'Offshore' salmon aquaculture and identifying the needs for environmental regulation.

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Abstract

'Offshore' aquaculture has gained increased attention as a potential route of expanding production of commercially important finfish species such as Atlantic salmon (*Salmo salar*). However, there is a lack of clarity about the term 'offshore' and how different 'offshore' environments are, compared to more traditional coastal or inshore locations. This uncertainty is an issue for effective governance and regulation and is a bottleneck for development that must be addressed. This study used a mixed method approach to evaluate what is meant by 'offshore' production and determine if existing approaches are suitable for licensing and regulating 'offshore' salmon aquaculture in Scotland, as a case study. First, a systematic literature review was used to assess academic studies and then an online questionnaire was used to gather views from salmon aquaculture stakeholders in Scotland and other countries. The results show there is inconsistency in what is perceived by the term 'offshore' aquaculture, making it challenging to determine a global definition. Literature, which was not limited to salmon production, tended to focus on distance from the coast but salmon aquaculture stakeholders had very mixed views, though a slight majority considered wave exposure was the key characteristic. The stakeholders indicated there may be a number of benefits of 'offshore' salmon aquaculture, but also suggested that existing regulations are not appropriate for 'offshore' salmon production and could be enhanced. The study results suggest that regulators and stakeholders need to agree on consistent terminology that characterises the production environment. Depending on local or regional complexities, several classifications that reflect key features, may be required. Additionally, new or adapted approaches to aquaculture licensing, regulation and site suitability may also be needed to account for physical and ecological differences from more traditional farming locations. Ultimately, environmental regulation will only be fit-for-purpose if it is evidence-based and relevant to the environmental conditions, surrounding ecosystem, and species being produced. Ironically, the biggest constraint to 'offshore' aquaculture regulation seems be understanding what 'offshore' is and means, and until this is addressed there will continue to be uncertainty and confusion that hinders development of the sector.

Key words: Aquaculture planning**,** exposed, offshore aquaculture, regulation, salmon farming, site selection.

Highlights

- Regulation is a bottleneck that is limiting expansion of 'offshore' aquaculture
- Inconsistency in how 'offshore' aquaculture is defined is creating confusion and uncertainty
- 'Offshore' regulation must be relevant to the environment, species, and production method

1. Introduction

Coastal regions are highly productive and an important resource for food production through aquaculture and fisheries. However, there is considerable competition and conflict from other users, so space for expansion of aquaculture is often limited (Sanchez-Jerez et al. 2016). Such constraints could affect contributions to global food supply as demand for aquatic products continues to rise (FAO, 2018). Thus, in many areas, if the aquaculture industry is to grow and increase production, there is a need to consider other locations. One of the alternatives to coastal farms is the use of so called 'offshore' sites, and consequently 'offshore' aquaculture has gained increased attention in recent years for both fish and shellfish (Jansen et al., 2016; Gentry et al., 2016; Barillé et al., 2020).

In 2010 the Food and Agricultural Organization of the United Nations (FAO) held a workshop that classified mariculture into three categories based on site location (coastal, off the coast and offshore). The expert group defined mariculture as "*offshore when it is located > 2 km or out of sight from the coast, in water depths > 50 m, with waves heights of 5 m or more, ocean swells, variable winds and strong ocean currents, in locations that are exposed (open sea, e.g. ≥ 180° open) and where there is a requirement for remote operations, automated feeding, and where remote monitoring of operating* *system may be required"* (Lovatelli et al., 2013). This definition is prescriptive and consequently only relevant at present to few existing or exploited sites. The workshop did not define 'off the coast' mariculture, meaning there is still confusion in perceptions on what 'offshore' or 'non-coastal' aquaculture is, and so how it should be included in regulation and governance. Most regulatory systems for fish-cage mariculture have been developed for inshore sites. Through an extensive analysis of primary and grey literature, Froehlich et al. (2017) have shown there is inconsistency in definitions of 'offshore' and often the descriptions cover sites or areas that are closer to the coast and shallower depths than one might originally expect. These descriptions do not conform to the FAO definition outlined in Lovatelli et al. (2013). The 'offshore' wind sector has had similar issues, where there are differences in opinion of what 'offshore' means, as some people consider 'offshore' to be a considerable distance out to sea in open-ocean conditions, while others use the term literally as "*off the shore and located in the sea*" (Haggett, 2008). The contrasting environmental conditions of coastal areas and open sea have different implications for aquaculture operations, but the term 'offshore' covers a range of conditions across studies and opinion. Thus, the lack of clarity surrounding 'offshore' is a key issue for aquaculture planning, licensing and regulation and must be urgently addressed.

Most countries have a formal planning and licensing process for establishing fish farms and this will involve meeting certain criteria and providing information on the proposed site and potential impacts (Bankes et al., 2016; Carter, 2018). Once a fish farm has been developed, producers must meet statutory requirements and operate in compliance with environmental limits that have been set by regulatory authorities (McGhee et al., 2019). The limits are established based on scientific evidence and vary between species due to the differences in how they interact with the environment (FAO, 2009). The scientific evidence is based on knowledge of existing sites, so if farms are to be established in new areas 'offshore' then this may require revised regulations and/or new monitoring protocols that are more relevant for those conditions (Roberts et al., 2014). Furthermore, the other activities and user groups in 'offshore' environments may be very different to inshore locations, so multi-use governance arrangements will need to be developed (Krause and Stead, 2018).

Atlantic salmon (*Salmo salar*) is an important farmed fish species due to its nutritional benefits and popularity with consumers (Sprague et al., 2016). The salmon aquaculture industry is an important economic activity in several countries, contributing to national economies and trade, while also providing an important livelihood to many local communities, often in rural locations McGhee et al., 2019). In 2016, total annual production of salmon was 2.25 million tonnes, with Norway, Chile and Scotland responsible for 54%, 24%, and 7% respectively (FAO, 2018). Salmon is one of the key focusses for 'offshore' aquaculture, and industry press examples highlight some of the research and development that is underway, particularly testing of cage technology (e.g. Garcés, 2019; Holland, 2020; Poulsen, 2020).

The aim of this study was to evaluate what is understood by 'offshore' salmon production and determine if existing approaches are suitable for planning, licensing and regulation. A mixed-method approach was used that included a systematic literature review followed by a stakeholder questionnaire. The study primarily focused on Scotland, though broader context is provided via responses and inputs from other countries. Salmon production has changed significantly since its inception in Scotland and it has become a highly innovative industry for the country (Peel and Lloyd, 2008; Peel and Lloyd, 2014). At present, the Scottish salmon industry is in a period of growth and transition (McGhee et al., 2019), and to ensure sustainability and long-term success is achieved, the exploration of new sites is essential as there are limited opportunities for further development within sheltered sea embayments. A new regulatory framework for marine finfish aquaculture in Scotland has been established, but 'offshore' production is not specifically mentioned (SEPA, 2019). This makes Scotland a good case study as 'offshore' sites may be part of the future of the Scottish salmon industry. Though Scotland is the primary focus, the results are relevant to all countries that are considering 'offshore' aquaculture of any fish or shellfish species.

2. Methods

A mixed method approach of systematic literature review followed by online stakeholder questionnaires was used to gather a combination of qualitative and quantitative data for further analysis. An important consideration was to identify if there is any disparity between scientific research and stakeholder views, with the review of primary literature providing an insight into research and academic studies, and the online questionnaires capturing the thoughts and experience of stakeholders to help fill knowledge gaps from outcomes of the review.

2.1 Review of literature

A review of literature was completed following the guidance set in place by Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher *et al*. 2009). The review process is given in Figure 1. An initial search of literature took place using the literature database found on both Scopus and Web of Science online databases. Three key search terms were used on Scopus using the phrases: 'offshore' AND 'aquaculture' OR 'fish farming'. To narrow the search results even further the search was limited to 'Title, Abstract and Keywords'. This revealed 911 items from January 1970 to July 2019. The same search terms were used in Web of Science to obtain any relevant literature missed from the Scopus database. This uncovered 195 items with dates spanning 1970 to July 2019. Both search results were collated, and duplicates (131 items) removed, to give a total of 975 records. The titles and abstracts were then screened to identify the most relevant literature and disregard irrelevant items (613 were excluded). During the final eligibility assessment, the full text of 362 articles was assessed, from which 119 articles were selected for the final evaluation. These articles were selected for evaluation as they were most relevant in relation to the aims set out for this paper, focusing on the key topics of 'offshore' aquaculture, regulation, and governance and/or environmental implementations of the aquaculture industry.

2.2 Online questionnaires

The questionnaire used in this study comprised of 16 questions consisting of multiple choice, scale/rank and short answer text questions (see Table 1). Its purpose was to pick up on issues raised in the literature review and inquire further with 39 targeted stakeholders with known and extensive expertise in the field. The limited number of stakeholders contacted was not designed to be of statistical relevance, but to ensure that they had experience to give an informed answer to the questions. The literature review highlighted areas that needed further investigation; relating to environmental issues and regulation, biological and technological factors within offshore environments, and how is 'offshore aquaculture' defined. Consequently, Questions 1 to 3 were designed to collect demographic information on the respondents. Questions 4 to 7 were designed to assess the respondents' opinions on present issues with salmon farming and explore a need for offshore aquaculture. Questions 8 to 16 were designed to gain further information on environmental and regulatory issues, and biological and technological issues in relation to offshore aquaculture and on the definition of 'offshore'.

JISC online surveys (JISC, 2019) was used to construct and carry out the online questionnaire. This software package has a wide range of features allowing a variation in question types to be produced, to obtain both qualitative and quantitative results. The 39 participants, each acknowledged to have experience and knowledge of salmon production and regulation, from different aquaculture and related organisations were specifically targeted by email[1] with links to the online survey. The organisations included feed companies, production companies, NGOs, regulators, research academics, consultants, industry representative bodies, and equipment suppliers and manufacturers. Participants were from a number of different countries: Scotland, Norway, USA, Canada, Chile and

[1] According to procedures outlined under the General Data Protection Regulations EC/2016/679 (under Data Protection Act 2018, UK).

China. All of participants were involved in salmon production and assessing the use of 'offshore' cage systems.

3. Results

3.1 Literature review results

Once compiled it was found that most of the reviewed articles could be assigned into 3 distinct thematic groups, "Technical feasibility", "Biology" and "Environmental impact". Those that could not be assigned were classed as "other". Where articles fell into more than one thematic group, the most predominant subject represented was used during the assignment process. The theme, description and number of articles in each group is given in Table 2. Of those reviewed, most concerned 'Environmental impact' (52 articles, 44% of the total), and biology (30 articles, 25%), with technical feasibility of the systems accounting for 18 articles (15%).

The distribution of number of articles and their themes, from January 1986 to July 2019, are given in Figure 2 and show an increase in publication over time. From January 2004 to July 2019 numbers of articles for "Technical feasibility" and "Biology" remained relatively consistent. However, the "Environmental impact" theme showed a consistent increase from 2016 and especially from January 2018, suggesting that published research in development of 'offshore' technology and production is consistent, but interest in environmental impacts of 'offshore' aquaculture are becoming a more important consideration and focus recently.

The studies found covered a range of species, though for ease of analysis were divided into three groups; finfish, shellfish and 'not specified'. There were 70 studies on finfish, 11 studies on shellfish, and 38 studies that did not fit into a specific category. The number of articles related to shellfish aquaculture showed an increase from 2014 onwards to date, whereas the number of articles related to finfish aquaculture tended to fluctuate initially with an increase since January 2018. Finfish research focussed most specifically on salmon aquaculture with 27 (39%) out of the 70 articles relating to the salmon industry.

Though most papers did not refer to a location for the research, those that did were spread over 16 countries. Most of these related specifically to salmon producing countries and aquaculture systems, but also included 'offshore' research in the Mediterranean with seabass and seabream, as well as fish cage culture along the coasts of Indonesia and Malaysia. Most papers which referred to environmental impacts were associated with salmon and salmon producing countries (Norway, Chile, Scotland, Canada, Australia, USA and China), with most papers being relevant to the USA and China. However, in addition, there was interest in development of 'offshore' aquaculture in the Gulf of Mexico, the Mediterranean Sea, the North Sea and off the coast of Indonesia. A breakdown of the 16 countries where studies on offshore aquaculture are being undertaken and the number of publications relevant to those countries is given in Figure 3.

A definition for 'offshore' aquaculture was given in only 11 of the 119 articles (9%) reviewed suggesting that there is either little consideration or an implicit assumption of what 'offshore' aquaculture actually means. For the 11 studies where a definition was found there was significant variation based on physical factors such as distance, for example >2 km from shore (Bostock *et al*. 2010) or out of site from the coast (Buck and Langan. 2017), considering a depth of >20 m (Lester *et al*. 2018), or 30 – 60 m (Ferreira *et al*. 2014), and/or focusing on wave exposure (Gentry *et al*. 2017). However, since only a small number of definitions were provided, it is difficult to determine a definitive definition from these results. 'Distance from the shore' and, a combination of both 'water depth' and 'distance from the shore' were the two most popular criteria used. This suggests that the term 'offshore' in academic publications is considered as a function of distance from shore rather than exposed environments.

3.2 Dictionary review results

To determine a clear and general definition for the term 'offshore', an analysis of online dictionaries was conducted. Eight of the most well used online dictionaries were evaluated, with the same term of 'offshore' inserted into each search engine. The dictionaries and corresponding definitions for the term 'offshore' are given in Table 3. Out of the eight dictionaries analysed, all suggested that the term is derived as a 'distance'. Though there are no values included, several of the definitions emphasised at 'some distance' from the coast which implies a considerable distance from the coast rather than close proximity. Public perception can be influenced by what is promoted to them, and this is true when it comes to defining the term 'offshore'. Consequently, it may be reasonable to assume that, based on the dictionary definitions, the general public would perceive 'offshore' aquaculture to be at a considerable distance from the coast.

3.3 Questionnaire results

The scope of the questions was constructed to investigate the environmental differences and likely sensitivities between inshore and 'offshore' environments. They were formulated to relate to the aims set out for the paper, to identify what stakeholders perceive as the environmental regulations and implementations of governance for 'offshore' aquaculture are, whilst determining how 'offshore' production could be a satisfactory solution for environmental sustainability of the salmon industry.

In total there were 21 questionnaire responses from 39 targeted stakeholders (54%), representing all countries contacted; Scotland (11), Norway (2), USA (1), Canada (1), Chile (1) and China (5) (Question 1). Respondents from Scotland represented the largest national group, with relatively low numbers from other salmon producing countries, therefore respondents were collated into two groups - Scotland, and 'Outside Scotland' (Norway, USA, Canada, Chile and China) – for further interpretation. However, the background expertise of the respondents for these two regions (Questions 2 and 3) were skewed with Scotland having a wide range of different stakeholder types, whereas the 'Outside

Scotland' countries they were less diverse, with a strong representation by academics. Table 4 shows a breakdown of stakeholders for each country and their experience. The different range of stakeholders in the different regions may lead to skewed opinion and outcomes, suggesting that the wider stakeholder range for Scotland are more representative of the salmon aquaculture sector, as a whole.

Further background questions about the existing situation (Question 4) indicated that most respondents for both groups, Scotland and 'Outside Scotland', and across all stakeholders found that their existing regulatory systems do not meet the needs of the salmon industry. Scottish respondents felt there was more space to expand aquaculture in the coastal environment than the 'Outside Scotland' countries (Question 6), though this comparison could have been due to the large percentage of academic respondents in the latter. All stakeholder types in both regions felt that at present sea lice and disease transfer were biggest environmental issues for the salmon industry at present (Question 7). The presence of predators and visual impacts of the farms were considered the least important, see Table 5.

Results from the open question (Question 8) "*How would you define 'offshore' aquaculture?"* were compiled into seven categories which were most fitting in terms of the response. These are presented in Figure 4. In contrast to the results from the literature review and dictionary analysis (Sections 3.1 and 3.2) that highlighted distance as the key factor, questionnaire responses were mixed, though descriptions that contained waves ('wave exposure', 'wave and depth', 'wave, depth and distance') had a slightly higher majority (11 respondents in total, 6 for Scotland and 5 for Outside Scotland). Distance (defined as 'Distance', 'Depth and distance', 'Wave, depth, and distance') was seen as the second most important factor (9 respondents in total, 4 for Scotland, and 5 for Outside Scotland), with depth ('Depth', 'Depth and distance', 'Wave, depth and distance') being least popular choice (7 respondents in total, 3 for Scotland, and 4 for Outside Scotland). One respondent suggested the definition of 'offshore' should be related to specific technology, monitoring and regulation, and economics required in ‘offshore’ locations, rather than the environment (description under Other in Figure 4). Several respondents commented that alternative terminology to ‘offshore’ such as ‘open sea’ or ‘high energy’ would be more useful as this describes the dispersive characteristics of the site and that is an important feature that should be the focus of new sites rather than an arbitrary distance.

Participants were asked to select one option from the Likert Scale (Extremely likely, Likely, Neutral, Unlikely, and Extremely unlikely) to answer the question (Question 9) “*How likely do you think aquaculture will move to ‘offshore’ in the next ten years?”* Responses are presented by stakeholder and country groupings in Figure 5. Four out of the twenty-one respondents (19%) were undecided or felt that a move to ‘offshore’ aquaculture was unlikely during the next decade while the remaining seventeen (81%) assured that ‘offshore’ development is either likely or extremely likely to take place. There was clear similarity in responses between the two country groups (see Figure 5). Of the 11 Scottish respondents, six considered it likely and a further three thought it was extremely likely that aquaculture will move offshore. Only the environmental regulator suggested this was unlikely.

To obtain an overview of perceived benefits and risks of ‘offshore’ aquaculture, participants were asked (Question 10) to select one option from the Likert Scale (Much better, Somewhat better, About the same, Somewhat worse, and Much worse), in association to whether they think that ‘offshore’ aquaculture will offer advantages in comparison with inshore aquaculture under six categories. A relative percentage was then determined for each response within its category and presented in Figure 6. It is evident that, for each of the areas, ‘offshore’ aquaculture was perceived as being advantageous or “the same” compared to inshore aquaculture. Only a small percentage of participants considered it would be worse. In particular, public perception, environmental sustainability and production potential were considered ‘much better’ for ‘offshore’ aquaculture. However, it was thought that factors related to the fish (health/welfare and disease risk) would have no advantage in ‘offshore’ systems, and in some cases be worse. Interestingly, the majority of respondents (85%) considered that there would also be no advantage for aquaculture practice in relation to impact from climate change if moved into more 'offshore' environments.

Participants were asked (Question 12) to select one option from the 3-point scale (Yes, No, and Unsure), in answer to whether they think that there are suitable techniques available for 'offshore' salmon farmers to measure and monitor impacts of salmon production on the environment in their country. The responses by stakeholder and country groups are given in Figure 7. Results show different opinions found between the stakeholders and by country groups. In Scotland there was relatively more confidence by industry stakeholders that techniques for suitable environmental monitoring were available, though several stakeholders including the environmental regulator were still unsure. The 'Outside Scotland' stakeholders generally believed that these techniques were not yet available. The difference this could be because due to the higher number of academic and low number of industry stakeholders in the 'Outside Scotland' region and that there was little consensus of what 'offshore' means between the groups. (see Figure 4).

Figure 8 shows percentage responses from a Likert Scale (Strongly agree, Agree, Neutral, Disagree, and Strongly disagree) for eight topics related to the availability of knowledge and research (Question 13) to ensure the success of salmon aquaculture in 'offshore' environments. Respondents suggested that there was a lack of knowledge available on regulation cost/finance and operational issues, but more was known about the technology needed, and suitability of 'offshore' sites for salmon aquaculture. Environmental monitoring and modelling gave a mixed response, with there being both agreement and disagreement from the various stakeholders.

These results suggest that though it is believed the technology is available to exploit these environments, there is still some doubt about whether enough is known or understood about environmental monitoring/modelling, regulation and finance issues to ensure environmental and economic sustainability of these systems. A respondent highlighted that "*currently there are no protocols for environmental monitoring of 'offshore' sites*", many respondents noted that further research will be required to ensure appropriate techniques are developed for these complex systems. It was noted that modelling techniques for physical characteristics for the 'offshore' environment have been established by other sectors. To support sustainable development of 'offshore' aquaculture, a respondent suggested that "*a broader ecosystem approach to environmental monitoring might be required to guarantee sustainable farming*". The stakeholder also noted that changes in environmental conditions due to 'offshore' production will have changes in the wider ecology and different food web dynamics to those commonly found at inshore sites. So further research into the different conditions and the impact of aquaculture is required before licenses are granted in such areas.

As previously mentioned, the respondents suggested that there is enough knowledge and research available for technology to ensure the success of salmon aquaculture in 'offshore' locations. A point was addressed by a respondent that *"as technology advances, so too will the development of locations previously unexplored for marine farming".* Although some respondents disagreed or were unsure, one producer suggests that *"the technology and knowledge is available to make the development a success, there will just need to be a period of transition and learning".*

Figure 9 shows the responses by stakeholder and country group to the question (Question 14) *"Is existing regulation in your country effective for regulating 'offshore' aquaculture?".* The stakeholders showed agreement in that only two from the 21 respondents (10%) thought that existing regulation would be effective for managing 'offshore' aquaculture. In Scotland, nine out of the 11 (82%) respondents thought that regulation was not appropriate or should be improved. Interestingly the respondent from the Scottish environmental regulator gave a positive reply, though it is important to note the same person thought Scottish aquaculture is unlikely to move 'offshore' in the next ten years (Figure 5). Without appropriate regulation available, it will be very challenging for aquaculture to expand into 'offshore' locations. This agrees with the outcomes from perception of research and knowledge availability, shown in Figure 8, where more research was believed to be required for effective ‘offshore’ regulation. It can be suggested from the results in Figure 9, that regulation could be the key bottleneck which is hindering the move to ‘offshore’ environments.

3.4. Additional comments from stakeholder feedback

The respondents to the questionnaires were also given the opportunity to provide additional comments. There were several comments on the ability of present environmental regulation to manage the needs of more ‘offshore’ sites for sustainability, with some disagreement between stakeholders. It was reiterated that environmental regulation required for ‘offshore’ locations is a “*different ball game*” in comparison with inshore sites, and though it was accepted that ‘offshore’ technology is “*advanced and that the design and engineering should not be considered as a significant challenge*” regulation may prove to be a bottleneck

Many respondents identified that there is presently almost no regulation cover for ‘offshore’ aquaculture, but that in Scotland “*the new [regulatory] framework can cope with the movement to further offshore*” and replace the “*outdated*” system that does not serve the needs of the industry. It is unclear whether this statement is referring to distance offshore and/or more dynamic open coast environments, as the term “offshore” is not mentioned in the new regulations (SEPA, 2019). It was pointed out that an “*increasing number of farms* [away from the coast] *are placed on hard and mixed bottom habitats*” and that “*little is known about the impact of organic enrichment on long lived epibenthos*”. There was a suggestion that regulation and licensing would therefore need to be assessed over different temporal and spatial scales to those used presently. In addition, it was pointed out that any new legislation had to be based on “*strong, fair, science-based regulation*” which supports sustainability of the industry and provides confidence to consumers.

4. Discussion

‘Offshore’ aquaculture is often considered a way of increasing sustainable aquaculture production (Gentry *et al*. 2016; Holm *et al*. 2017). However, from this study, it is clear there are several fundamental issues that must be addressed for the salmon industry in Scotland and elsewhere. First and foremost, is the need to establish clear and consistent definitions and terminology when referring to 'offshore' systems. The literature review showed that most studies did not provide a clear definition and, of the minority that did, distance to coast was the key consideration. The assumption of authors may be that 'offshore' aquaculture as a concept is widely understood and (based on the definition of 'offshore' in the dictionaries), refers to distance from the coast. However, this is not the case amongst stakeholders in the online questionnaires. The most used term to describe offshore conditions was 'wave exposure', though terms referring to distance and depth were also selected to a lesser degree, suggesting there is no clear consensus on what 'offshore' means.

The majority of respondents in Scotland thought that existing regulation could be improved for offshore salmon aquaculture. Lack of suitable regulation has been highlighted as a constraint to 'offshore' aquaculture development in other countries throughout the world (Davies et al., 2019; Galparoso et al., 2021). Scotland's new regulatory framework for marine finfish aquaculture does not refer to 'offshore' sites specifically, although a justification for revising the original framework was in recognition that farms are moving away from the very sheltered locations where fish farming was first established (SEPA, 2019). Instead, when discussing differences between sites, the regulatory framework refers to how hydrodynamically dispersive a site is (SEPA, 2019). This is unsurprising since finfish aquaculture in Scotland is primarily regulated based on dispersion of wastes. In this case, suggestions by respondents to use terminology such as 'open-ocean 'and 'high energy' may be more useful than 'offshore'. However, since the term 'offshore' is frequently used by stakeholders, media and researchers, even if it is not formally used in policies or regulation, it is important to explain this and adopt clear terminology and avoid confusion. Consequently, as shown in this study, it may be better to consult with a range of stakeholders and take location and/or species into account to relate the terminology to production requirements and regulations. Given the present findings, broad terms and generalisations such as 'offshore' are clearly insufficient and there may be a need for several categories or terms to cover the range of conditions, regional and local factors.

Considering that Scottish salmon aquaculture regulation is focused on dispersion of wastes and benthic impact, it is interesting that most of the respondents chose physical or hydrodynamic features to define 'offshore' rather than substrate. In Scotland, most of the existing inshore sites are found in areas of soft sediment, but as aquaculture expands into new locations, other substrate types may be encountered, including hard bottom areas (Roberts et al., 2014), with epifauna being more common than infauna. The seabed in many of these areas are also dominated by sandy sediments (Scottish Government, 2016), which have different infaunal communities and environmental sensitivities than those of the sedimentary inshore sites (Tyler-Walters, 2005), suggesting that there would be different environmental effects from fish farm wastes. In Scotland's new regulatory framework, the need for different biological standards for the different seabed habitats is recognised and it is acknowledged that they are not available for all habitats at present. The Scottish Environment Protection Agency (SEPA) will use visual surveys in the intermediate term, until scientific evidence is available to establish appropriate biological standards (SEPA, 2019). In this present study, nearly half of the Scottish respondents thought suitable techniques already exist to monitor impact. This could be related to different interpretations of what 'offshore' is, or an opinion that development would not occur in hard substrate areas, or there may also be a perception that monitoring approaches that are used or under development in other locations would be suitable. In Canada and Norway, salmon aquaculture farms are already located in areas with mixed and hard substrates. Some of the standard monitoring requirements have been adapted (Hamoutene et al., 2016), but the need for new and improved approaches for monitoring impact in such environments is acknowledged, particularly where it is difficult or not possible to obtain grab samples, so research is underway to identify and develop new methods and techniques (Hamoutene et al., 2015; Keeley et al., 2021).

Although the literature review showed an increasing number of studies, there were mixed opinions amongst the stakeholders regarding the knowledge and research available on a number of key aspects of 'offshore' salmon farming. More than half of the respondents thought that there is suitable technology available for 'offshore' salmon aquaculture. This will be linked to their own perception of what 'offshore' means, and it is not clear if they mean existing cage technology that is currently used or the technology that is being developed and tested. Biophysical and environmental modelling can play a key role and simulate interactions between the environment and aquaculture sites (Rabe et al., 2020), or assess site suitability (Falconer et al., 2013). However, in situ trials at commercial scale are still required for testing, validation, and confirmation, but there are so few examples of 'offshore' salmon farming systems, that there only limited or initial results presently available (Hersoug et al., 2021). As such, this may contribute to the stakeholders' broad and ambiguous range of views on offshore aquaculture.

As this study shows, there are differences between stakeholders in perception of 'offshore', the operational issues in the environment and the regulatory and data needs for exploitation of 'offshore' aquaculture. This is particularly illustrated in the differences between the literature review and the 'Outside Scotland' stakeholders, both dominated by academic perceptions, and those of the most diverse stakeholder group in Scotland. Though the sample site is acknowledged as small, the targeted stakeholders' responses, along with the literature review, illustrate that there are still many questions to answer before 'offshore' aquaculture can be fully implemented. The study shows there is interest in understanding more about how 'offshore' salmon aquaculture can be developed and most stakeholders thought that 'offshore' aquaculture will either have the same advantages or be better than inshore production for selected criteria, particularly environmental sustainability, and public perception. The results from the study can be used to show the issues to focus on and open a wider discussion.

5. Conclusion

Regulatory bottlenecks are one of the main factors limiting expansion of 'offshore' aquaculture. If environmental regulation is to be fit-for-purpose, then it must be relevant to the environmental characteristics of the area and the production methods used. However, as shown here for salmon aquaculture in Scotland, there are different perspectives over understanding what 'offshore' refers to, which makes it difficult to characterise what 'offshore' conditions actually are. Clearly, 'offshore' can mean different things in different contexts, for different countries and legislations. Therefore, it should not be assumed that people know what 'offshore' is referring to. There may be a need to use as range of definitions that offer more clarity about specific characteristics and it is recommended to consult with relevant stakeholders to relate the terminology to production requirements and regulations. Researchers should also clearly define what they mean if using 'offshore' within studies to better facilitate knowledge exchange and open discussion about the opportunities and issues of moving aquaculture 'offshore'.

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Ethics statement

All questionnaires and data collected from stakeholders during this study conform to and have been approved by the General University Ethics Panel of the University of Stirling. All stakeholder data has been fully anonymised and informed consent received.

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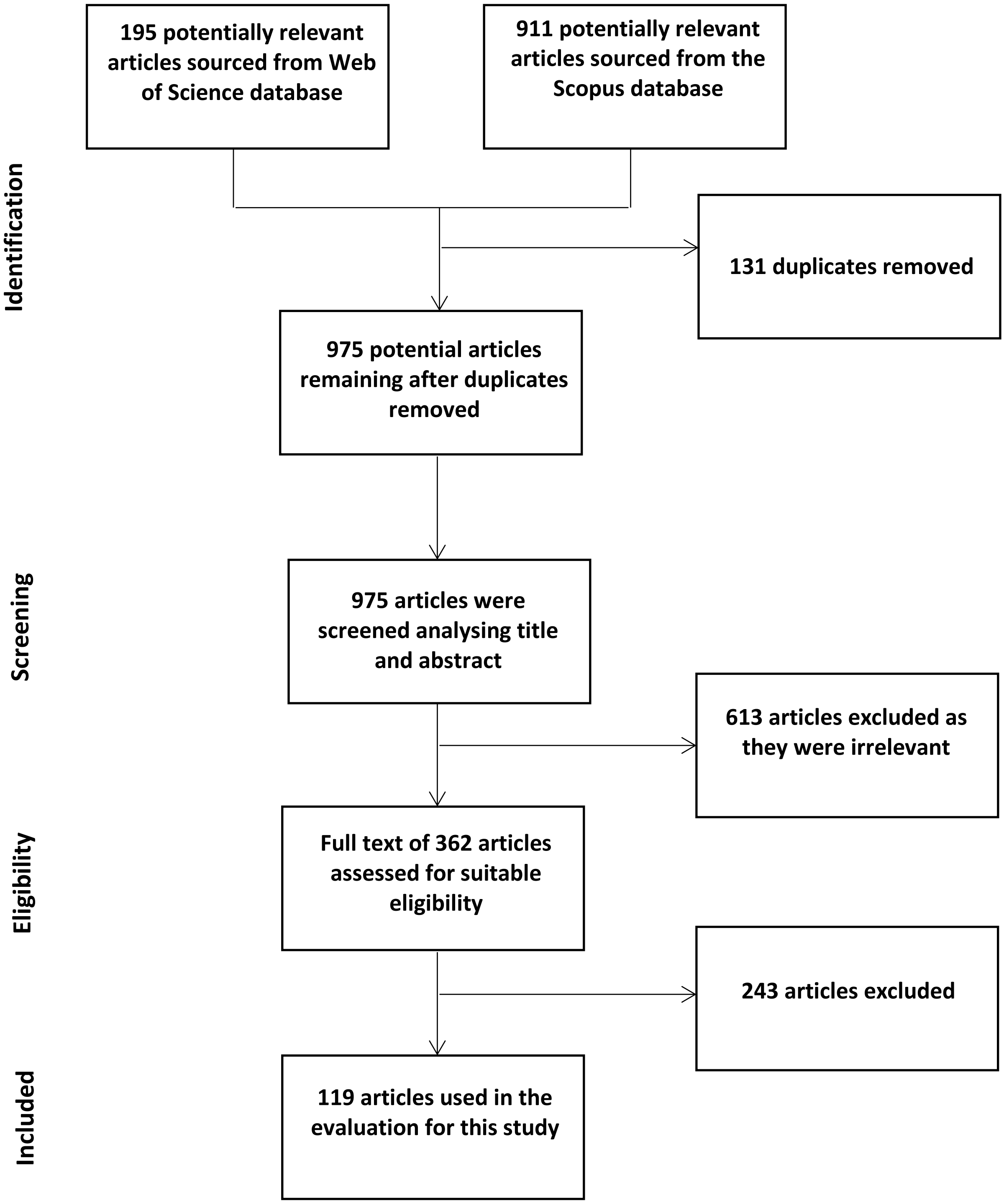

Figure 1: Overview of the literature search on offshore and aquaculture for more in-depth analysis using the guidance set by Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA).

Table 1: Questions used in the online questionnaire

	Question	Potential Answers
Q1	What country is your company / organisation based in?	Scotland Norway Other
Q2	What best describes your organisation?	Feed company Producers NGO Regulator Academic Consultant Industry representative body Other
Q3	How long have you worked in the aquaculture sector?	Under 5 years 5-10 years 15-20 years 20 years or above
Q4	Do you think the existing regulatory system is effective and meets the needs of the salmon industry?	Strongly agree Agree Neutral Disagree Strongly disagree Additional comment box
Q5	Do you think the salmon industry in your country is operating sustainably at present?	Yes No Unsure Additional comment box
Q6	Do you think there is space for aquaculture to expand in the coastal environment?	Yes No Unsure Additional comment box
Q7	What are the greatest environmental issues that your organisation experiences with the salmon industry in inshore locations at present? (Rank in order of Importance; 1 = most, 8 = least)	Disease transfer Sea lice spread Escapees Discharge of organics waste Feed sustainability Pollution (e.g. eutrophication) Predators Visual impact
Q8	How would you define 'offshore aquaculture'	Comment box
Q9	How likely do you think aquaculture will move to 'offshore' in the next 10 years?	Extremely likely Likely Neutral Unlikely Extremely likely Additional comment box
Q10	Do you think that 'offshore' aquaculture will offer any of the following advantages in comparison with inshore? (Much better, somewhat better, about the	Production (tonnes) Disease risk Health and welfare

	same, somewhat worse, much worse)	Environmental sustainability Public perception Climate change impact
Q11	Are there ‘offshore’ salmon farms in your country?	Yes No
Q12	Are there suitable techniques available for ‘offshore’ salmon farmers to measure and monitor impacts of salmon production in an ‘offshore’ environment in your country?	Yes No Unsure Additional comment box
Q13	In your opinion, do you think there is enough knowledge and research available to ensure the success of salmon aquaculture in these ‘offshore’ environments? (Strongly agree, agree, neutral, disagree, strongly disagree)	Technology Regulation/governance mechanisms Monitoring methods Environmental modelling Operational issues Site suitability Health and welfare knowledge Costs/finance
Q14	Is existing regulation in your country effective for regulating ‘offshore’ aquaculture?	Yes No Could be improved Additional comment box
Q15	Do you think moving aquaculture to ‘offshore’ could present challenges for your organisation?	Yes No Unsure Additional comment box
Q16	Is there anything else you would like to share that you think is relevant to this research?	Comment box

Table 2: Summary of thematic groups that covered the range of evaluated articles from the review process

Thematic groups	Description	Number of articles
Technical feasibility	Studies which require engineering requirements	18
Biology	Studies highlighting the physical, chemical, physiological, and development processes	30
Environmental impact	Studies which highlight the consequences (positive and negative) of a development, and/or regulations and governance associated.	52
Other	Studies that did not fit into a specific thematic group	19
Total		119

Table 3: Summary of dictionary and definition for the term “offshore “

Dictionary	Definitions for the term “offshore”
Collins Dictionary	From, away from, or at some distance from the shore
Oxford English Dictionary	In a direction away from the shore At some distance from the shore; at sea
Cambridge Dictionary	Away from or at a distance from the coast
Merriam-Webster	At a distance from the shore
Dictionary.com	Off or away from the shore At a distance from the shore
The Free Dictionary	Moving or directed away from the shore Located at a distance from the shore
Lexico	Situated at sea some distance from the shore
Google Dictionary	Situated at sea some distance from the shore

Table 4: Summary of research participants and background in the industry

Country	Background	Years of experience in industry
Scotland	Rental Equipment Provider (Tech)	5-10 years
Scotland	Technical Supplier (Tech)	21 years or above
Scotland	Equipment Manufacturer (Tech)	11-15 years
Scotland	Feed Company	16-20 years
Scotland	Regulator	5-10 years
Scotland	Consultant	11-15 years
Scotland	Industry Rep. Body (Other)	Under 5 years
Scotland	Academic	5-10 years
Scotland	Producer	5-10 years
Scotland	Non-depart. Public Body (Other)	21 years or above
Scotland	Producer	Under 5 years
Canada (Outside Scotland)	Academic	16-20 years
USA (Outside Scotland)	NGO	11-15 years
Norway (Outside Scotland)	Academic	5-10 years
Norway (Outside Scotland)	Regulator	11-15 years
Chile (Outside Scotland)	Producer	5-10 years
China (Outside Scotland)	Academic	21 years or above
China (Outside Scotland)	Academic	5-10 years
China (Outside Scotland)	Academic	16-20 years
China (Outside Scotland)	Academic	11-15 years
China (Outside Scotland)	NGO	5-10 years

Table 5: Ranking of environmental issues in order of importance in response to the online questionnaire question: what do you think the greatest environmental issues are with the salmon industry in inshore locations at present?

Environmental Issues	Issues in rank order of importance*	Relative weighting of respondents (%)
Sea lice spread	1	60
Disease transfer	2	45
Discharge of organic waste	3	35
Feed sustainability	4	35
Escapees	5	30
Predators	6	30
Visual impacts	7	25

* (1 = most important, 7 = least important)

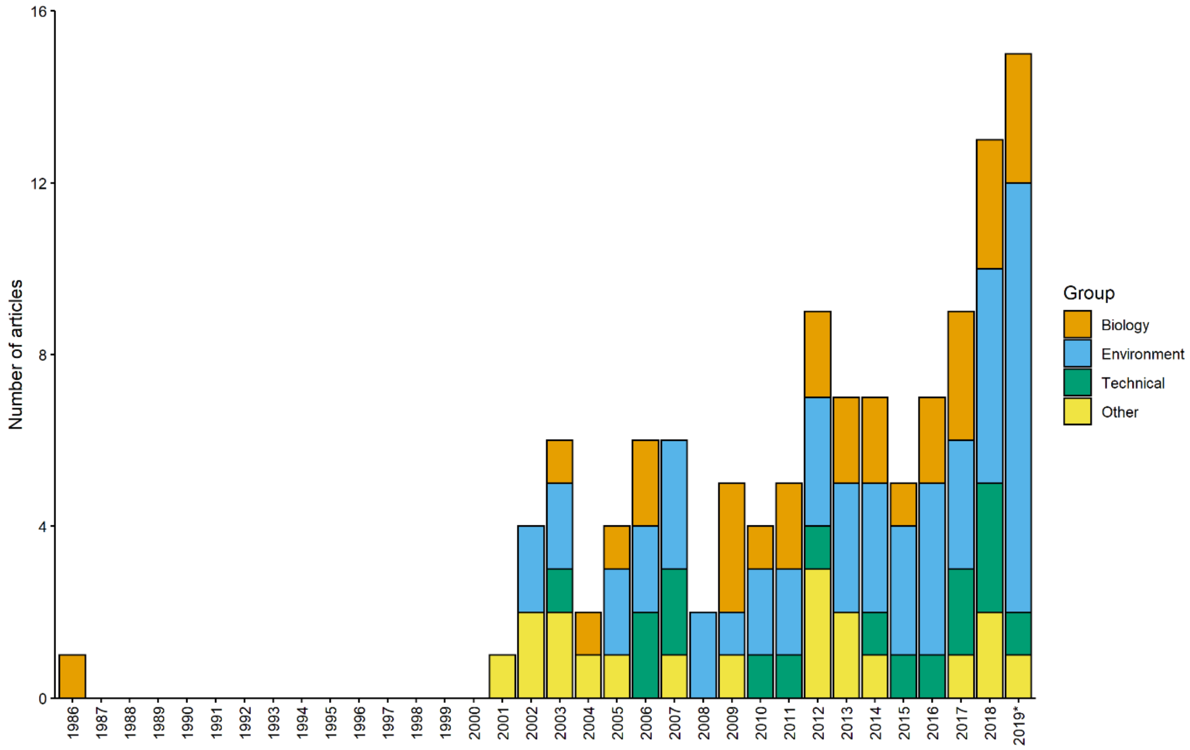

*Figure 2: The number of articles published each year in the thematic groups; Technical feasibility, Biology, Environmental impact and Other. * = up to July 2019.*

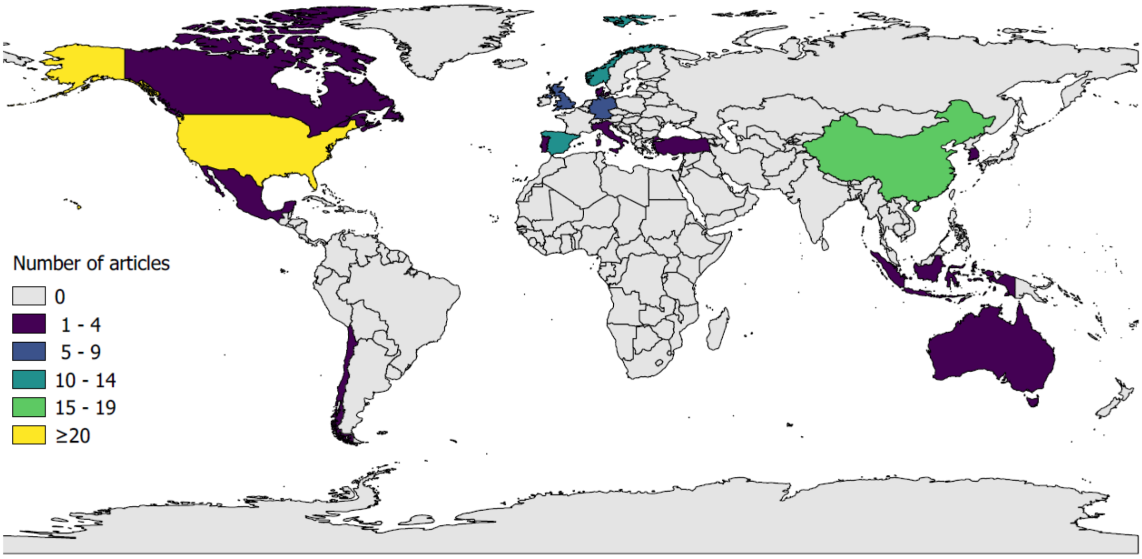

Figure 3: Countries where studies on 'offshore' aquaculture are taking place (N = 16). The colours refer to the numbers of publication articles relating to these countries found during the literature review.

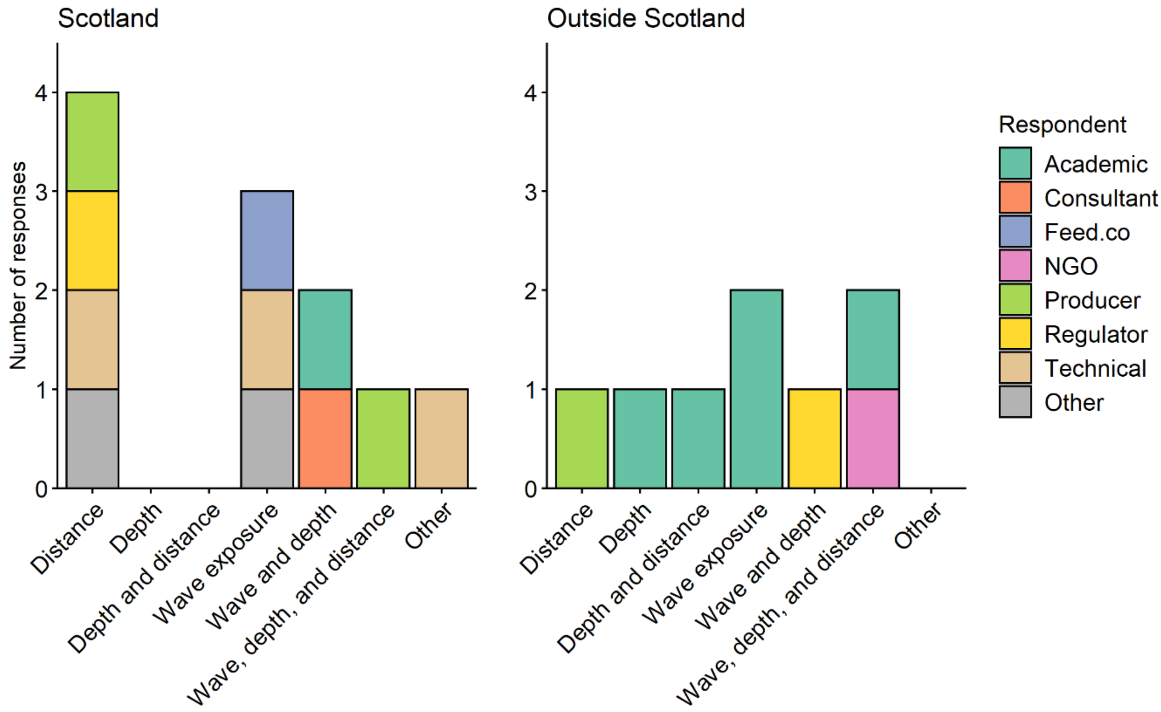

Figure 4: A stacked bar chart displaying the number of responses (country and stakeholder level) to the question: How would you define 'offshore' aquaculture?

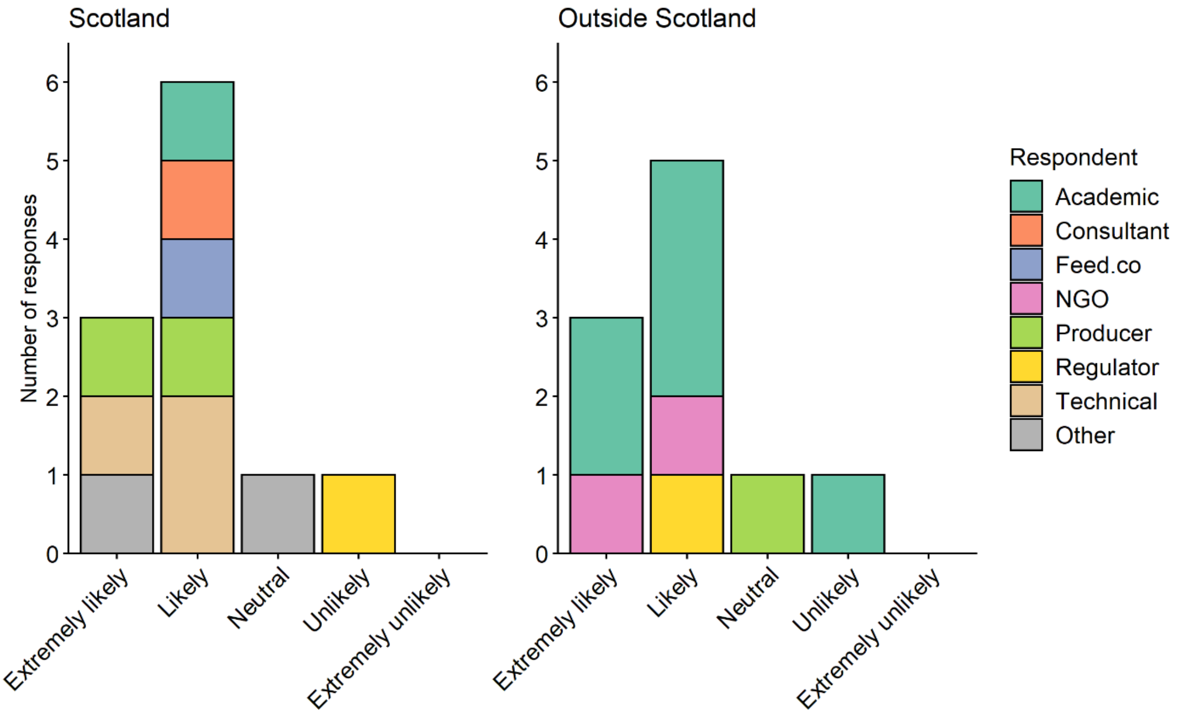

Figure 5: A stacked bar chart displaying the number of responses (country and stakeholder level) to the question: How likely do you think aquaculture will move to offshore in the next 10 years?

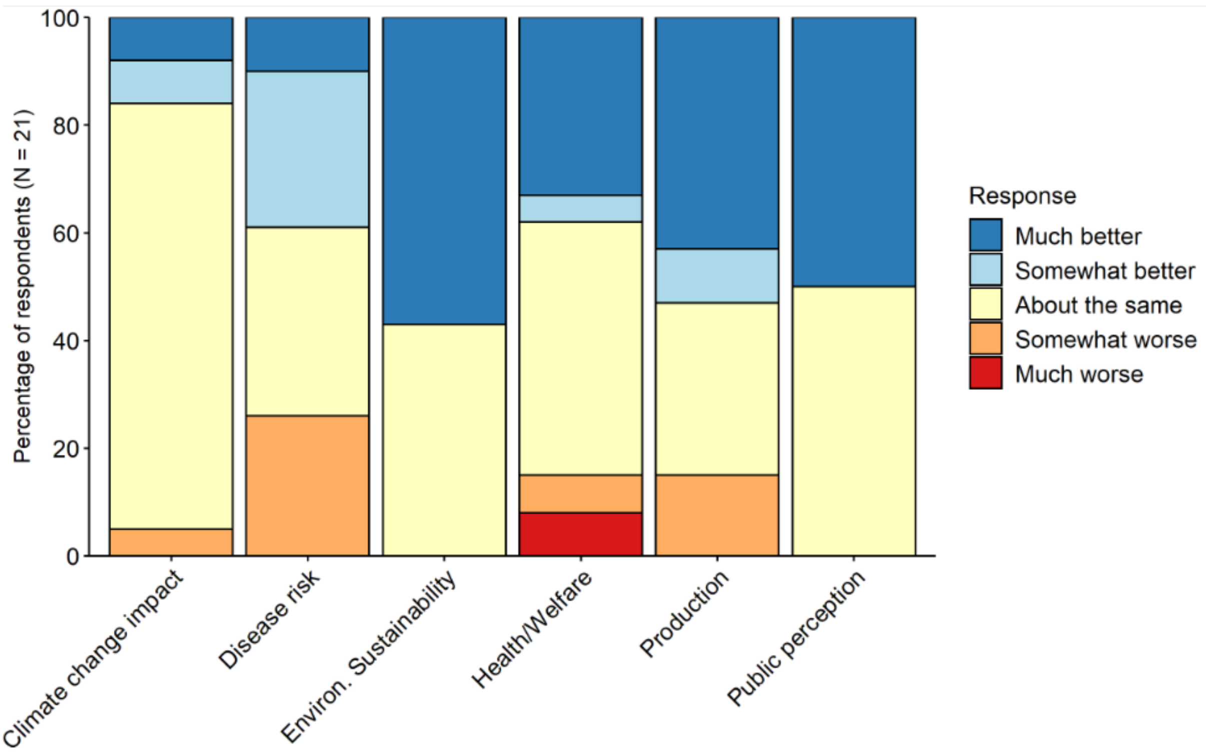

Figure 6: A 100% stacked bar chart displaying the percentage response to the question: Do you think that offshore aquaculture will offer any of the following advantages in comparison with inshore? N = 21

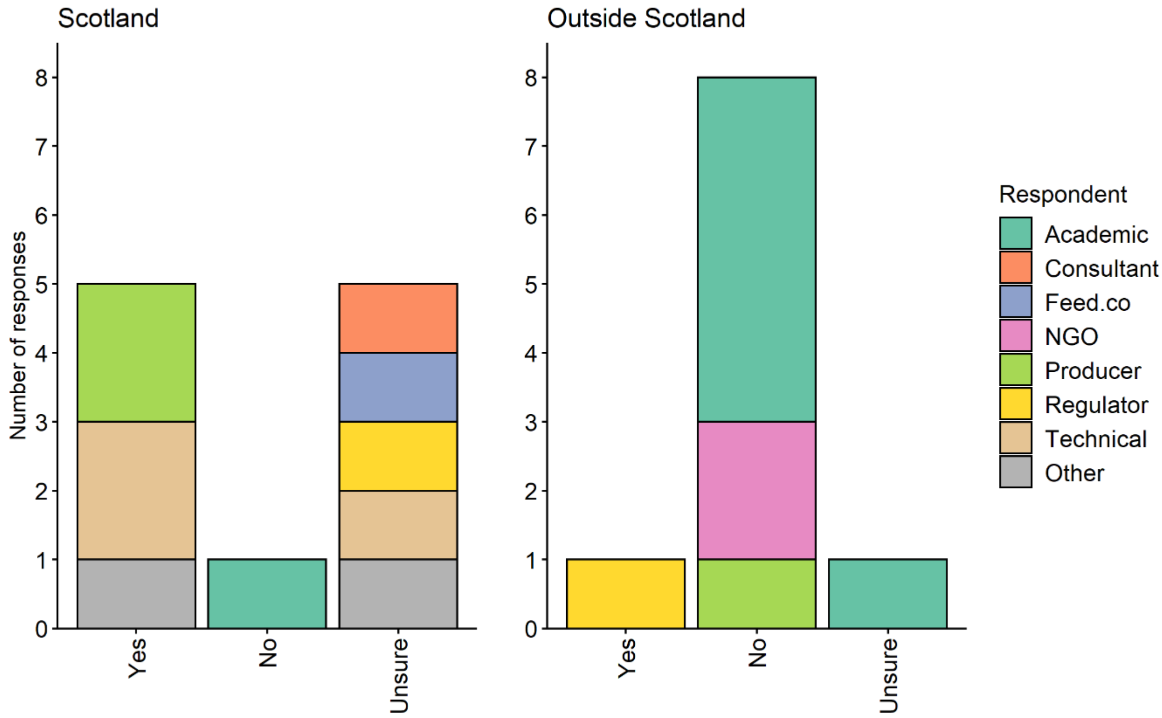

Figure 7: A stacked bar chart displaying the number of responses (country and stakeholder level) to the question: Are there suitable techniques available for offshore salmon farmers to measure and monitor impacts of salmon production in an offshore environment in your country?

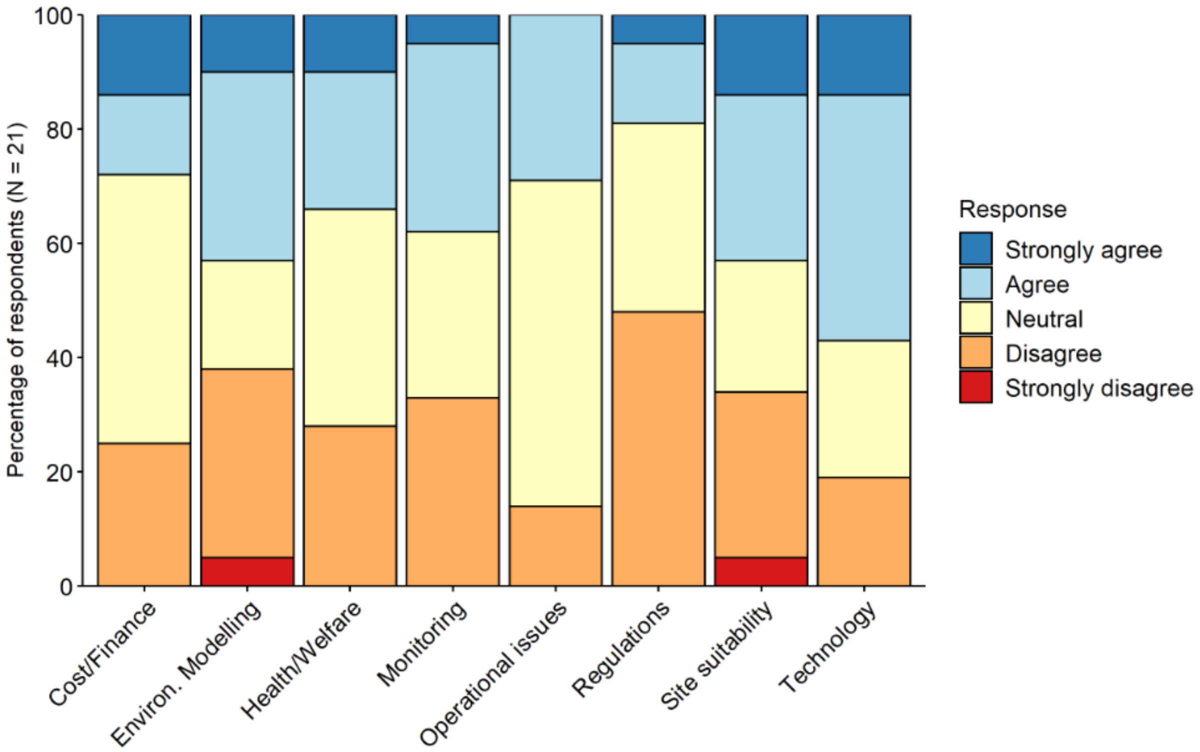

Figure 8: A 100% stacked bar chart displaying the percentage of response to the question: Do you think there is enough knowledge and research available to ensure the success of salmon aquaculture in these offshore environments? N = 21

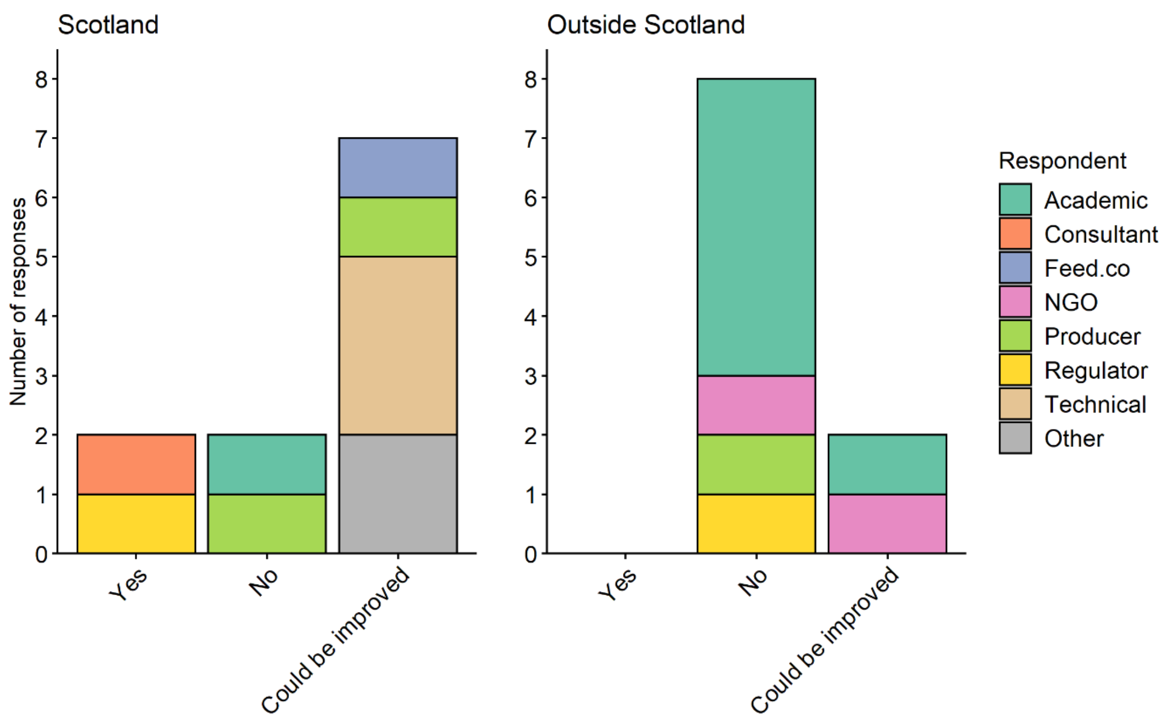

Figure 9: A stacked bar chart displaying the response (country and stakeholder level) to the question: Is existing regulation in your country effective for regulating offshore aquaculture?