–104.

Raposa, K.B., Wasson, K., Smith, E., Crooks, J.A., Delgado, P., Fernald, S.H., Ferner, M.C., Helms, A., Hice, L.A., Mora, J.W., Puckett, B., Sanger, D., Shull, S., Spurrier, L., Stevens, R., Lerberg, S., 2016. Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices. Biol. Conserv. 204 (B), 263–275.

Schoolmaster Jr., D.R., Grace, J.B., Schweiger, E.W., Guntenspergen, G.R., Mitchell, B.R., Miller, K.M., Little, A.M., 2013. An algorithmic and information-theoretic approach to multimetric index construction. Ecol. Indicat. 26, 14–23.

Shannon, L., Coll, M., Bundy, A., Gascuel, D., Heymans, J.J., Kleisner, K., Lynam, C.P., Piroddi, C., Tam, J., Travers-Trolet, M., Shin, Y., 2014. Trophic level-based indicators to track fishing impacts across marine ecosystems. Mar. Ecol. Prog. Ser. 512, 115–140.

Shi, X., Liu, J., You, X., Bao, K., Meng, B., Chen, B., 2016. Evaluation of river habitat integrity based on benthic macroinvertebrate-based multi-metric model. Ecol. Model. 353, 63–76.

Soto, D., Aguilar-Manjarrez, J., Hishamunda, N. (Eds.), 2008. Building and ecosystem approach to aquaculture, FAO/Universitat de les Illes Balears Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. FAO Fisheries and Aquaculture Proceedings, vol. 14 FAO, Rome.

Tlusty, M.F., Thompson, M., Tausig, H., 2016. Statistical tools to assess the breadth and depth of shrimp aquaculture certification schemes. Fish. Res. 182, 172–176.

Valenti, W.C., Kimpara, J.M., Preto, B.L., Moraes-Valenti, P., 2018. Indicators of sustainability to assess aquaculture systems. Ecol. Indicat. 88, 402–413.

Vandergeest, P., Unno, A., 2012. A new extraterritoriality? Aquaculture certification, sovereignty, and empire. Political Geogr. 31 (6), 358–367.

Wang, L., Fan, Y., Yan, C., Gao, C., Xu, Z., Liu, X., 2017. Assessing benthic ecological impacts of bottom aquaculture using macrofaunal assemblages. Mar. Pollut. Bull. 114 (1), 258–268.

World Bank, 2018. World Bank Publications. The World Bank Group, Washington DC, USA. https://www.doingbusiness.org/content/dam/doingBusiness/media/Annual-Reports/English/DB2018-Full-Report.pdf5.

Xiao, Y., Ferreira, J.G., Bricker, S.B., Nunes, J.P., Zhu, M., Zhang, X., 2007. Trophic assessment in Chinese coastal systems—review of methods and application to the Changjiang (Yangtze) Estuary and Jiaozhou Bay. Estuar. Coasts 30 (6), 901–918.

Young, N., Brattland, C., Digiovanni, C., Hersoug, B., Johnsen, J.P., Karlsen, K.M., Kvalvik, I., Olofsson, E., Simonsen, K., Solås, A.M., Thorarensen, H., 2019. Limitations to growth: social-ecological challenges to aquaculture development in five wealthy nations. Mar. Policy 104, 216–224.