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Availability and usefulness of economic data on the effects of aquaculture: a North Atlantic comparative assessment

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Abstract

This paper focuses on the availability of economic indicators and metrics to assess effects of marine aquaculture production in the North Atlantic area (the EU, Norway, Canada and USA), including also social and environmental effects. We consider how aquaculture planning and management is organised in the different countries and the usefulness of economic information to address different aquaculture-related policies. We find that the most relevant economic data for aquaculture management should be at the local and regional levels rather than nationally. The availability of such economic data is mapped for national, regional and local level. The focus is on data that are publicly available from authorities or research institutions. The availability of data is generally fairly good for national and regional data on the direct economic effects of aquaculture. Data on how aquaculture-related products or input markets are affected are however poorly available, as are economic data on external effects from aquaculture. Countries with a larger aquaculture sector tend to have better availability of aquaculture-related economic data than those with a smaller sector. An index is developed and calculated to show more specifically where the countries have relatively good or poor data availability compared to their needs. While it will not always be cost-effective or meaningful to collect economic data on the effects of aquaculture, our study indicates that several countries could benefit from expanding such data collection. It can make trade-off decisions more consistent and easier to perform, and aquaculture policies and measures can be better tailored to specific contexts.

Key words: aquaculture, economic data, management, planning, policy relevance.

Introduction

Aquaculture continues to grow rapidly as the fastest food production sector worldwide, and since 2014, it provides more food for human consumption than traditional fisheries (FAO 2018). While it has taken place in the North Atlantic Ocean for hundreds of years, modern marine aquaculture started mainly from the 1950s (FAO 2017).

The total marine and brackish water aquaculture production in this region was 2.2 million tonnes in 2016, more than 5 times as much as in 1976 (FAO 2019). Diadromous fish dominate overall with 76 % of the total volume, nearly all of this in Europe. The growth in production of diadromous fish (salmon and trout) has been practically exponential since the 1970s. Norway is the dominant producer in the region both in terms of quantity (60% share in 2016) and value (70% share). The UK, Spain and France are other major producers, and together, they represented 24% of the quantity and 17% of the value. The USA and Canada provided 6% of the total production volume in 2016, and 5% of the value. The sector in Norway, Canada and the UK is strongly dominated by diadromous fish production, while mollusc production dominates in Spain, USA and France. In the other countries, the production is to a lesser degree dominated by a single aquaculture sub-sector.

With a farm-gate value estimated at almost 11 billion USD for the North Atlantic region, and 234 billion globally for 2016[2], aquaculture supports jobs, income generation and wealth to many people (Beveridge *et al.* 2013; Béné *et al.* 2016), and makes an important contribution to welfare in rural areas (Burbridge *et al.* 2001; Ceballos *et al* 2018; Filipski & Belton 2018). It can also impact a range of other industries and actors, both near and far from where the production is located (Burbridge *et al.* 2001, Asche & Tveteras 2004, Deutch *et al.* 2007, Naylor *et al.* 2009, Troell *et al.* 2014, Cao *et al.* 2015). Related product or input markets (Anderson 1985; Troell *et al.* 2014) and the environment/surrounding ecosystem (Hall *et al.* 2011, Taranger et al. 2014) are just a few examples of potentially impacted sectors and interests. Consequently, aquaculture is strongly regulated in many countries (Bankes *et al.* 2016), albeit stringency varies (Abate *et al.* 2016).

For planning and licensing purposes, Krause *et al.* (2015) argued that the potential effects of aquaculture on economic, social and environmental aspects, both positive and negative, should be assessed. Ideally, different effects should be easy to compare (Zheng *et al.,* 2009), and having effects assessed in economic terms could help with this. Authors have advocated the use of economic methods for doing comprehensive assessments of aquaculture (Knowler 2008), and also, central policy frameworks like the EU's Marine Strategy Framework Directive ask for economic analyses (Oinonen *et al.* 2016). Anderson *et al.* (2019) find that the economic peer-reviewed literature on aquaculture is limited and that economists are 'underrepresented' in the debates on aquaculture policy and regulation. It may be that the use of the economics toolbox is constrained by availability and quality of suitable data related to aquaculture.

This paper focuses on the availability of economic indicators and metrics – quantitative measures or estimates of effects on production, consumption, supply, demand, benefits and costs – to assess effects of marine aquaculture production, considering also social and environmental effects. We use the North Atlantic area (selected European Union (EU)-countries, Norway, Atlantic Canada and Atlantic USA) as case studies for a comparative assessment aimed at exploring the following questions: (i) What economic data are available and at what level, to assess different types of effects of aquaculture, are these regularly updated, and how does it differ for geographic levels and across countries? (ii) Does the data availability match the needs for planning and management at the appropriate decision-making level? and (iii) What are the priority areas for improving economic data availability to better estimate related effects of marine aquaculture in the North Atlantic area?

The study aims to increase awareness of the availability of existing economic data, indicate where economic data collection and utilisation on the effects of aquaculture could be improved to better understand the effects of aquaculture on society and the environment, and support better decision-making.

In the following sections, we present three types of economic measures of effects of aquaculture, followed by a methods section. Subsequently, a description of the results obtained for each of the three research questions, namely an overview of available relevant data and studies for different geographic levels in the case study countries; an assessment of the types of economic data most useful for different types of planning and management decisions related to aquaculture; and an overview of how these different types of planning and management systems are organised in the countries, are provided. All these elements are then brought together in analyses of how well data needs are met in the various countries, where the most important gaps are, and which data that are available for some regions or sub-sectors should particularly be prioritised to be made available for other areas.

Understanding economic effects of aquaculture

Attempts to assess social and economic effects of aquaculture were done fairly early in the development of salmonid aquaculture in Europe (e.g. Neiland *et al.* 1991; McCunn 1992). Neiland et al.'s preliminary evaluation of social and economic effects of European aquaculture in 1991 found that '[. . .] the information-base is weak in comparison to that for biological and technical aspects of aquaculture and does not permit a comprehensive evaluation at the present time'. Burbridge *et al.* (2001) noted a lack of reliable information 'resulting in a distorted and inconsistent view of the associated costs and benefits of expanding and diversifying mariculture' (Burbridge *et al.* 2001, p. 200). Also, the EU Marine Strategy Framework Directive (MSFD) addresses the demand for economic analyses (Oinonen *et al.* 2016). A key conclusion from studies aiming at suitable indicators for sustainability of aquaculture was that a reliable and robust assessment of aquaculture must include all economic effects, also beyond the financial ones throughout the value chain, to capture the full social costs of aquaculture production (Knowler 2008). These include indirect, intangible and secondary benefits and costs (Burbridge *et al.* 2001), where the lack of economic information seems to be particularly large for the benefits and costs that are not visible in a market context (US Ocean Economics 2019).

Direct and multiplier effects

Aquaculture can provide positive economic effects for a region due to the sector's core activities (a direct economic effect), activities in upstream and downstream industries (*indirect effect* – also termed type I multiplier effect) and through the additional multiplier effect from spending of increased income for households and taxes for the public (*induced effect* – type II multiplier effect) (Jacobsen *et al.* 2014).

Besides revenues, returns, wages and net taxes, the *value added* is a metric often preferred by economists to describe an economic sector's importance (Bostock *et al.* 2016). It is the surplus value from a company or industry's activity, calculated as the difference between the sales value of products (revenues) and the cost of input factors aside from labour and financial capital. The gross value added goes to profits to company owners, wages to workers, net taxes to public authorities and interest to lenders of financial capital. If the replacement cost of wear on physical capital (capital depreciation) is deducted from the gross value added, we get net value added.

The indirect and induced economic effects can be assessed using input–output techniques, which also enable the estimation of economic multipliers (Jacobsen *et al.* 2014). These multipliers indicate how activity in the core industry affects other parts of the economy through financial transactions in and from the core industry value chain. They show the economic linkages between sectors, and also, how activities in different industries may give very different impacts. Multipliers are calculated at different geographic scales, and their values will depend on the industry structure in the region studied, the degree of vertical integration in the core industry, the geographic pattern of supply and demand and size of the region considered. Multipliers are typically estimated for revenues, employment and value added.

Effects on non-aquaculture markets

Aquaculture can impact industries not part of its value chain by affecting the markets shared with these other industries (Bjørndal & Guillen 2016). This can be the product markets for seafood (Anderson 1985; Knowler 2008; Xie *et al.* 2009; Bjørndal & Guillen 2016; Tran *et al.* 2017) or food in general (Troell *et al.* 2014), or input factor markets, for example for labour (McCausland *et al.* 2006; Knapp 2008) or feed (Asche & Tveteras 2004; Naylor *et al.* 2009; Natale *et al.* 2013). In economics jargon, the aquaculture industry can affect the market for substitutes or complements to its products and input factors (Asche *et al.* 2001).

The industries affected can be near or far from where the studied aquaculture industry is operating (Villasante *et al.* 2013; Troell *et al.* 2014). The markets for physical products are generally geographically larger than the markets for services and labour, but this varies with market demand, transportation costs, possible trade barriers, type of service, labour mobility and also the time horizon being considered. Increased demand for inputs can give higher input prices in the short run, but could improve supply in the longer run, especially if there are economies of scale in the input industries. A bigger market can also sustain more advanced and specialised input industries.

External effects

Further, aquaculture can affect activities such as recreation, tourism and wild-capture fisheries indirectly through effects on landscape, the marine environment or wildlife, among others (Diana 2009; Grigorakis & Rigos 2011; Hall *et al.* 2011; Outeiro & Villasante, 2013). When these positive or negative effects have no direct impact on the aquaculture operation itself, they are *economic externalities*: effects of consumption or production activities that affect others, but not through price changes, which the actors causing them have no incentive to consider (Tirole 2008). Increasingly, however, aquaculture companies seem to realise that they need to consider also these effects to retain their social licence to operate (Mather & Fanning 2019).

Material and methods

The research originates from the 'Working Group on Social and Economic Dimensions of Aquaculture' of ICES (International Council for the Exploration of the Sea), and the assessment framework described in Krause *et al.* (2015). Most of ICES' work is centred on the North Atlantic region, and the countries we consider as case studies in this paper are therefore all from this region. While the countries chosen differ much in terms of the size, value and dominant type of aquaculture sector, they are all at a high level of economic development and generally have advanced governance systems in place. This makes a comparison between them relevant. Moreover, while inland aquaculture dominates over marine aquaculture globally in terms of volume produced, the reverse is true in the North Atlantic region (FAO 2018), and hence, we focus on marine and brackish water aquaculture. Nonetheless, the approach and results of the paper are deemed relevant for regions and systems elsewhere to consider.

Data collection

We searched for economic data from government or other institutions (like research institutions) that should be independent of the aquaculture industry, where methods of collection and compilation are transparent, and data are freely and publicly available. Two major data collection approaches were used in the present study. First, the knowledge and network of the ICES WGSEDA group was used to identify relevant data sources and information available in National Bureaus of Statistics and similar EU sources (like STECF 2016), in grey literature and central peer-reviewed articles. Second, a comprehensive literature review was undertaken for the case study countries using Google Internet searches and Google Scholar searches using a number of keywords, searching global databases on economic studies and from works citing relevant literature. A list of major keywords is included in the Appendix S1. We have gone through these databases: www.oceaneconomics.org (last accessed 5 April 2019), http://www.marineecosystemservices.org (last accessed 12 July 2019), https://www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/ (last accessed 12 July 2019, and https://www.evri.ca/Global/HomeAnonymous.aspx (last accessed 27/2-2018).

We have not done a systematic review based on a predetermined set of keywords. This was because the literature and other information sources in different countries are in different languages, it can be difficult to translate terms between languages and similar terms can be used differently between countries. Due to all this, and the breadth of topics, the set of search keywords evolved as identified information sources used new keywords or cited references with new keywords. Major keywords used are in the Appendix S1.

Data analysis

Data availability

Using the full suite of literature and datasets identified for the study, the availability of economic data to assess the effects of aquaculture was determined as follows: (i) direct and multiplier effects; (ii) effects on non-aquaculture markets; and (iii) economic externalities.

It was determined based on whether or not data were present, if it was regularly collected, and for which geographic level. The geographic levels considered were national, regional and local: *National* implies data availability for a whole country; *regional* refers to major regions within a country (provinces/states in Canada and the US); and *local* implies data availability for an even finer geographic resolution than on regional level.

For direct and multiplier effects, 11 variables were assessed (see Table 1). For effects on non-aquaculture markets, five variables were assessed (see Table 2). Further, we assessed economic externalities on 10 different sectors/interests (see Table 3). For each of the variables and geographic levels, colour codes were assigned based on the following criteria: green: data are regularly collected, annually or bi-annually; orange: some data are available, but not on a regular basis; red: no data are available.

Match between data availability and data need

To analyse the match between data availability and data needs at the level of decision-making, a three-step approach was used. First, an assessment of the hierarchical levels (national, regional and/or local) involved in relevant policy decisions was done by reviewing the literature and by using expert judgement from the members of the ICES WGSEDA. The policy areas identified as most important for the management of aquaculture across the countries' studies were aquaculture production licensing, area-based planning for the inshore/coastal zone, area-based planning for offshore areas, location permits and other aquaculture relevant permits.

Second, based on expert judgement, the general degree of usefulness of economic data was assessed for each of the three main types of economic effects data, for each of the different types of policies identified. Here, we used a simple qualitative ranking of 'X = Information can be useful; **XX** = Information is important to make a knowledge-based decision; and ?=Will depend on the kind of other permit'. The logic for setting the qualitative ranking was to consider to what degree the concerns that (should) matter for deciding on a particular policy type are of an economic nature and if economic data could make decision-making easier, especially trade-offs between different effects and interests. More specific reasoning for the assessments for each type of policy are in sections "Aquaculture-related public planning and management" and "Usefulness of economic information for aquaculture management".

Lastly, for each country and type of regulatory policy, we used the results of steps 1 and 2 to identify in detail which types of economic data are useful at the different levels (local, regional, national), and assessed the data availability against the needs using colour coding. The colour coding of data availability for each type of economic data usually varied between the individual variables of that type of economic data and between geographic levels relevant for

Table 1 Availability of data on direct and multiplier effects of aquaculture

Statistic	National									Regional									Local							
	EU	NO	SCO	FR	CA	US	ES	IRL	GER	EU	NO	SCO	FR	CA	US	ES	IRL	GER	NO	SCO	FR	CAN	US	ES	IRL	GER
Production volume (physical)	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Orange	Red	Red	Green	Orange	Green
Production value	Green	Green	Green	Green	Green	Green	Green	Green	Green	Orange	Green	Green	Green	Green	Green	Green	Green	Orange	Red	Green	Orange	Red	Red	Green	Orange	Orange
Direct employment	Green	Green	Green	Green	Green	Red	Green	Green	Green	Orange	Green	Green	Green	Green	Red	Green	Green	Orange	Orange	Green	Orange	Red	Red	Green	Orange	Orange
Value added	Green	Green	Green	Green	Green	Red	Green	Red	Green	Red	Orange	Green	Red	Green	Red	Green	Red	Red	Red	Orange	Red	Red	Red	Green	Red	Red
Wage cost	Green	Green	Green	Green	Green	Red	Green	Green	Green	Red	Orange	Green	Red	Green	Red	Green	Red	Red	Red	Green	Red	Red	Red	Green	Red	Red
Other costs	Green	Green	Green	Green	Green	Red	Green	Green	Green	Red	Orange	Green	Red	Green	Red	Green	Red	Red	Red	Green	Red	Red	Red	Green	Red	Red
Data by species/species group	Green	Green	Green	Green	Green	Green	Green	Green	Green	Orange	Green	Green	Green	Green	Green	Green	Green	Orange	Red	Green	Orange	Red	Red	Green	Orange	Orange
Data by production technique	Orange	Green	Orange	Orange	Green	Orange	Green	Green	Orange	Red	Green	Green	Red	Green	Green	Green	Green	Red	Red	Green	Red	Red	Red	Green	Orange	Red
Trade (export data)	Green	Green	Green	Green	Green	Green	Green	Green	Green	Orange	Red	Orange	Orange	Green	Green	Green	Orange	Orange	Red	Red	Red	Red	Red	Green	Red	Orange
Multiplier studies	Red	Green	Green	Red	Green	Red	Red	Red	Red	Red	Orange	Red	Red	Orange	Orange	Red	Red	Red	Red	Red	Red	Red	Orange	Red	Red	Red
Indirect employment	Orange	Orange	Orange	Red	Green	Red	Red	Red	Red	Red	Orange	Orange	Red	Orange	Red	Red	Red	Red	Red	Orange	Red	Red	Red	Red	Red	Red

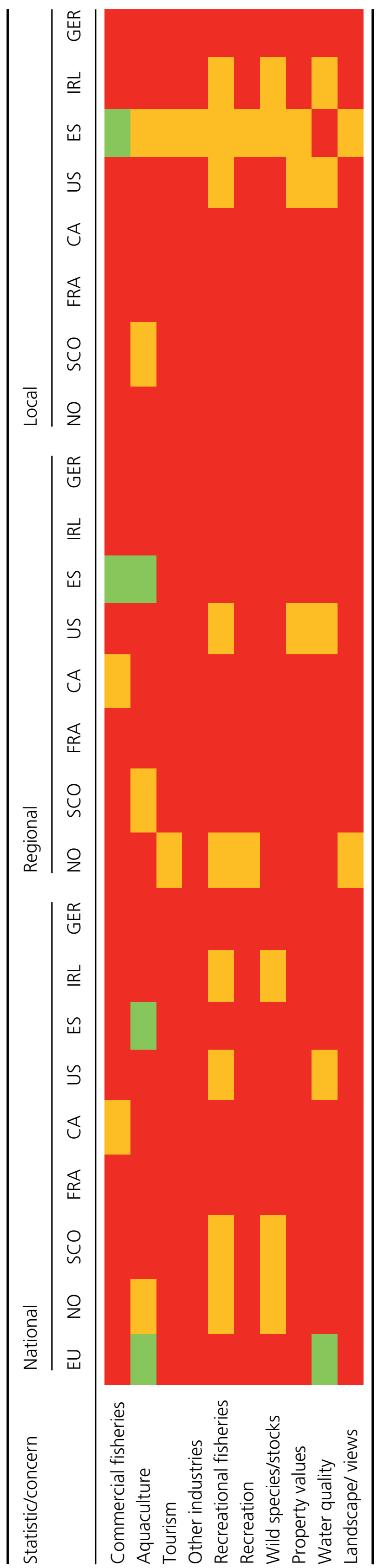
Green: annual/regular data available; orange: some data available; red: data not available.

Table 2 Availability of data on effects on non-aquaculture markets

Statistic	National									Regional								Local							
	EU	NO	SCO	FRA	CA	US	ESP	IRL	GER	NO	SCO	FRA	CA	US	ES	IRL	GER	NO	SCO	FRA	CA	US	ES	IRL	GER
Seafood/fish products	Orange	Orange	Red	Orange	Orange	Orange	Orange	Red	Red	Red	Red	Orange	Orange	Orange	Green	Red	Red	Red	Red	Red	Red	Orange	Green	Red	Red
Food products generally	Red	Orange	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
Labour	Red	Orange	Red	Red	Orange	Red	Red	Red	Red	Red	Red	Red	Orange	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
Feed/feed components	Red	Orange	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
Other inputs	Red	Orange	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red

Green: annual/regular data available; orange: some data available; red: data not available.

Table 3 Availability of economic data on externalities proper of aquaculture



Green: annual/regular data available; orange: some data available; red: data not available.

decision-making. To accommodate for this, an average score was calculated based on green = 3, orange = 2 and red = 1, and rounded to an integer value to decide the code colouring.

This averaging process took two steps. First, for each type of economic data and geographic level an arithmetic average was calculated across the variables that make up that type of economic data. For example, for the direct and multiplier effect data, an average for the scores obtained for the 11 variables associated with this type of data was determined for each geographic level. Second, for each type of policy and economic data, the data availability was calculated based on the geographic level at which the policy decision is made. If data are only needed for one geographic level, the colour coding is obtained directly from the assessment in step one. If data are needed for two or all three geographic levels, the overall colour coding is the average, rounded score of the respective geographic levels' colour coding obtained in step one. The colour coding calculated by averaging can mask large differences between countries. To better accommodate for these differences in the analysis, and to give an overall numerical assessment of the data availability against the data needs, an index has been developed and calculated for each of the three types of economic information and overall. To calculate index scores, the data availability for the different types of economic information at different geographic levels is weighted based on the perceived usefulness of that information for different policy types. Overall index scores for individual countries are calculated as the weighted average from these. The Appendix S1 section "Discussion" has details, and also a sensitivity analysis of how changes in relative weighting between 'Information is important to make a knowledge-based decision' and 'Information can be useful' affect individual countries' overall index score.

The index scores were used to identify the types of economic information for which countries had relatively poor data availability compared to their needs, both compared to other countries, and compared to their own overall index score.

The extent to which the variation in data availability between countries can be explained by scale and structure of the aquaculture sector in the countries is also investigated. One hypothesis is that the availability of relevant economic data increases with the size of the aquaculture sector, either as production volume (in tonnes) or as the production value. Another hypothesis is that not only the total size of the aquaculture sector matters, but also the type of aquaculture production. For the latter, the reason being that different types of aquaculture can cause very different effects thus requiring different needs of economic information. For example, molluscs as filter feeders can improve environmental water conditions, while fish and crustaceans that require external feed supply may entail pollution risks, and the need for economic data on the external effect of aquaculture could then be very different. It could also vary with the size of the aquaculture industry (an interaction effect between type and size). Similar differences in effects can exist also through the aquaculture value chains and on other interests. Practically, overall index scores have been linearly regressed with production volume or production value for either the total industry, mollusc production or the production of diadromous fishes + marine fishes + crustaceans ('fish+'), or a multiple regression with volume/value for molluscs and fish + as explanatory variables. The value of the coefficient of determination (R^2) from the simple linear regressions was considered, and adjusted R^2 for the multiple regressions. The analyses were done in Microsoft Excel 16. With data for only 8 countries, that is 8 observations, no interaction effects analyses were conducted.

Results

Aquaculture data availability

This section focuses on the first research question of mapping the availability of data for the three main types of economic effects of marine aquaculture for countries in the North Atlantic area, on national, regional or local level. The data availability is summarised below. Details for each of our case countries are in the Appendix S1, including data sources and literature references.

We find that the availability of data on direct and multiplier effects of aquaculture varies between countries, type of statistics, and between geographic levels (Table 1) (the countries are listed in order of descending value of the aquaculture sector in 2016 in all tables). All countries regularly collect national-level data for production volume and value, and the most collect data on direct employment, wage costs and trade. National-level data on economic multipliers and indirect employment are less available. This is also the case for the regional and local level. For the regional level, data availability is generally poorer than for national level, but the larger producing aquaculture countries stand out compared to the smaller ones, except for France. For the local level, data availability is generally poor, except for Scotland and Spain.

As depicted in Table 2, data and studies on how the aquaculture industry can affect product or input markets for other industries are limited. We have not found any regular collection and publication of such data/studies.

Economic studies of external effects of aquaculture are very limited for the countries we have studied, as shown in Table 3. Regularly collected data were not found for any of our case countries. Some ad hoc studies could be found for external effects on aquaculture, recreational fisheries, wild fish stocks and commercial fisheries. While data on external effects were poor overall, Scotland and Norway had the best coverage on national-level data, whereas the latter, together with Spain, had comparatively good data coverage on the regional level as well. For local-level studies, Spain led over the other study countries.

Aquaculture-related public planning and management

To answer our second research question addressing the match between data availability and data need, we first identified the main types of relevant policies and the different hierarchical levels involved in policy decisions affecting aquaculture in our study countries (Table 4). In the subsequent sections, we considered which kind of economic information is most useful for different policy responses and which should be available at what geographic levels to make more informed decisions (depending on the level at which management occurs).

A range of public planning tools and policies are relevant for marine aquaculture development (GESAMP, 2001), and these should be balanced for the different needs and interests of all actors concerned (Soto *et al.* 2008). A key public policy objective for having such tools is to grant permission and determine the conditions for aquaculture operations. To structure and facilitate this process, different approaches, such as area-based planning, production licensing, location permits and pollution permits, might be applied on national, regional and/or local level. A production licence may be issued independently of a location

Table 4 Geographic level of authority in the regulatory framework for aquaculture in the case study countries

	NOR	SCO	FRA	CAN‡	US	ESP	IRE	GER
Production licence	N	N	R(L)	R(N)	R(N)	N(R)	N(L)	R(L)
Area planning inshore/CZ	L(R/N)	R/L	R	R	R(N)	N(R)	N(L)	R
Area planning offshore	N	R/L	R	N	N(R)	N(R)	N	N
Location permit	R	R	R(L)	R	R(N)	N(R)	N(L)	n.a
Other permits†	N	N	R	L/R/N	N/R	N(R)	L	R(L)

N = National (countries, federal level for CAN&US), R = Regional (regions/counties/states in countries in Europe, CAN provinces, US states), L = Local (municipalities or similar), n.a.=not applicable. Brackets indicate some influence, while slashes (/) indicate roughly equal influence. CZ = coastal zone.
†For example, pollution, veterinary and shipping lanes.
‡Only for Atlantic provinces of Canada.

permit, or the two may be combined in one licence, like it is in Norway (Hersoug *et al.* 2019). Another objective for public planning and policies is to support the development of industries through investments in infrastructure, educational and research programmes and similar support to innovation and business development. However, this latter objective is not considered in the present study as the related possible measures and policies are more vague than those for formal regulation of aquaculture through licensing, permits and area planning, and would go beyond the scope of this article. The availability of relevant economic data for designing and implementing policies to support aquaculture development is, however, an important issue that is worthy of further investigation.

The aquaculture-related management in four of our case countries involved authorities at all three levels, while for each of the remaining countries only two levels are involved (illustrated in Fig. 1). For France, only the local and regional level is deemed relevant, for US and Spain only the regional and national level, whereas for Ireland only local and national level is involved in planning. Overall, more decisions seem to be taken by regional and national rather than local authorities, but the extent to which regional and national authorities are involved, varies between the countries.

Area-based planning is understood as the identification and zoning of areas suitable for aquaculture. However, not all countries have implemented explicit area-based planning. The countries we studied used different definitions of coastal, inshore and offshore waters, and have authorities at different geographic levels, as Table 4 indicates. Area planning mainly involves regional and/or national authorities. For area planning inshore/in the coastal zone, regional authorities dominate more often, while for offshore area planning national authorities dominate. Aquaculture production licensing in the case study countries mainly involves regional and/or national authorities (illustrated in Fig. 2). Location permits are mainly issued by regional authorities, while national authorities more often deal with other types of permits.

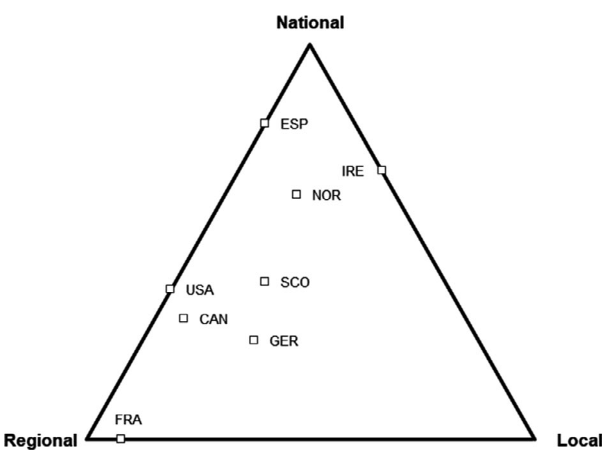


Figure 1 Triangle plot illustration of how aquaculture-related management is distributed between national, regional and local management levels in our case countries.

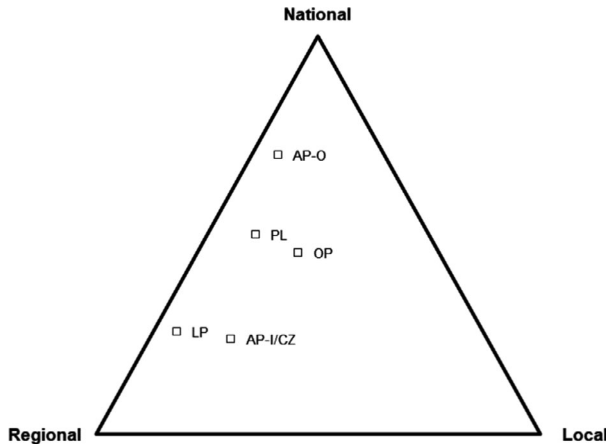


Figure 2 Triangle plot illustration of how different types of aquaculture-related management is distributed between national, regional and local management levels across our case countries. PL = production licence; AP-O = area planning offshore; AP-I/CZ = area planning inshore/coastal zone; LP = location permit; OP = other permits.

Usefulness of economic information for aquaculture management

Based on expert judgement, Table 5 provides a qualitative assessment of the usefulness of the three types of economic data to inform policy decisions on aquaculture. This assessment is done irrespective of the hierarchical or geographic level at which decisions affecting the sector are made.

When general production licences are granted, major national and/or regional concerns should be considered in concert. Such major concerns are the level of returns from aquaculture, the distribution of income and the sustainability, taking into account also environmental factors (Tisdell 1994). General production licences for aquaculture should thus consider all three types of economic effects. Data on direct and multiplier effects can help to identify and prioritise the benefits from aquaculture. Economic data on how aquaculture can affect other industries and stakeholders through the markets for inputs and outputs and through external effects can make it easier to compare all the effects against each other.

Area planning generally dictates the activities that can be permitted in a specific area. The potential influence of a specific activity on stakeholders in the geographic vicinity is the main concern. Information on possible external

Table 5 Usefulness of information on types of economic effects of aquaculture for different types of aquaculture-related management

Type of economic effect Type of policy	Direct and multiplier effects	Effects on non-aquaculture markets	Economic externalities
Production licence	**XX**	**XX**	**XX**
Area planning	X	X	**XX**
Location permit	X	X	**XX**
Other permits	?	?	**XX**

X = Information can be useful. **XX** = Information is important to make a knowledge-based decision. ?=Will depend on the kind of 'other permit'.

effects, for example related to pollution, is thus the most useful type of information here. Direct and multiplier effects, like employment and income, especially at the local or regional level can also be useful, as well as possible impacts on local or regional markets for related products or input factors.

Handling aquaculture location permits usually concerns the same issues that are relevant in area planning, but on a more detailed level. Location permits can also require other permits, or at least acceptance from other authorities. These can concern pollution, risk of spread of diseases or parasites, waterways and navigation, fishing and more. For these kinds of permits, economic data and information on external effects are viewed as most important.

Besides the type of economic information being useful for different aquaculture management decisions, the geographic level of the information is also an important factor that should be considered. The relevant geographic level of this information will depend not only on the type of economic effect and type of policy, but also on the local, regional and national context. The identification of major challenges will depend on the country-specific social, economic and environmental situation, and the respective prioritisation by those in charge of management. This means that the hierarchical level at which a policy is decided on *can* matter for which geographic level information is most useful, but will not always determine it. Local authorities may be most concerned with local-level effects of aquaculture, but cannot or should not ignore effects on regional or national levels. Likewise, national-level authorities cannot ignore regional or local effects.

Assessment of the availability of relevant economic data for our case countries

In the assessment of the availability of relevant economic data, we have relied on the expert judgement of the authors for which geographic level different types of economic information is most useful for the target policy. This is assigned in the column 'Data need level' in Table 6. The colour coding in Table 6 indicates whether relevant economic information for different policy responses is available on the appropriate geographic level for planning and management of aquaculture in the different countries. Green indicates that such information is well available, orange that some is available, and red that no or very little information is available. Since different aspects of these three main types of effects can have different availability of data, we have assigned values in correspondence with the colour coding in Tables 1–3, so that green = 3, orange = 2 and red = 1. Then, we have calculated the average value to determine the colour coding for cells in Table 6. We have also calculated the average when data have been needed for several geographic levels. See Appendix S1 section "Understanding Economic Effects of Aquaculture" for tables with these calculations. The white cells indicate data types, which are not very relevant for that particular type of planning or management. For each country, additional rows with information and analysis of more detailed policies or considerations are added if relevant, under the corresponding 'main' policy/consideration. These are marked with an asterisk first.

Given that for most countries regularly collected data are only available for direct and multiplier effects on the national and regional level, the respective column in Table 6 is the only one containing green marked cells. However, most of this column is nonetheless orange, suggesting that even for this important effect, data availability is limited. This is because the level of decision-making most relevant for this kind of information is at regional and local level, where there is limited availability of such data. For effects on non-aquaculture markets and external effects, the availability of economic data relevant for planning and management is mainly absent, and no data are regularly updated. Only for Norway is some relevant information available here.

Note also, how the geographic 'Data need level' in Table 6 matches with the 'Decision level' in the columns left to it to varying degrees: there is full geographic match for 13 rows, partial match for 25 rows, and no match for the remaining 2 rows. Only Ireland and Germany have full match for all rows/policy types.

The colour coding in Table 6 masks large differences, as the tables in section "Material and methods" of the Appendix S1 show. To include these differences in the analysis, and also give a numerical assessment of the data availability against the data needs, an index was developed and calculated. The index ranges from 1.0 (none of the needed economic information is available) to 3.0 (all needed economic information is regularly updated). The index scores

Table 6 Knowledge needs and availability summed up for individual countries (a–g)

(a) Norway

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	N	**N**	**XX**	**XX**	**XX**
Area planning	L (R/N)	L, R	X	X	**XX**
Location permit	R/N	L, R	X	X	**XX**
*Impact assessment	L	L, R	**XX**		**XX**
*Food safety, veterinary	N/R	L, R			**XX**
*Pollution	N/R	L, R			**XX**

(b) Scotland

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	N	R	X	XX	**XX**
Area planning	R/L	L, R	X	X	**XX**
Location permit	R	R	X	X	**XX**
*National Marine Plan	N	N,R,L	XX	XX	**XX**

(c) France

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	R	R, L	**X**	**X**	**XX**
Area planning	R/L	L, R	X	X	**XX**
Location permit	R	L, R	X	X	**XX**
*Impact assessment	L	L	**XX**		**XX**
*Other permits	R	L			**XX**
*Food safety etc	N	R, L			**XX**
*Pollution	R	R, L			**XX**

(d) Canada‡

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	R (N)	R	**XX**	**XX**	**XX**
Area planning	R	R, L	**XX**	X	**XX**
Location permit	R	R, L	X	X	**XX**
*Impact assessment	R	R, L	**XX**		**XX**
*Other permits	N/R/L	R, L			**XX**
*Veterinary	R	R, L			**XX**
*Pollution	R	R, L			**XX**

(e) United States

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	R(N)	**R**	**XX**	**XX**	**XX**
Area planning	R	R	X	X	**XX**
Location permit	R/N	R	X	X	**XX**
*Impact assessment	N	R	**XX**	X	**XX**
*Other permits	N/R	N/R/L	X		**XX**

(e) Spain

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	N (R)	R, L	**XX**	**XX**	**XX**
Area planning	N (R)	R, L	X	X	**XX**

Table 6 (continued)

(e) Spain

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Location permit	N (R)	R, L	X	X	**XX**
*Other permits	N (R)	R, L			**XX**

(f) Ireland

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	N (L)	N, L	**XX**	**XX**	**XX**
Area planning	N (L)	N, L	X	X	**XX**
Location permit	N (L)	N, L	X	X	**XX**
*Other permits	L	L	X		**XX**

(g) Germany

Type of policy/ consideration	Decision Level	Data need level	Direct and multiplier effects	Non-aquaculture market effects	External effects
Production licence	R(L)	R, L	**XX**	**XX**	**XX**
Area planning	N	N	X	X	**XX**
Location permit	n.a.	n.a.			
*Other permits	R/L	R, L	**X**	**X**	**XX**

X = Information can be useful. **XX** = Information is important to make a knowledge-based decision. ? = Will depend on the kind of 'other permit'. N = National (countries, federal level for CAN&US), R = Regional (regions/counties/states in countries in Europe, CAN provinces, US states), L = Local (municipalities or similar), n.a.=not applicable. Brackets indicate some influence, while slashes (/) indicate roughly equal influence. CZ = coastal zone.
†For example, pollution, veterinary and shipping lanes.
‡Only for Atlantic provinces of Canada. Green: annual/regular data available; orange: some data available; red: data not available.
Colour coding of cells: Green = relevant economic information well available on relevant level; orange = some available; red = none/little available where data are deemed useful/important; white = data not deemed useful/important.

for some countries are sensitive to the relative weighting of X («information can be useful») against **XX** («information is important»). Table 7 gives index scores based on weight of X = 0.3 and **XX** = 1.0. The Appendix S1 includes a sensitivity analysis of the choice of weight of X.

The overall index scores are rather low for all countries, but there is variation among them. Norway has the highest score, while France has the lowest. Scotland is the country with index score most sensitive to the weighting of X, indicating that Scotland has a better economic data availability for «information that can be useful» than for information «that is important».

Table 7 also gives average index scores for each type of economic information. For all countries, the index score for data on direct and multiplier effects contributes positive to the countries' overall index score, being higher than the overall index score. The data availability on the effects on non-aquaculture markets and external effects all contribute negatively to the countries' overall index score, with one exception; Norway's index score for data availability on the effects on non-aquaculture markets is higher than its overall index.

Some countries' index scores for individual types of economic data stand out. Those values that are higher than the average value is marked with green in Table 7. Compared to the average value, France has a very low score on direct and multiplier effects, while Scotland's score is very high. On non-aquaculture markets, Scotland, Ireland and Germany have very low scores in contrast to Norway with a very high score. Regarding external effects, France and Germany have relatively low scores and USA and Ireland relatively high, but all countries have low absolute scores.

Some of the countries have index scores for individual types of economic data that differ qualitatively from their

Table 7 Index scores of economic data needs and availability†

	Direct and multiplier effects	Non-aquaculture markets	External effects	Overall index
Norway	2.18	1.63	1.22	1.53
Scotland	2.62	1.00	1.11	1.41
France	1.47	1.10	1.00	1.10
Canada	2.18	1.33	1.06	1.41
USA	1.96	1.20	1.30	1.48
Spain	2.14	1.20	1.20	1.41
Ireland	1.88	1.00	1.26	1.36
Germany	1.73	1.00	1.00	1.19
AVERAGE	2.01	1.18	1.14	1.36
Standard deviation	0.31	0.20	0.10	0.13

†Green cells have values that are higher than AVERAGE. Detailed explanations are in section "Discussion" of the Appendix S1.

overall index score. For the countries with overall index score above average, Scotland scores below average on non-aquaculture markets and external effects, Canada on external effects and USA on direct and multiplier effects. For the countries with overall index score below average, only Ireland stands out by having above average index score for external effects.

Given the scores for data availability for different types of economic data, and also the index scores for countries' data needs and availability, it is interesting to see whether there is some correlation regarding the size (production volume or value) or type of the aquaculture sector in the countries. Simple linear regression analyses of the countries' overall index score with volume or value of the countries' aquaculture production, either the overall production or fish + production or molluscs production alone, show low degrees of correlation. Tables in the Appendix S1 show R^2-values from 0.03 to 0.43, with most being around 0.30. France stands out as having relatively low data availability compared to the size and value of its aquaculture sector. Without France, R^2 was 0.42 for linear correlation analysis with total production volume as independent variable, and 0.38 with total production value as independent variable. Regression against the relative value of the aquaculture sector compared to the total economy gave $R^2 = 0.29$.

A power regression was also tested. This may be more plausible than assuming a linear relationship. As an industry becomes of a significant size, a certain level of information is needed for good governance, but the need for extra information as the industry grows will be limited, and at some point, it will not be possible to get much more information. The R^2-values were low when all countries' data were included (0.24 with production volume as independent variable, and 0.22 with production value). However, when France was taken out of the data set the corresponding R^2-values were 0.54 and 0.60, which is rather high.

Multiple linear regression with volume or value for fish + and molluscs aquaculture as explanatory variables also shows low possible degrees of correlation (adjusted R^2 0.03 and 0.38, and statistically not significant F-statistic nor regression coefficients at 95% level). We interpret this as indication that the size of the aquaculture sector to some degree influences the availability of relevant economic aquaculture data in our case countries, but that the type of aquaculture in terms of species (groups) produced had little to no influence.

Discussion

Data availability

In general, countries with best data availability are major aquaculture producing nations in terms of overall volume and value, that is Norway, Scotland, Canada, USA and Spain. When considering production and economic information about aquaculture on the Atlantic coast of Canada and USA, the data availability about the national (federal) level might have benefited from these countries also having considerable aquaculture industry elsewhere. France, while also being a fairly large aquaculture producer, has surprisingly poor general data availability.

The best availability of data is generally on direct and multiplier effects of aquaculture because several of the variables included in this group are collected by the countries for purposes other than aquaculture management. This includes handling taxes and tariffs, workplace health and safety, and trade.

For effects on non-aquaculture markets, only ad hoc economic data were found at national and lower levels, and only for a few cases, including seafood and labour. For seafood products and feed components, this is probably due to their markets largely being international. For labour and other inputs where the most relevant markets are national and regional, assessments of impacts are maybe integrated in aquaculture development proposals and presented within case documents for political or administrative handling that we have not detected as we searched for specific economic studies.

Economic data on external effects from aquaculture were also far between, and only produced ad hoc. There does not seem to be any pattern among the studies identified related to themes covered or the overall data availability of the different case study countries.

We have considered data coming from government institutions, peer-reviewed publications and research institutions. Whether data from producer organisations or other industry representatives would change the overall picture of data availability, and to what extent those data would be seen as reliable, are two relevant questions for further investigation.

Match of data availability and need

The second research question was whether the availability of economic data on the effects of aquaculture matches the needs in the case countries. As the data availability in general is poor, the fulfilment of the needs is expected to be similarly poor. Only for direct and multiplier economic effects on national and in part, on regional levels, are data availability good compared to the countries' needs. Consequently, according to our assessment, the economic data availability matches the needs for only a few types of policy in a few countries: Norway and Spain for production licensing, area planning in Scotland, Spain and Germany, and granting location permits in Spain.

One possible explanation of the poor availability of economic data is that it can be difficult and expensive to

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collect/establish. However, many environmental data can also be very expensive to collect. Still, the public management criteria for aquaculture have to a large degree been environmental, and not based on economic analyses (Anderson *et al*. 2019).

Our assessment of how the data availability matches the identified needs is based on our expert judgement to a considerable degree. This includes identifying which types of economic data are important for different types of aquaculture policies, and the geographic levels the different countries have their economic data needs for. We believe the authors' breadth and depth of knowledge is high, reflecting the 'invited only' eligibility of ICES Working Group members, we recognise that the expert judgements make up a source for uncertainty for our assessment. We agreed the key trends identified are unlikely to differ whether other methods were used. The mapping of data availability did not rely on expert judgement. For the effects on non-aquaculture markets and external effects, the data availability was so poor for all countries that if such economic data at all are deemed useful for aquaculture governance, our conclusions hold.

The process to analyse data needs have also involved mapping the aquaculture governance arrangements of the case countries. To date, insufficient attention has been given to aquaculture governance especially in a marine spatial planning context which is key to the development of this sector and the benefits that may be derived at local, regional and national levels (Stead, 2005a; Slater *et al.*, 2013; Krause & Stead, 2017; Stead, 2019). Our results show interesting differences of how hierarchical levels of administration are involved between the countries, and between the different types of aquaculture policies. Some countries are 'centralistic', having almost all power with national authorities, like Spain, while France may be considered as 'regionalistic'. The local level has a role in many countries, but it is smaller than the national and/or regional level. The hierarchical governance set-up probably affects the availability of data for the various geographic levels, and one may wonder if changes in responsibility could be done to improve data availability. The differences in governance set-up may, however, reflect different priorities on fundamental democratic values. Where national authorities have large influence on aquaculture governance, they can ensure that national minimum standards are met everywhere and control cumulative effects nationally, for example on the landscape or nationally threatened species. Where regional and local authorities have more influence, the concern may be more with local effects than national ones. Subsidiarity and local democracy as governing principles may also be deemed more important in some countries than others. However, the legislative and administrative set-up in most countries has evolved over time and are historical and path dependent (Kelly *et al*. 2019). As such, the possibility to make explicit choices related to fundamental values, like the ones mentioned above, may have been limited by institutional lock-in, such as for Norway (Hersoug *et al*. 2019).

Only for a minority of policy areas and countries were there full match between the hierarchical level of authority and the geographic level data were needed for. It is easy to think that ideally, they should match. The principle of subsidiarity that decisions should be taken on the lowest level possible, matching the level affected by the decisions, seems to support this. Safeguarding national objectives and ensuring equal treatment across regions can however be reasonable arguments against full match of geographic levels for some policy areas, including biodiversity protection and health and safety standards. That most policy areas across the different countries have at least a partial match between level of hierarchical authority and geographic level data is needed for may also be seen as indication that the geographic level affected by decisions are involved in decision-making in most cases.

Priority areas for more economic data

Our third research question addressed the priority areas for improving economic data availability on the effects of aquaculture in our case countries. Relevant information of good quality is a prerequisite for good planning and management. Countries cannot expect that information for one setting can be transferred to other settings. Krause *et al.* (2020) show, for example, how social effects of aquaculture can vary a lot across different levels, aquaculture systems and contexts.

In a cost–benefit approach to management, collection of economic data should be related to the benefits the data could provide. For example, when the aquaculture industry is large, even small individual changes resulting from economic data and analysis can have a big overall impact on net benefits. There may also be economies of scale in collecting the data, creating a large net benefit. This might partly explain why we find some correlation between availability of relevant economic data and the size of the aquaculture sector in the different countries. However, even in a country where the industry is relatively small, the net benefits of economic data and analysis can be high if they lead to regulatory or other changes that facilitate industry growth. When planning economic data collection on the effects of aquaculture, countries must consider the structure of the sector, its possible development, and the likely issues at different spatial scales.

We have shown that only for the direct economic and multiplier effects of aquaculture are relevant economic data available to a substantial degree in our case countries, and then largely for the national level. For the other two types of economic effects, the data availability is poor both in absolute terms and in relation to the assessed needs for aquaculture management.

Anderson *et al.* (2019) find there is surprisingly little focus on the opportunities presented by the growth of the aquaculture industry, but the impact the industry may have on the environment and other industries, and the resulting effects on net economic benefits are also very important (NFD 2015; Manning & Hubley 2016; Olsen & Osmundsen 2017). There is a recognised need for better economic data that makes it easier to do trade-off analyses, by seeing costs and benefits of aquaculture jointly (Anderson *et al.* 2019). Non-market valuation data on the impacts of aquaculture on aesthetic view, environmental quality and other ecosystem services are for our case countries mostly lacking and could have a significant impact on planning and management decisions where trade-offs are made. While some authors point at controversies and challenges in the application of non-market valuation approaches (Plieninger *et al.* 2013, Bas Ventín *et al.* 2015, Hanley *et al.* 2015, Pascual *et al.* 2017), others think they can be useful when carefully applied (Knowler 2008). One example of such a trade-off analysis is Aanesen and Mikkelsen (2020), where there is a cost–benefit analysis of aquaculture expansions in a region, comparing direct and indirect economic impacts with the population's willingness to pay to get/avoid the expansion.

The geographic levels where economic data gaps were identified are mostly local (needed in 30 instances in Table 6) and regional level (26 instances). National-level information was only found to be necessary in five instances. This points towards a need for more local and regional data. However, these needs will probably be more costly to fulfil than for national data, as many studies and more respondents are required to get reliable data on low geographic levels while for the national level one representative study may suffice. Consequently, the value of getting the local and regional data may be too low compared to the cost of producing them.

In addition to the general findings above that concern all or most countries, the results show the areas which individual countries should consider improving availability of economic data for. France stands out as a rather large aquaculture producer that has poor data availability, especially on direct economic and multiplier effects. Scotland and France should consider improving availability of data about effects on non-aquaculture markets. When it comes to considering improving data on external effects, those two countries are joined by Canada, another large aquaculture producer. Germany has the lowest data availability among the case countries. Germany will however most likely remain a very small marine aquaculture producer, limiting the need for better data. Ireland, on the other hand, while being the current second smallest producer among our case countries, is aiming for considerable growth (DAFM 2015). Ireland's overall data availability is average for the case studies in our assessment, but its availability of economic data on external effects is only surpassed by the USA.

The development of aquaculture depends not only on the effects it might have (direct, indirect, non-monetary), but also on the expectations and perceptions stakeholders and the public have in relation to these effects (Kaiser & Stead, 2002; Whitmarsh & Palmieri 2009; Tiller *et al.* 2012). Better knowledge of these expectations and perceptions could help authorities prioritise which types of economic data to collect (Stead, 2005b). As such, how economic data on the effects of aquaculture are used by different actors (e.g. government, NGOs, communities), on varying scales (local, regional, national), to what ends (e.g. policy and governmental decision-making, lobbying, marine spatial planning, education), and how useful it is perceived, should be a priority research area. This knowledge can then be used to provide more relevant good-quality information to the public (Stead *et al.*, 2002). This can strengthen the industry's social licence, but also trust in government. As the Canadian Manning-committee notes '. . .reporting information to the public on a wide range of topics related to the aquaculture industry is a tool [. . .] to enhance social acceptance'. (Manning & Hubley 2016). Of course, economic data on the effects of aquaculture will be used by both supporters and opponents of aquaculture when giving input on suggested policies, aquaculture licences and locations (Stead, 2019).

Improving the availability of economic data on a broad scale may require coordinated action or a 'push' by public authorities. Many of the countries around the North Atlantic are members of the European Union or the European Economic Area. Therefore, the demands for economic data and analyses have been increasing in marine-related strategies and directives in recent years. This might speed up and expand the regular collection of economic data as identified in this paper. Activities at sea that may affect ecosystems must be impact assessed (EIA Directive 2014/52/EU), but these assessments take a lot of time and can slow down aquaculture licensing processes. Faster licensing is a main priority in the strategic guidelines for the sustainable development of EU aquaculture (COM/2013/0229), and it is conceivable that better availability of relevant economic data could contribute to more informed decision-making. Likewise, the construction of marine management plans requires proper socio-economic assessments of the uses of marine waters and the costs of environmental degradations (Marine Strategy Framework Directive MSFD; Directive 2008/56/EC). However, our analysis suggests considerable gaps in the availability of and need for relevant economic data across the case study countries, limiting the ability to meaningfully analyse trade-offs and socio-economic consequences of different scenarios of policy action as is required for marine spatial planning (MSP Directive 2014/89/EU).

We acknowledge that it does not make sense to assess and present all effects of aquaculture in economic terms. Still, it seems more economic data can help achieve knowledge-based management, where the development of aquaculture is based on facts and a balancing of actual benefits and costs rather than misconceptions about the industry (Kaiser & Stead, 2002). Aquaculture governance could be improved with better access to robust and systematic economic data. It would make necessary trade-off decisions in planning and aquaculture regulation easier and more transparent and make trade-offs between different national interests or groups more consistent across regional and local processes.

Conclusion

This article investigated which types of economic data are available on the effects of marine aquaculture for several countries around the North Atlantic, including social and environmental effects. We consider at which geographic level it is available, and whether it is regularly collected or is only available from ad hoc studies. We have focused on data that are publicly available, from public authorities, published research or accessible from other actors independent of the aquaculture industry. The availability is generally good for national and regional level economic data to inform on the direct economic and multiplier effects of aquaculture. Economic data on how non-aquaculture markets are affected are however poorly available, as are data on external effects from aquaculture.

The set-up of management and planning for aquaculture vary across the countries we have studied, not least on which hierarchical levels the policy authorities reside. We find that most required economic data for aquaculture management are for the local and regional level, much more than the national level. The matches between data availability and data needs are poor in general but vary between countries. An index was developed and calculated to show more specifically where the countries have relatively poor data availability compared to their data needs to assist in prioritisation of addressing knowledge gaps.

The benefits of having economic data on the effects of aquaculture should in general be higher when aquaculture is important in a country. At the same time, it will typically be cheaper to produce such data – per study – when higher numbers of similar studies are conducted. This corresponds with our finding that the larger aquaculture producer countries tend to have better availability of economic aquaculture-related data than the smaller ones. France however seems to have relatively poor economic data availability given the size of its aquaculture sector.

While not all effects of aquaculture can meaningfully or cost-efficiently be presented in terms of economic data, it seems likely that more robust economic data could be useful for several of the countries' aquaculture governance. Future studies should analyse how different types of economic data are used for aquaculture management and planning, and their usefulness. It will help the authorities prioritise which economic data on the effects of aquaculture need to be produced in the future.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Statistics on aquaculture production volume and value in the North Atlantic Ocean area.

Detailed description of the availability of economic data on the effects of aquaculture at the EU and individual country level, with reference to publications and data sources.

Tables with data availability with number codes and calculations to assign colour coding to cells for individual countries in table 6 in the paper.

Description of the management system for aquaculture in the different regions/countries.

Description of index for data needs and data availability.

Analysis of correlation between aquaculture sector characteristics and index scores.

Keywords for literature searches.

Reference list.