Vivaldi Project

Disease management strategies ranking by stakeholder groups

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- ✓ **Executive summary**: particular care should be paid to the executive summary. Please, briefly present the context, the objective(s) of the work done, the different approaches followed by involved partners , the main results and the perspectives of the deliverable

- ✓ **General introduction**: it should present the state of the art and the hypothesis of the work done in the deliverable

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- ✓ **For each section**, carefully follow the proposed structure: objectives, material and methods, results and conclusion. Please don't forget that deliverable reports are not only read by experts. Be accurate and as detailed as possible.

- ✓ **The final conclusion** gathers conclusions of each specific work presented in the deliverable report. Identify links with other works in the project and general perspectives

- ✓ **Acronyms, Abbreviations and Latin words,**: Acronyms and Abbreviations should be written in full the first time they are used. Latin words should be written in full at the beginning of each paragraph and can be shortened afterwards. Latin words must be written in italics.

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PROJECT INFORMATION

Project Name: VIVALDI
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Description: The European project VIVALDI (PreVenting and mItigating farmed biVALve DIseases) aims at increasing the sustainability and competitiveness of the shellfish industry in Europe, developing tools and approaches with a view to better preventing and controlling marine bivalve diseases. VIVALDI is a 4-years European Horizon 2020 project coordinated by Ifremer (2016-2020): 21 mostly European, public and private partners are involved in it, representing the diversity of the European shellfish industry landscape. VIVALDI will not only bring new knowledge on the complex interactions between shellfishes, environment and pathogens, but it will also develop practical tools and approaches aiming at better preventing and controlling marine bivalve diseases. Hence, instruments allowing for an early detection of pathogens, good health indicators and prediction tools assessing the environmental influence on the emergence and development of the diseases will be developed in this project. A better understanding of how the shellfish stakeholders are organised will also improve the dissemination of results and of the tools developed in the project. It will also allow to better identify the best communication strategies when it comes to disease management.

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VIVALDI CONSORTIUM

IFREMER	Ifremer	MI	Marine Institute Foras na Mara	IMR	HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH
CNRS	cnrs	NUIG	NUI Galway OÉ Gaillimh	DLO	WAGENINGEN UR For quality of life
SYSAAF	SYSAAF	ATLANTIUM	Atlantium Illuminating Water Technologies	CEFAS	Cefas
LABOGENA	LABOGENA	UNIGE	UNIVERSITÀ DEGLI STUDI DI GENOVA	QUB	Queen's University Belfast
CSIC	CSIC	UNIPD	Università degli Studi di Padova	AWI	AWI ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG
IRTA	IRTA INVESTIGACIÓN Y TECNOLOGIA AGROALIMENTARIA	UNITS	UNIVERSITÀ DEGLI STUDI DI TRIESTE	DTU	DTU Technical University of Denmark
UCC	UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh	NOFIMA	Nofima	ULiv	UNIVERSITY OF LIVERPOOL

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EXECUTIVE SUMMARY

The growth potential of the shellfish industry is hindered by mortality outbreaks that have economic and social consequences. There has been previous work undertaken on bivalve diseases, however, many gaps remain in the understanding of these diseases. At EU and international level, more expertise is needed to make the appropriate steps towards more efficient regulation in the field of animal health and food safety. A number of possible scientific innovations could reduce the impact of shellfish diseases and mortalities on the production: earlier pathogen detection, genetic selection, improve water treatment in closed facilities, risk-ranking and pathogen transmission models and reviewed farming practices. In order to reach this level of innovation, VIVALDI project will generate new knowledge at the fundamental research level and new tools, at the applied technological level. It is therefore expected that in the end, VIVALDI should allow for a better prediction of diseases and improved disease management methods.

This document is a compulsory deliverable of work package 6, related to the task 6.2: Deliverable 6.8 “Disease management strategies ranking by stakeholder groups”. In this deliverable the involved partners (ULIV, QUB, IFREMER and CSIC) evaluate the perceptions of stakeholders about disease risk perception of stakeholders and analyse the reasons why these stakeholders decide (or not) to implement measures to fight against the diseases.

WP6 task 2 sought to evaluate the perceptions of stakeholders about disease risks and preventive practices. Mixed qualitative research methods were applied, including semi-structured in-depth interviews to investigate the perceptions, and focus groups to explore stakeholder group dynamics and understandings. These approaches were employed in order to gain depth and breadth of understanding, using a two-phased approach. Phase 1 involved detailed case-study explorations to gain rich understanding from specific stakeholders and sites. Phase 2 utilized the findings of Phase 1 to engage with stakeholders across different geographic locations in order to explore variation across the major shellfish producing countries in Europe.

In both areas studied in the Phase 1 case studies, French and Northern Irish farmers considered diseases/mortalities in quite general sense, focussing on an economic point of view. Generally, they did not believe that disease is an overall threat for the shellfish industry, and notably they were not sure diseases are a contributing factor to mortality. Nevertheless, oyster farmers in both regions mentioned key pathogens including Ostreid herpes virus OsHV-1. In Northern Ireland, the implemented mitigation and control measures were reactive, whereas French shellfish farmers mainly implemented measures to manage the economic impacts of mortality consequences on their individual businesses.

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Proactive measures to prevent disease introduction were also commonly believed, in both phase 1 and 2, as important included enhancement of surveillance as an early alert system to detect disease outbreaks and ensuring minimum-stress conditions during farming (e.g. decreasing the shellfish farming manipulations).

In the Phase 2, 13 preventive measures extracted from the Phase 1 interviews were hierarchized according to their perceived effectiveness, feasibility, cost and acceptability by different stakeholder groups in different locations. “Managing shellfish transfers” was revealed to be perceived as the most effective measure overall, and among farmers and scientists separately. It was also well regarded in terms of feasibility, cost and acceptability. Otherwise, despite evidence of regional beliefs, there was also considerable variation with single locations, most evident between the different stakeholders’ categories.

A key novel perspective developed in this work package highlights the critical importance of variation in beliefs and priorities across location, mollusc species, and stakeholder categories. Part of this variation may be explained by the differences in the priorities of different stakeholder groups, and the stakeholder networks within and between participating countries. These results strongly suggest that these differences should to be taken into account for prevention measures/strategies to be successfully and sustainably implemented at the EU level but also at the national level.

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GENERAL INTRODUCTION

Background

In the European Union (EU), aquaculture is an important economic activity in many coastal and continental regions, providing work for over 8,000 companies, primarily small ones (DG Health and Food safety of the European Commission 2018). For EU countries, the production of oysters, clams, scallops and mussels, is a very important component of the aquaculture industry.

However, bivalve mollusc farming is regularly impacted by massive mortalities associated with several infectious pathogens, weakening the sustainability of EU production. Within the last decade, massive mortality events in spat of cupped oyster, *Crassostrea gigas*, have been reported associated with OsHV-1 detection in different EU countries, notably in the French and Irish coastlines (EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare) 2015) and in Spain (Roque, Carrasco et al. 2012). Adult mortalities in *C. gigas* have also been related to the presence of *Vibrio aestuarianus* in France and in Ireland (EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare) 2015). Mass mortality events were also observed in other bivalve molluscs, but these were more localised. For example, massive mortalities in cockles, *Cerastoderma edule*, were reported in Spain (Galicia) in 2012, associated with *Marteilia cochillia* detection (Villalba, Iglesias et al. 2014). Since 2014 in France, massive mortalities were observed in mussels, *Mytilus* spp., associated with *Vibrio splendidus* clade detection (Garcia et al., 2015).

Facing such disease outbreaks by implementing effective control measures is challenging, as diseases may spread rapidly in the marine environment. Effectively, with the exception of hatcheries, shellfish production is extensive with no requirements for feed or the use of veterinary medicines. Thus, it is crucial to prevent the disease introduction and diffusion. However, despite the existence of regulatory frameworks at the European level to manage shellfish diseases, implementation of management measures is not always homogeneous between the countries. Multiple factors may explain this variation of implementation, such as the species produced, the ways they are produced, and the structure of the stakeholders' network within and between the countries. A previous study was conducted within the VIVALDI project to identify the stakeholders affected by mollusc diseases and related management measures, and to determine these stakeholders' influence and interest in management practices (VIVALDI Deliverable N°6.6, 2017). All these elements contribute to shape the perceptions of the stakeholders about the disease risks and the ways they weight the risks and benefits between potential actions and of action versus inaction.

For this reason, understanding the risk perception and beliefs of the stakeholders and the measures that they apply to fight against diseases is essential to successfully merge the findings of the scientific community and the practices of the producers, retailers and the competent authorities.

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This could be an effective way to prevent and mitigate the diseases that affect the production of bivalve molluscs.

Objectives

The objectives of WP6 task 2 were (1) to evaluate the perceptions of the stakeholders about the disease risks and (2) to will identify the reasons why they implement (or not) key management measures, and the multiple ways such measures are practiced.

In particular, we sort to unpack the varied perceptions of stakeholders with regard disease hazards and the ways they weigh the risks and benefits of different potential actions and of action versus inaction. This enabled exploration of the importance of different disease management measures for each group of stakeholders, based on the factors they deem to be important (e.g. economics, acceptability, perceived benefit, understanding); ranking these management measures also assisted comparison between the groups. Throughout these studies we sort to compare perceptions between stakeholders involved in production of shellfish species, different stakeholder categories, and across VIVALDI partners' countries.

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OVERALL OBJECTIVE

The aim of the task WP6.2 was to evaluate the perceptions of stakeholders about disease risks and reasons why they implement, or not, key management strategies, and the multiple ways they are practiced.

The overarching aim was to identify the facilitators and barriers to implementation of disease mitigation/control measures at a country/EU level.

In particular, we sort to unpack the varied perceptions of stakeholders with regard disease hazards and the ways they weigh the risks and benefits of different potential actions and of action versus inaction. This enabled exploration of the importance of different disease management measures for each group of stakeholders, based on the factors they deem to be important (e.g. economics, acceptability, perceived benefit, understanding); ranking these management measures also assisted comparison between the groups. Throughout these studies we sort to compare perceptions between stakeholders involved in production of shellfish species, different stakeholder categories, and across VIVALDI partners' countries.

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Phase 1: detailed case-study explorations/interview analysis

1.1. Objectives

Phase 1 involved detailed two case-study explorations to gain rich understanding from specific stakeholders and sites. These study sites were (i) Charente-Maritime, France, and (ii) Northern Ireland, UK.

1.2. Materials and methods

Although similar methods were adopted in each of the study sites, some approaches were modified by participating partners in order to maximise data yield and quality under local circumstances.

1.2.1 Participant recruitment

In keeping with the goals of qualitative research, purposive sampling was undertaken in order to ensure we included people with an appropriate range and diversity of characteristics. Subjects for inclusion in this study were recruited through existing contacts and databases held by the study team and were grounded in the findings of WP 6.1.

In Northern Ireland, potential participants were divided up into sub-groups (strata) based on (1) their activity in the supply chain; (2) species cultivated; (3) location. Subsequently the participants were randomly selected from each stratum until saturation was achieved. In total 25 stakeholders made up of shellfish farmers, government, food inspectors and independent agencies were interviewed. All participants provided informed verbal consent and the study was approved by the School of Biological Sciences Ethical Committee at Queen's University Belfast.

In France, a similar stratified random sample was used, based on sampling categories that captured production stages and locations of the farming cycle. Five sampling categories were used to obtain a range of perceptions from (1) the oyster and mussel production systems, based on shellfish production stage and location of the farming cycle (only local or beyond), (2) national or regional representative body for the shellfish farmers and (3) national or regional decision makers. In addition, the random stratified sample was further complemented by snowball sampling, in which participants identify other potential participants who they believe have an interest in the aims of the study. In total 52 stakeholders were interviewed.

Contact with potential participants was initiated by email or letter, with follow-up by telephone in order to arrange one-to-one interviews.

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1.2.2 Interview guide

In Northern Ireland, an interview instrument was constructed based upon a review of previous literature and the opinion from a number of experts involved in the aquaculture supply chain (n=3). The interview guide was piloted for clarity, comprehension, reliability and timing with three individuals and refined prior to implementation. The questions were designed to elicit participant's perceptions regarding their experiences with shellfish production including: their role/activity in the supply chain; the prevalence, threat and impact of disease to their production; and mitigation measures. This topic guide was adapted for use in France. Both guides are available in *Annex 1 and 2*. The interview guides listed topics to be covered in the discussion, but not the specific questions nor the order of the questions. This enabled the interviewee to talk in their own way about the topics of greatest importance to them, but ensured all relevant topics were covered in the interview. This approach enabled the discussion to move into, and explore in detail, new issues as they emerge within an interview.

1.2.3 Data collection

One-to-one semi-structured interviews were conducted with key stakeholders (including shellfish farmers, fishermen, local and national policy makers, technical institutes and scientists). In the main, interviews were conducted face-to-face (Northern Ireland, n=24; France, n=49), but occasionally telephone interviews were conducted (Northern Ireland, n=1; France, n=3). Interviews were conducted in Northern Ireland between July 2017 and July 2018 by a single interviewer (MF; a Food Quality, Safety and Nutrition Scientist) and in France between September 2017 and May 2018 by two interviewers (GM; an Environment and Geographic Scientist and CL; a Veterinary Epidemiologist Scientist).

At the commencement of the interviews, interviewees were given a brief overview of the project and reassured there was no right or wrong answers. The interviews concluded when all topics had been covered and no new information emerged. Interviews were audio recorded with mean durations of 45 minutes (Northern Ireland) and 40 Minutes (France).

1.2.4 Data analysis

Audio recordings were transcribed verbatim, checked for precision and coded thematically; data management and coding were assisted through the use of Nvivo 12 (QSR International Pty Ltd, Victoria, Australia). As the emphasis was on the perceptions of the stakeholder, the study took a constructivist approach using thematic analysis to evaluate the aquaculture industry from the subject's point of view and assess the meaning of their experiences. The analysis process was iterative, and ran alongside data collection, such that each informed the other. Initially, the transcripts were coded and independently checked for coding consistency before consensus on the validity and reliability of the application of codes to the data was reached. Minor revisions were made to the terminology of some codes. Data saturation occurred as no new codes emerged from

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the interviews. Subsequently, codes were grouped into themes and categories which represented a common principle. These themes were then inspected for overlap to ensure there was a clear distinction within and between each of the categories and themes.

1.3. Results

1.3.1. Northern Ireland

- Perceptions about shellfish diseases

The stakeholders involved in shellfish aquaculture mentioned three different shellfish diseases: *Oyster herpes virus*, *Bonamia ostreae* and *Marteilia refringens,* related to cultivation in Northern Ireland. There were a number of different attitudes related to the prevalence of disease:

1. Not an issue.

"Disease isn't an issue" (Participant M1)

2. The risk of disease is uncertain.

"It is fair at the minute it was higher at a time and you don't know what is around the corner either." (Participant O8)

3. Not sure if disease is a contributing factor to mortality or not.

"We wouldn't [have disease]. Well I don't know. If I find oysters dead like I don't know what killed them. To me it could be stress..." (Participant O5)

4. Disease has been detected in the water body but has not caused an issue.

"They found Marteilia Refringens *in Belfast. So that seems to be a buzz word at the moment. But experience with this, yeah they found it but it doesn't seem to be doing any harm to the place."* (Participant M1)

- Disease impacts

In the oyster sector, a disease outbreak causes rapid mortality to production.
"Well you could be sitting here next September and I could be sitting there with maybe 100,000 Euros worth of stock to sell between now and end of November or October. I could lose that in a week. That would be sad. You know." (Participant O3)

This mortality has huge economic repercussions for the shellfish production business.
"The amount of money we have sunk into that… it's just thousands, thousands. And then one year we got a disease and it wiped me out. Just when I thought I was getting it under control. I started up and had no money for about three years. I had zero. And just when I'm starting a disease came and wiped me out. Two years then I was back with very little money. And now I have got to build it up again." (Participant O3)

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On the other hand, disease has not caused similar consequences to the mussel sector, despite the presence of *Marteilia refringens* in Belfast Lough and Dundrum bay.

"We have a scientist actually doing monitoring the Loughs at the moment, the Dutch authorities send him over every year… he was saying about this Marteilia refringens, he has seen it pretty much everywhere but that it doesn't seem to be something, if the water warms up, then we might have a problem with it, but in Ireland you know at current temperatures it doesn't seem to take hold. I know last year because it was a little warmer we saw it." (Participant M1)

In the disease-free areas, the shellfish farmers benefit from access to worldwide markets.

"I am Bonamia free so I can send them anywhere." (Participant O1)

Similarly, when disease is latent and not causing mortality, this provides the sector with an opportunity to capitalise on their increased production. This was particularly related to periods when disease outbreaks were causing mortalities in other production sites.

"…one year, not last year, the year before. Every other bay in Ireland had massive mortalities apart from Carlingford. So we were just selling everything and just getting top quality prices for it… They needed it and they paid for it and they paid the top dollar." (Participant O3)

However, some farmers in locations which have been declared disease free voiced frustration over difficulties in sourcing good quality, cheaper seed from French hatcheries.

"So being a disease-free bay is a problem for me. Because I can't have access to good quality seeds, the ones that grow better, the ones that are cheaper. I have to work with UK or Irish seed with comes from smaller hatcheries, with difficulties and what I got, it's not very good… the ones coming from France are coming from a selection program you know they get the best of them. So that's my problem today, I am not starting, I am not competitive I can't be competitive…" (Participant O2)

Consumer perception was also discussed as a potential impact in relation to awareness and understanding of shellfish diseases. In general stakeholders did not believe disease came under their radar.

"It doesn't really come under their radar… straight over their heads, an oyster is an oyster to them" (Participant O7)

However, some explained consumers may unjustifiably associate shellfish disease as harmful to humans.

"It is not harmful to them but there is always the association, it is oyster herpes disease, I am going to eat this diseased creature." (Participant 07)

Nevertheless, the common belief was that those interested in eating shellfish will eat it and those forming negative associations are not the target consumers anyway.

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"Well the world seems to be divided into two types of people. Some people who they will just not touch oysters or eat oysters or anything like that there and that is fair enough, I am not going to start going into that road… really the oyster herpes virus, it was proven that it was no risk to humans… but again there is some people who would say aww no I am not, it is like mad cow disease in cattle these things, or like the salmonella in eggs away years ago, you probably wouldn't mind that, but everything gets a rattle now and again, but there is people then who just wants to eat them and that's just the way it is, you have to go over to France or Europe, anywhere in Europe to see just how anxious, the Chinese are great customers, they will just eat everything…but someone who wants to be picky and one thing and another but in all honesty they weren't going to eat oysters anyway." (Participant O8)

- Risk factors for disease entry into NI

The stakeholders in the supply chain revealed a number of risk factors they believed were related to the prevalence and intensity of disease. The purchase of imported seed from regions were a disease is prevalent was the most commonly cited route of introduction.
"… because the gigas have so many diseases in them it is starting to hit us, it has been hitting the French, now it is hitting us because it has been transported over." (Participant O1)

Similarly, stakeholders believed they are vulnerable of illegal and unregulated movements of shellfish from a production area were disease exists by other water users into the shared water body.
"Now, you can actually go underground or go to French farmers because Native oysters or gigas oysters will reproduce there naturally in the water so they collect them and sell them and that's where disease comes from." (Participant O1)

The ploidy of the seed also played a role, with triploid believed to be more susceptible to disease.
"Triploid, yeah... But they are more susceptible to disease but they command a better price." (Participant O3)

Temperature was a significant factor important in the prevalence of a disease outbreak. For oyster herpes virus 16^{o}C was cited by all oyster farmers as the critical temperature which activates oyster herpes virus and initiates summer mortalities.
"…it's to do with the temperature of the water, it needs to be over 16.5…." (Participant O3)
"…oyster herpes virus doesn't help anybody and if we get water temperatures in excess of 16 degrees centigrade we can see substantial mortality here so we are not out of the woods, the further north you go the less of an impact it has because it is triggered by water temperature and that is why the French are here." (Participant G2)

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It is also believed temperature is an important factor for *Marteilia refringens,* with the current temperature regime limiting the opportunity for the pathogen to cause disease outbreaks.
"…about this Marteilia refringens…if the water warms up, then we might have a problem with it…" (Participant M1)

Parallel to temperatures, climate change has been cited as a risk factor for the prevalence of disease and the opportunity for new species or pathogens to survive.
"Climate change is a big one so it is at the minute we have the benefit that we are cooler than France, and if that whole thing moves up if it moves up we are going to be hit with the same diseases as France, the same prevalence of disease but are they going to get worse because they are going to get hotter they will be getting hotter than us I have caught fish in Carlingford Lough from Spain, Spanish trigger fish and that was several years ago." (Participant O7)

Although the mussel farmers did not believe the predicted two degree increase in global temperatures would be enough to cause significant concern in relation to disease.
"I don't believe two degrees in Ireland, in the water is going to cause too much problem. It could cause it elsewhere but not for the mussel industry. The oyster industry will have a huge problem with it because of the herpes virus and there is another one of those viruses but the mussels aren't susceptible to that." (Participant M1)

However, stakeholders did believe there was potential of new and emerging diseases with warmer climates and the importance of keeping the temperature below two degrees increase.
"Aww, like I said to you about the water warming up, you are learning about new diseases, it all depends, they are on about global temperatures you know, keeping them below two degrees." (Participant M1)
"The other problem now is the vibrio oyster and new disease which kill the oyster when they are commercial size which is quite a bigger problem actually than the herpes virus." (Participant O2)

- Disease management measures

The approaches taken for disease management and control vary and are generally reactive. Some farmers did not believe there were options to help prevent disease.
"Tough luck just…if it happens, it happens" (Participant O3)
"…to be honest it is one of the lessons you learn about this, there is always going to be mortality because oysters have no immune system, so you can't, well there is just too many of the things, but there is nothing you can do like animals where you can spray them or dose them or anything like that there, they just die and that's that…" (Participant O8)

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However, others recognised the role management procedures can have in preventing the entry, spread and consequences of disease. Ensuring stress free conditions was deemed important.

"…but what you try to do is try to make sure the conditions are right that they are happy sitting there growing." (Participant O8)

The density of production was also discussed with different stakeholders revealing conflicting views. Some farmers believed low densities helped to reduce the spread of disease.

"…with the oyster herpes virus is if the bay is low density, you know like a bay with not much production are not much affected it's like a class with many kids or a class with not many kids. If one kid gets sick in a crowded place they all get sick. And it is the same with the site. So it is all to do with the culture practice really like." (Participant O2)

"The problem you can have, if you don't plan ahead, you put so many oysters into a bag and then disease is more than likely to come in over peak growing time." (Participant O7)

Whilst others believed over-producing reduces the overall impact of a disease outbreak.

"…what you find as a response to the herpes virus mortality that people actually produce so much seed that they don't mind losing 50% of seed on the first year because what is left will keep growing until the end. You get your mortalities the first year. If you don't get it the first year you try to save it you should expose the oysters as soon as you get disease anyway so you are better off to lose them now so people use twice more seeds and lose half and the production and its back to normal." (Participant 02)

Movement restrictions and their importance in preventing the entry of disease into the waters were mentioned.

"There is a protocol in place if you are taking stuff from anywhere to put into your bed it has to be of the same disease status the water has to be the same disease status so if there is something that is *in this water that you don't have you can't take that across but you can take it back."* (Participant O7)

Surveillance methods are important as an early warning sign for the potential of a disease outbreak, particularly in areas were disease has been detected. This involves monitoring disease in the regions the seed is imported from and carrying out more rigorous inspection of the stock at times of high risk.

"We check, see if we have mortality in France after in the summer, after here check all the bag, few bag here, not each day but maybe every 15 days or sometimes when I go on the shore I check different bag to see if we start to see mortality on the oyster on. We follow that all through summer." (Participant O6)

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If farmers detect any unusual mortalities, they are expected to report this to the competent authorities as a part of the disease surveillance process in the region. However, this is dependent on the adherence of the stakeholders involved.

"Not really, no. We wouldn't. Well I don't know, if I find oysters dead like I don't know what killed them. To me it could be stress. Like every oyster I find, I suppose you're supposed to report it but you wouldn't be bothered to be honest. If you find a dead oyster you throw it away like. You know like it could be stress or anything I don't know or something, predators." (Participant O5)

The quality of seed was also cited as an important factor for the resiliency to disease. In particular, Pacific oysters from a selection program in Frances were considered the most robust to oyster herpes virus.

"The key success in the farm, the quality of seed would be number one. You know if you want to do farming you have to start with nice animals, good, healthy population. If you start with oysters that have problems with growing and no resistance to disease – the ones coming from France are coming from a selection program you know they get the best of them." (Participant O2)

A common theme was a lack of concrete knowledge regarding shellfish diseases. In some cases, stakeholders voiced frustration over the overly cautious decisions made based on incomplete information and no evidence of consequences of particular diseases, e.g. *Marteilia Refringens.* The lack of reliable detection methods was also cited as a weakness in the system.

"…There is another school of thought saying it is in the Foyle or it is in Belfast Lough and we can't see any damage being done just pick them out it is not doing any damage so why bother with them…" (Participant M3)

"The story with herpes virus I don't think they know very much what they are talking about in the department to be honest. This new virus, it is a variant that was detected in 2008-2009, everywhere in the world, many places at the same time. And it's a unique virus to the oysters, I mean it has a genome like that… this virus it is very stable so it doesn't mutate and it is part of the oyster population. I believe that it was present already in the Irish water a long time and French water a long time before it struck…in 2012 we don't know so much. So what we did was this program, to monitor the bay, like mortality in the bay, there was no mortality in the bay actually and they say you cannot import seed from a bay which are non-disease free which is a bay where the virus has been detected, to a disease free bay. The thing is, they consider because you cannot detect that its disease free, that there is no disease there. But I don't agree with that I think it is just because you cannot detect it not that the disease is not present. It's just your detection method may not be appropriate first or maybe because various other latent stage in the oysters can be detected because it's too difficult to detect them and that's it." (Participant O2)

However, there is risk of 'letting the genie out of the bottle' if we allow certain activities and movements without fully understanding the potential consequences.

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"…but then there is other people saying if let the genie out of the bottle then it is out of the bottle you don't get it back in." (Participant M3)

Similarly, some stakeholders revealed apprehensions over the reliability and effectiveness of detection methods, surveillance and enforcement measures.

"The thing is, they consider because you cannot detect that its disease free, that there is no disease there. But I don't agree with that I think it is just because you cannot detect it not that the disease is not present. It's just your detection method may not be appropriate first or maybe because various other latent stage in the oysters can be detected because it's too difficult to detect them and that's it." (Participant O2)

"What about Monopoly? It arrived in about 4 or 5 years ago? Did they do a check on it to make sure it was ok? They introduced a snail into Belfast Lough, from France…And I say, who gave this permission...And again its fisheries responsibility to come and check imported stuff." (Participant O1)

1.3.2. France

- Perceptions about shellfish diseases

Globally, all the stakeholders did not seem to be worried about a particular disease, as all diseases were seen as having the same tangible consequence, *i.e.* mortality of bivalves.

"We speak about diseases in general but… we mainly speak about mortalities and not necessarily of disease itself" (Q1 - National farmer representative body)

"In my mind, mortality, disease, it was… yes I was doing the connection… there are mortalities because there are diseases" (Q2 - Local farmer representative body)

"Because when you say that mussels were sick, I say no… if tomorrow you die will we remember that you were sick or that someone killed you with a weapon or so? At the end of the day, the result is the same" (Q3 - Mussel farmer #1)

During the interviews, all the stakeholders used the word "mortality" much more than the word "disease", except for the national competent authority in charge of shellfish health (Figure 1). Thus, this suggests that mortalities rather than shellfish diseases were a major concern for the stakeholders.

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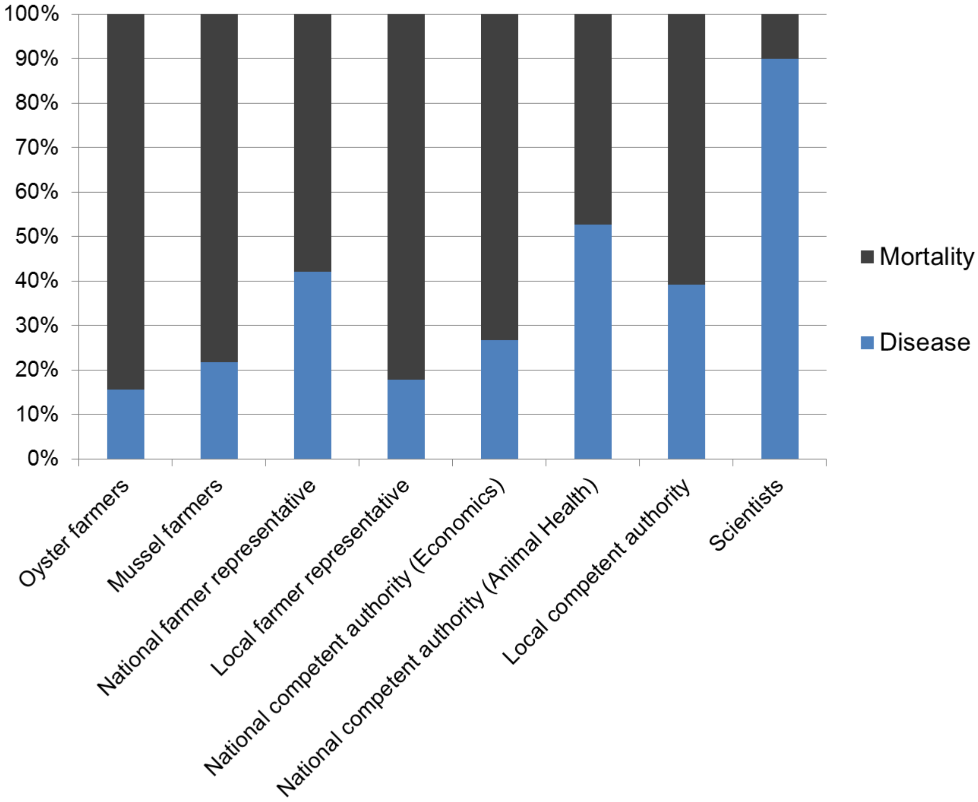

Figure 1. **Relative occurrence of the words in the stakeholders' interviews, France**

Oyster and mussel farmers showed a varying perception about diseases. Oyster farmers spoke about the mortality crisis in 2008-2010 and mentioned two pathogens: Ostreid herpesvirus 1 (OsHV-1), their worst memory, and *Vibrio aestuarianus*, the most worrying as it occurs at the end of the rearing cycle thus it cannot be compensated. Even so, one third of the oyster farmers believe that diseases were not a problem anymore. Mussel farmers mentioned a more recent crisis in 2014 and 2016. They only mentioned mortalities related to the bacteria *Vibrio Splendidus* clade and parasitism due to *Mytilicola* sp. The majority (90%) of the oyster farmers believed they had coped with the crisis situation, whereas only half (56%) of the interviewed mussel farmers had this perception.

For both oyster and mussel farmers and their representative bodies, the primary concern mentioned was that of environment quality, *i.e.* water quality:
"[…] but I think that today, pollution, we are sure, at least I am sure, I often fly over the area by helicopter and sometimes, we see different colours of the water, at the mouth of the Charente [river] and the week after, all have died… this is strange" (Q4 - Oyster farmer #21)

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"I don't know if this is a disease, to be clear, you used this term twice or three times but I am not sure this is a disease and if this is a disease what is causing it, this is the main issue. Thus, roughly, our observations on the field are that we clearly have the feeling that environment is deteriorating and we are looking rather for consequences than finding the causes." (Q5 – Oyster farmer #45)
"Shellfish are indicators, they are sentinels" (Q6 – Local farmer representative body)

Except the national competent authority in charge of animal health and the scientist representative, all stakeholders were not really concerned by an emerging or exotic disease.
"A [disease] which develop near the country borders and which could arrive in France, yes, there is all which is related to exotic diseases in general." (Q7 – National competent authority - Animal Health)
"The one which is not there yet, because we realize that we are equipped not to avoid it" (Q8 – Scientist representative)

- Disease impacts

Except the national competent authority or shellfish health, all stakeholders mentioned the economic impacts of diseases. Farmers and their national representative body also reported psychological and ethical impacts.

For shellfish farmers, the main impact of mortalities was the change of the shellfish production balance and the huge economic repercussions for the shellfish production business. Their shellfish production decreased whereas their production costs increased by increasing the number of spat collectors, loans for liquid assets … These structural changes contributed to weaken their business.
"The main repercussion is financial with the loans we had to contract" (Q9 – Mussel farmer #2)
"If you manipulate them [the oysters] you have to sell them immediately because… yes before we stoked them but now as soon as you manipulate them you have to sell them. Before, it was better. So now we wonder about the sale, for supermarkets for example, with high delivery which needs stock." (Q10 – Oyster farmer #20)
"We lost market shares because we couldn't deliver supermarkets" (Q11 – Mussel farmer #4)

Mortalities also changed the working habits: as the production volume was uncertain, farmers could not anticipate the market outlet anymore, changing for a just-in-time production. These contributed to increase of the anxiety and attention of the farmers, having psychological impact.
"Farming something that will die, this disturbed me. After a while, you get used to that, but this first year was quite odd" (Q12 – Oyster farmer #4)
"When chatting with people, we are feeling ridiculous to say "I manage to save 10% of the oysters". Because not any of farming would accept that"." (Q13 – Oyster farmer #4)

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For shellfish farmers, mortalities also create a negative image of the shellfish industry at the national level. For shellfish farmers, consumer perception was a concern, and trade was also impacted. This also contributes to a motivation decrease for mussel farmers.

"We don't notice but after that, years after, we realize the psychological motivation, when this appears only one year, this is ok but when this lasts for years, we know that there is something wrong. And I would say, we need to be passionate in our jobs, if there is no passion, this can't last. And I would say that this is passion which disappear and then, the wish to pass on" (Q14 – Oyster farmer #38)

For the other stakeholders, the main perceived impact was only financial.

*"For spat mortality, as the rearing cycle is long […], the impact on liquid assets is much less important than on adult oysters, which die at the end of the cycle […]. Here the financial impact is much more important" (*Q15 – Local farmer representative body)

"The oyster industry was helped during the first years of the crisis, the pattern then installed and stabilized. There were evident impacts on the businesses but the ones which coped with the situation, a priori, are still there. In the mussel industry, businesses are more fragile, mussel is a product with less economic value, they can less have an impact on price and there is concurrence with the imported products" (Q16 - National competent authority - Economics)

Whereas the scientists shared the belief of disease financial impact, they also believed that diseases had no impact on the Nature.

"The impact on the species is not obvious. In the long term. There are plenty shellfish species that can be exploited" (Q17 – Scientist representative)

The national competent authority representative in charge of shellfish health believed that the shellfish diseases and related mortalities had no impact at all.

"I didn't perceive any real impact on the industry […]. I am not sure these contributed to lower this sort of quest for profit that existed in the industry, I mean, increasing the production, increasing the densities." (Q18 - National competent authority – Animal Health)

- Disease management measures

Different management measures were undertaken by the stakeholders in response to shellfish mortalities.

Shellfish farmers revealed that the main measures undertaken to make do with the mortalities had nothing to do with disease management: they were mainly economical. They implemented four common main measures, which were implemented at the individual level:

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(1) Overcoming the production losses and getting back to a production balance, by increasing the production volume, reconstituting the loss stock, increase the purchases, decreasing the time between 2 batches;
(2) Getting back to a financial balance, by asking for financial compensation for production losses, increasing the sale price, layoff, decreasing investments;
(3) Diversifying the production, by changing the sales strategy (direct sale, export), adding production types, creating side business, moving the farming sites (spatial evasion);
(4) Changing work habits, i.e. farming practices, state of mind (increasing surveillance and attention, doing tests…).

"We changed our working habits on the production sites, for example from January to March, during the colder periods, we get back our oysters from Brittany, we calibrate them and we take them back, here or in Brittany […] we decrease the handling during the growth, we stress them as little as possible and place them in areas protected from a lot of coming and going, and from currents" – (Q19 – Oyster farmer #2)

Oyster farmers also mentioned the possibility to specialise in production stages or types, whereas this measure was not mentioned by mussel farmers.

About two thirds of the interviewed oyster farmers and three quarters of the mussel farmers were accompanied to implement these measures. Help was mainly given by other farmers in the oyster industry whereas it was mostly given by the competent authorities in the mussel industry.

The local farmers' representative body main implemented measure was helping and supporting the farmers' indemnity requests and this was perceived as useful by its representative.

The local competent authority implemented two measures that were perceived as useful by its interviewed representatives: (1) estimating the shellfish mortalities and the remaining stocks and following the spatiotemporal evolution of these, and (2) helping farmers to assemble their dossier related to the mortality declaration, in the context of indemnity requests.

The national competent authority in charge of industry economics implemented two funding measures. The first one was the funding of scientific observation networks of shellfish mortalities. Such a standardized description of the mortalities helped to define an abnormal mortality level, which helped to justify the initiation of financial compensation indemnities at the EU level. The second measure was the funding of a national research project to better understand the mussel mortalities. This latter measure usefulness was perceived as reserved by the interviewed representative because he/she put himself/herself in the place of the farmers.

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"The industry is very frustrated about research because research has a time step much longer than the industry's one" (Q20 - National competent authority representative - economics)

The national competent authority in charge of shellfish health implemented two disease management measures that were perceived as useless by the interviewed representative. The first one was the restriction of shellfish transfers when coming from zones in which mortalities were declared, and this was not respected by the farmers. The second measure was the development of process to qualify the spat in relation with certain pathogens, which never succeeded.

The scientists were the first to detect diseases, as they are in charge of the disease surveillance system based on mortality declaration. First, they warned the national competent authority in charge of shellfish health. Second, scientists implemented research activities to contribute to a better understanding of these diseases. They felt that communication during crisis period was complicated and failed. They also voiced frustration about a lack of feedback related to disease management within but also between the different stakeholder categories.

Broader investigation of the perception of the stakeholders about disease management measures revealed that some measures would be desirable to prevent diseases and others measures, on the contrary, that the shellfish industry did not want to implement.

The following 13 desirable management measures were cited by the interviewees (without any ranking):

- Diversifying the business activities and the promotion modalities of the products;
- Using triploid oysters or mussels;
- Controlling the infectious status of shellfish before their transfer;
- Knowing shellfish movements and the shellfish stocks in production;
- Declaring the mortality in a reactive way and implementing an early alert system;
- Implementing quarantine zones;
- Developing new farming areas (offshore or in the rivers);
- Decreasing shellfish farming densities;
- Decreasing shellfish farming manipulations;
- Decreasing the shellfish immersion time;
- Managing the quality and quantity of freshwater runoff;
- Oxygenating and purifying shellfish in purification ponds;
- Improving knowledge about mussel mortalities.

The following 9 non-desirable management measures were cited:

- Increasing shellfish farming densities;

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- Decreasing mussel densities (“clearing”) during the farming cycle;
- Depending only on shellfish produced by hatcheries;
- Developing hatchery mussels;
- Developing triploid mussels;
- Increasing oyster movements;
- Developing good practice guidance (for oyster farming);
- Diversifying the occupations;
- Using medicinal measures.

Two prevention measures revealed conflicting views: restriction of shellfish movements and use of genetic disease-resistant oysters.

1.4 Conclusions

As the composition of the stakeholders’ samples was different between Northern Ireland and France, comparisons only concern the perceptions of the oyster and mussel farmers. These two case-studies provided insights into the perceptions of disease risk and preventive disease management measures in the oyster and mussel industries of two major shellfish producing countries.

Disease risk was perceived by oyster and mussel farmers almost similarly in Northern Ireland and France. Farmers did not believe that disease is a threat for the shellfish industry, and notably they were not sure diseases are a contributing factor to mortality. In particular, for French farmers, the water quality was the main issue to explain shellfish mortalities.

Oyster farmers mentioned the Ostreid herpes virus OsHV-1 both in Northern Ireland and in France, as massive mortality events were reported in these two countries the last decade (EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare) 2015). Irish oyster farmers also cited notifiable diseases (*Bonamia ostreae* and *Marteilia refringens*) whereas these concern another oyster species (flat oyster, *Ostrea edulis*) that the one they mainly farmed for human consumption (Pacific oyster, *Crassostrea gigas*) and mussel *Mytilus edulis*, which is sometimes produced in the same bay as Pacific oysters. This reflected the status of shellfish diseases reported by the Department for Agriculture, Environment and Rural Affairs (DAERA 2018). This interest is explained by the fact that flat oysters or mussels are present near the Pacific oyster farming areas and the presence of these pathogens causes movement restriction of Pacific oysters to other aquaculture locations, as these species are considered as vector species. As in France the disease status is “unknown” for these notifiable diseases, the French farmers did not feel worrying about these. However, French oyster farmers mentioned *Vibrio aestuarianus*, which causes strong direct economic losses as it affects

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marketable sized oysters (Azéma, Lamy et al. 2017). Irish farmers did not mention this vibriosis, whereas oyster mortality events were also regularly reported in Ireland (EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare) 2015).

Irish mussel farmers mentioned *Marteilia refringens,* which is a notifiable disease at the OIE and EU levels, whereas they did not experience any mortality associated with the detection of this pathogen. This pathogen was not cited by the French mussel farmers, who were experiencing massive mussel mortalities since 2014. They rather mentioned the bacteria *Vibrio Splendidus* clade, which was suspected to be associated to these mortalities (Garcia, Francois et al. 2015), and parasitism due to *Mytilicola* sp..

In Northern Ireland, farmers did not really worried either about diseases or mortality risk under the current temperature regime, but they were aware of potentially emerging diseases under climate warming scenario. In contrast, the French shellfish farmers did not feel concerned by emerging or exotic diseases.

The main perceived impact of disease by oyster farmers was similar in Northern Ireland and in France: mortalities had substantial financial consequences to oyster production businesses. Reputation was also mentioned in the two case studies. Such consequences have been highlighted in previous studies of shellfish disease (Oidtmann, Thrush et al. 2011; Peeler, Allan Reese et al. 2012). The huge economic impact was also mentioned by the French mussel farmers, who experienced massive mortality events since 2014. These latter also reported a strong psychological impact due to the uncertainty of the production volumes, leading to a decrease of motivation for their activities. On the contrary, Irish mussel farmers did not discuss widely the economic impacts. This difference of perception between the mussel farmers may be explained by the different epidemiological situations in the two countries.

Once a disease is introduced into shellfish farming area, mitigation and control are often illusionary. Thus, disease prevention measures should be mostly considered. However, in Northern Ireland, the implemented mitigation and control of disease were reactive and French shellfish farmers mainly implemented economic measures to manage the mortality consequences on their individual businesses; these measures had little or nothing to do with management of the disease itself. Ten years after the beginning of the massive mortality events in the French oyster industry, these management strategies have not really changed (Carlier, Prou et al. 2013). This may be explained by the fact that some shellfish farmers, both in Northern Ireland and in France, did not believe there were options to prevent diseases. But other farmers recognised the benefit of measures in preventing the entry, spread and consequences of diseases, both in Northern Ireland and in France. These measures commonly believed as important were the surveillance methods as an early alert system to detect disease outbreaks and ensuring stress free conditions during farming (e.g.

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decreasing the shellfish farming manipulations). However, conflicting views were observed as regards the benefits of the density of production in Ireland whereas French farmers believed that lower densities would help to reduce the impact of diseases (*i.e.* mortalities) and did not want to increase the farming densities. Similarly, conflicting views were observed regarding the movement restrictions in France, whereas Irish farmers highlighted this measure in preventing the entry of disease into the waters. The quality of seed was mentioned as an important factor to consider by Irish farmers. They voiced that the seed sourced from French hatcheries had the greatest resistance to oyster herpes virus disease, as it come from a robust selective breeding program. This topic was further discussed in France, where oyster farmers had conflicting views regarding the use of genetic disease-resistant oysters and mussel farmers were reluctant to develop hatchery mussels. Same difference in perception was reported about the seed ploidy, with Irish farmers believing that triploid seeds to be of better quality and more robust, whereas French farmers, and notably mussel farmers, were reluctant to develop triploid mussels.

Both in Northern Ireland and in France, shellfish farmers voiced frustration over the lack of concrete knowledge regarding shellfish diseases. In France, they had also high expectations from other stakeholders to obtain such information.

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Phase 2: variation of perceptions across Europe with regard to disease prevention measures

2.1. Objectives

Phase 2 built upon the findings of Phase 1 to engage with diverse stakeholders across different geographic locations in order to explore variation across the major shellfish producing countries in Europe. This Phase used participatory focus group discussions (FGDs) to explore stakeholders' experiences of disease and disease control. The purpose of the FGDs undertaken in Phase 2 was to enable participants to rank key disease prevention practices identified in Phase 1, according to their effectiveness, and to score them on their feasibility, cost and acceptability (Kumar, 2002).

2.2. Materials and methods

2.2.1. Focus group discussions

FGDs were constituted with the aim to have, as far as possible, a reasonably homogeneous group of people within each group, in order that group participants may find easier to talk to one another. Each group usually included around 5 to 6 participants, with the aim of not exceeding eight participants, because too large groups are more likely to break off to talk in sub-groups and leave people out of the discussion (Adams and Cox 2008). Thus, participants were arranged into the different groups according to their stakeholder category and, where appropriate, their preferred speaking language.

Before starting the discussions, participants were asked to fill a description sheet to record their role and the shellfish species they worked with, to check the homogeneous composition of the FGDs. For each FGD, a facilitator ensured that all participants understood the activities, the activities were conducted according to the time available, and that the data were recorded.

The conduct of the FGDs was typically as described here, though in some cases the format was altered in order to suit the particular circumstances of a meeting; such variation is described in *Annex 7*. FGDs were based on a series of participatory exercises (see *Annex* 6). Initially the participants were presented with a set of sticky notes with the names of 13 specific preventive practices on them (Figure 2). These preventive measures were drawn from those identified in the interviews with both oyster and mussel stakeholders conducted in Work package 6.2 phase 1 and were selected following discussion with topic experts.

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Farming practices & techniques: ◦ Decreasing shellfish densities in farming areas ◦ Decreasing the manipulations of shellfish ◦ Decreasing the immersion time of shellfish (*e.g.* by farming oysters higher on the foreshore…) ◦ Managing shellfish transfers ◦ Increasing shellfish observation during farming ◦ Testing shellfish for pathogen presence/absence
Farming places: ◦ Moving farming zones in other areas / Finding other farming places ◦ Cleaning abandoned farming zones ◦ Grouping the farming zones by shellfish species / age
Water: ◦ Monitoring water quality (*e.g.* detection of pathogens or algal blooms, faecal contamination, pollution, temperature, salinity…)
Shellfish: ◦ Developing genetic disease-resistant shellfish ◦ Using only hatchery produced shellfish ◦ Increasing the use of triploid shellfish/oysters

Figure 2. List of the preventive measures to discuss during the FDGs

Participants discussed these measures to ensure all participants understood the practices and to identify any other practices considered important by the group – if additional practices were identified they could be written on sticky notes. Inclusion of additional practices occurred only sporadically, hence they are not included in the summaries presented here.

The participants were then asked to rank the practices in terms of their effectiveness in controlling infectious diseases (i.e. ability to prevent disease entering a farm), from most effective to least effective, ignoring the three other criteria. A specially designed matrix was provided for the participants to rank the practices, by placing the sticky notes in the left most columns, with the

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most effective in the top row and least effective in the bottom row. Once the ranking was complete, the participants were asked to score each practice in terms of its feasibility (i.e. how easily/readily it can be undertaken) and to record these scores in the second column, next to each practice. The participants were then asked to score each practice in terms of its likely cost of implementation and conduct (i.e. cost to set up and cost to maintain) and to record these scores in the next column. Finally, the previous step was repeated with the participants scoring each practice for acceptability (i.e. can it be applied equitably regardless of scale of operation, is it harmful to the environment) and to record these scores in the final column. Details of these activities can be found in Annex 6.

A consensus opinion was sought within each FGD, but any points of disagreement/discussion about the activities were recorded by the facilitators in a notebook. Once the activities were completed, participants were asked to review the matrix and make any final comments, which were recorded in the notebook.

At the end of the process, the matrix was photographed to create a record of the findings. Collected data were then entered into a spreadsheet programme (MS Excel©) to enable the results from all FGDs to be summarised.

2.2.1. Implementation opportunities

The FGD was pilot-tested during the VIVALDI stakeholder's workshop at the AQUA2018 Conference held in Montpellier (France) on the 29th August 2018, entitled "Acting together to better prevent and mitigate farmed shellfish diseases". At the end of this workshop, a summary of preliminary results was presented to the participants; however, this was not feasible at other meetings except in Normandy, France.

Additional FGDs were conducted in across several VIVALDI partner countries (France (Normandy), Spain (Vigo), Italy and UK (Northern Ireland)), sometimes in conjunction with other meetings. These regions represented a range of industry types and disease risks.

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2.3. Results

2.3.1. Summary of data by location

Summaries of the results of the workshops held at each location are displayed in *Annex* 7. Here, these results are summarised 1.2o give an overall perspective, with location-specific data included to highlight areas of consistency and variation between regions.

Those measures deemed, overall, to be most effective were "Managing shellfish transfers" and "Monitoring water quality" (Figure 3). The effectiveness of managing transfers mirrored results from the individual interviews (Phase 1), whilst the important role of monitoring water quality likely reflected concerns for both non-infectious and infectious causes of disease and mortality described in the Phase 1 interviews. The least effective (overall) were use of "Triploid shellfish", "Decreasing immersion time" and "Grouping by species and age". Although some measures demonstrated considerable homogeneity in responses between locations (eg "Decreasing shellfish densities" and "Grouping by species and age"), many showed considerable variable (eg "Increasing observation", "Moving farming zones", "Testing for pathogens" and "Decreasing immersion time"). The reason for this variation could not be determined, but could relate to different local considerations, different group composition between regions (for example types of farmers (eg oyster v mussel), type of stakeholders (e.g. decision makers v farmers v scientists), different interpretation of the measures, or other factors.

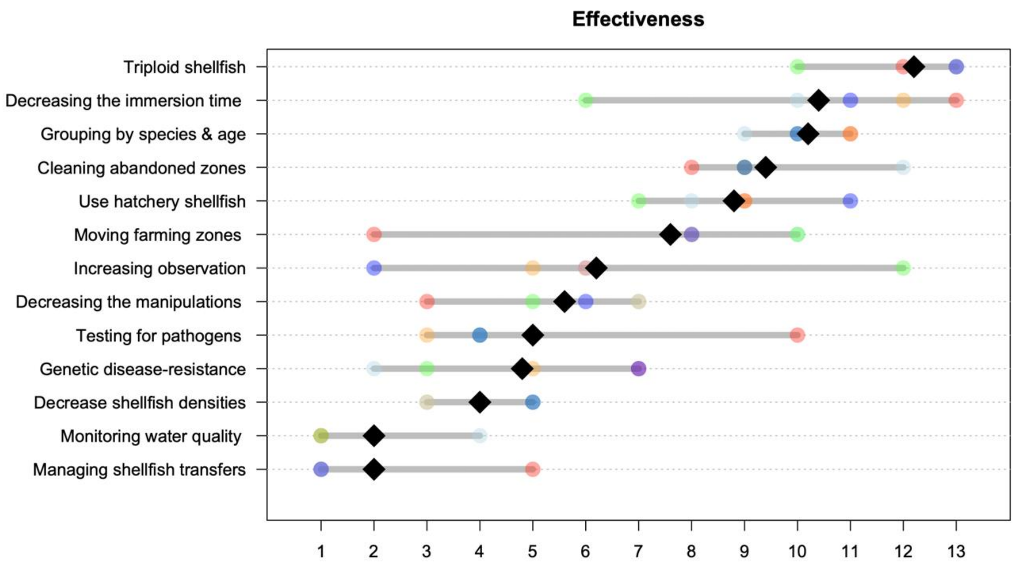

Figure 3. Mean effectiveness ranks for each of the thirteen measures across the five locations (black diamonds). 1 = most effective, 13 = least effective. The coloured circles indicate the values for each location: Red = Italy, Orange = Spain, Light blue = France (Montpelier), Blue = France (Normandy), Green = UK (Northern Ireland). The solid grey lines represent the range between the highest and lowest mean ranks between the regions.

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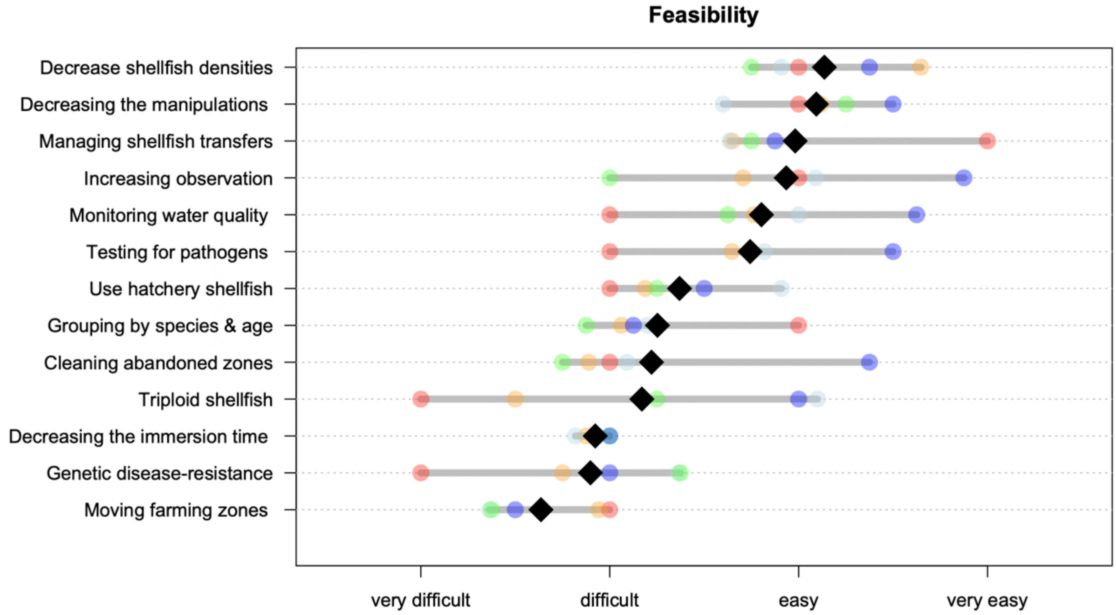

Figure 4. Mean feasibility scores for each of the thirteen measures across the five locations (black diamonds). The coloured circles indicate the mean values for each location: Red = Italy, Orange = Spain, Light blue = France (Montpelier), Blue = France (Normandy), Green = UK (Northern Ireland). The solid grey lines represent the range between the highest and lowest mean ranks between the regions.

Those factors reported to be considered most feasible (Figure 4) included "Decreasing shellfish densities", "Decreasing manipulation", "Managing shellfish transfers" and "Increasing observation", all of which were considered, on average, to be easy to very easy to implement. Two other measures, "Monitoring water quality" and "Testing for pathogens" also approached "easy" in terms of feasibility. The measures reported, on average, to be most difficult to implement included "Moving farming zones", "enhancing genetic disease-resistance" and "decreasing immersion time".

"Decreasing manipulations" was considered to be the least costly measure (Figure 5), followed by "Decreasing shellfish densities", "Decreasing immersion time" and "Managing shellfish transfers". This may reflect the act that these measures not require additional investment in equipment. In contrast, measures that involved utilising enhanced shellfish stock ("Genetic disease-resistance" and "Triploid shellfish)" were considered to have a moderate to high cost, although there was considerable variation between locations in some of these. The results from the workshop in Italy, in particular, seemed to score several measures as having small or negligible costs when results from some other locations identified greater costs. The reason for this difference could not be elucidated but may have arisen due to different interpretations of the questions, or different understanding of the likely costs of these measures.

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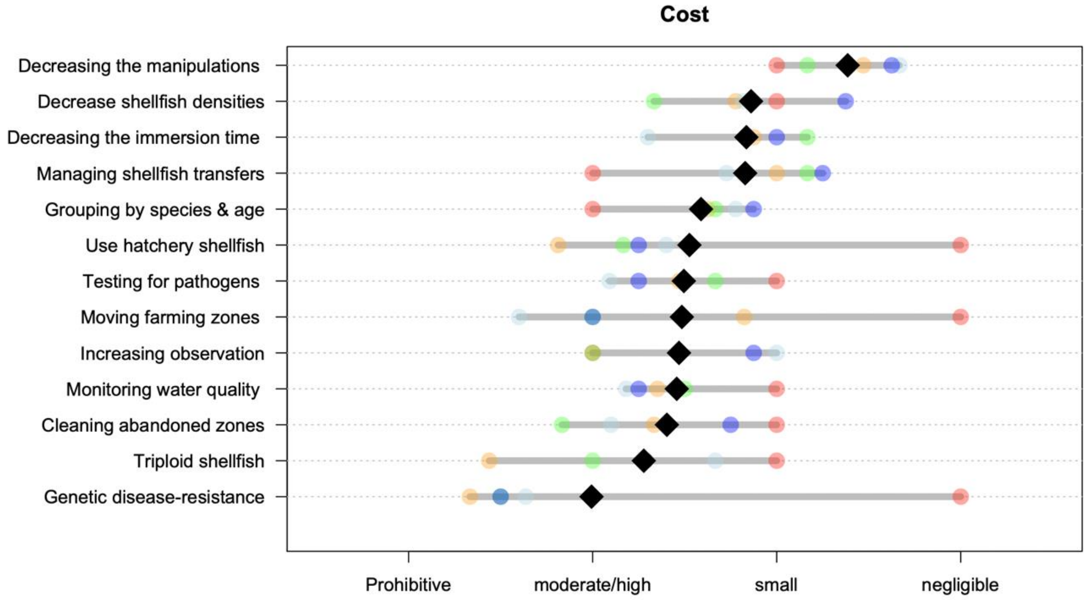

Figure 5. Mean Cost scores for each of the thirteen measures across the five locations (black diamonds). The coloured circles indicate the mean values for each location: Red = Italy, Orange = Spain, Light blue = France (Montpelier), Blue = France (Normandy), Green = UK (Northern Ireland). The solid grey lines represent the range between the highest and lowest mean ranks between the regions.

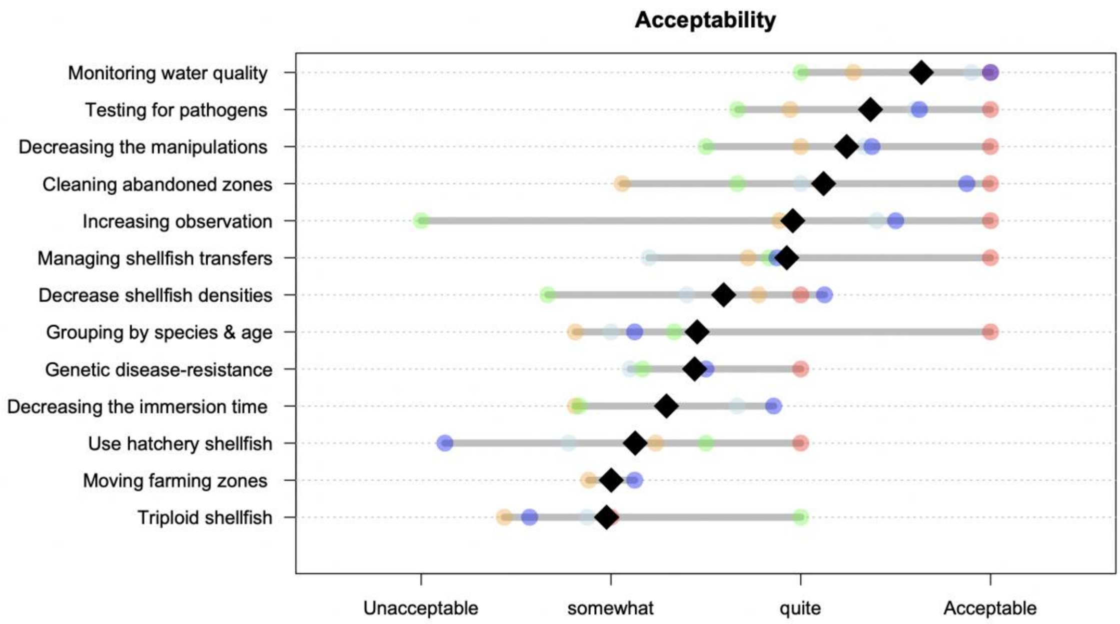

Figure 6. Mean Acceptability scores for each of the thirteen measures across the five locations (black diamonds). The coloured circles indicate the mean values for each location: Red = Italy, Orange = Spain, Light blue = France (Montpelier), Blue = France (Normandy), Green = UK (Northern Ireland). The solid grey lines represent the range between the highest and lowest mean ranks between the regions.

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In terms of acceptability (Figure 6), those measures scoring well included those involving testing/monitoring ("Monitoring water quality", "Testing for pathogens", "Increasing observation") or enhancing practices around shellfish movement and interventions ("Decreasing manipulations", "Managing transfers") or enhancing environmental care ("Cleaning abandoned farming zones"). In contrast, those factors seen as least acceptable included use of alternative stock ("Triploid shellfish", "Use of hatchery shellfish") or those requiring substantial physical disruption ("Moving farming zones").

Overall, "Managing shellfish transfers" was ranked most effective with good scores for feasibility, cost and acceptability (Figure 7), suggesting this could be a suitable target for intervention. Similar overall findings were reported for the next 2 measures reported as being most effective ("Monitoring water quality" and "Decreasing shellfish densities"), although there was somewhat more concern about the cost of the former and, perhaps, the acceptability of the latter. Although "Genetic disease resistance" was considered quite effective, there was some concern about the cost and feasibility of this measure.

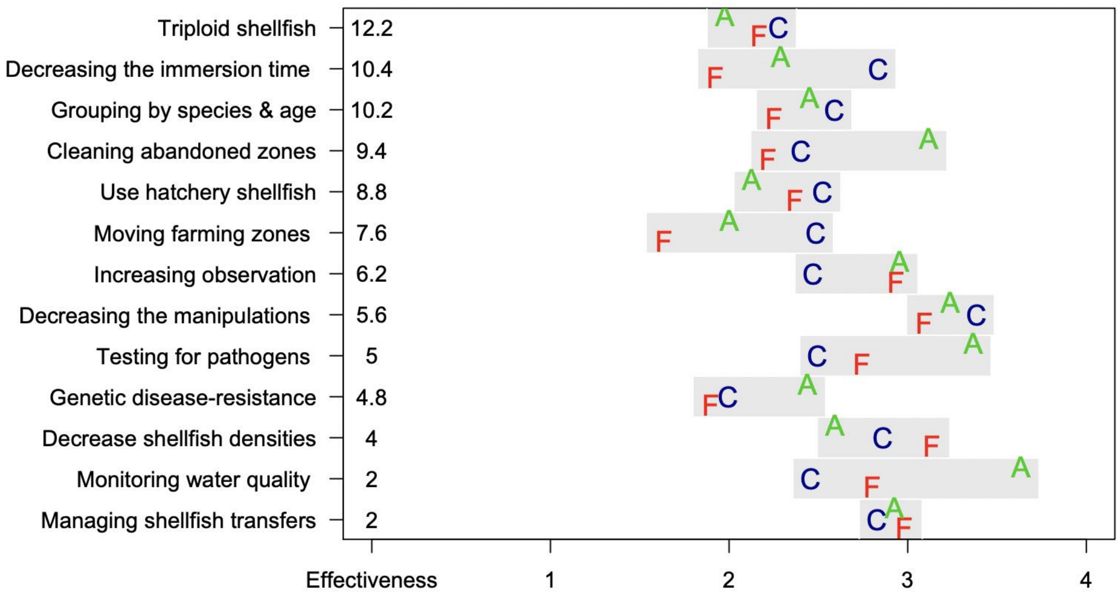

Figure 7. Summary data for all 13 specified measures across all locations. The measures are ranked from those considered least effective at the top to most effective at the bottom. A = acceptability, C = cost, F = feasibility. Score 1 = worst/lowest, Score 4 = best/highest. The grey rectangles highlight the difference between the highest and lowest mean scores among feasibility, cost and acceptability for each measure.

2.3.2. Summary of Farmer responses

The two major groups included in the workshops were farmers and scientists. When considering farmers only (Figure 8), two quite distinct sets of measures were evident. The 6 measures considered most effective also tended to score reasonably well in terms of feasibility, cost and

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acceptability, whereas those 7 measures ranked as least effective had lower scores for at least one of these criteria.

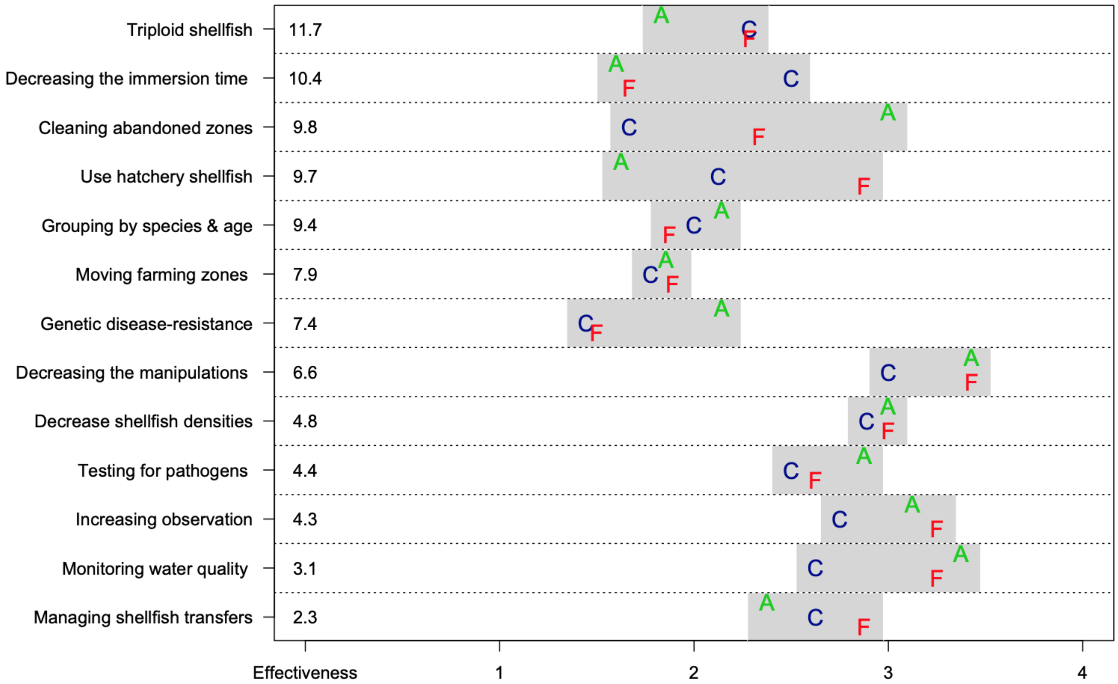

Figure 8. Summary data reported by farmers for all 13 specified measures across all locations. The measures are ranked from those considered least effective at the top to most effective at the bottom. A = acceptability, C = cost, F = feasibility. Score 1 = worst/lowest, Score 4 = best/highest. The grey rectangles highlight the difference between the highest and lowest mean scores among feasibility, cost and acceptability for each measure.

2.3.3. Summary of scientist responses

Among scientists (Figure 9), there was evidence that the two measures considered most effective ("Managing shellfish transfers" and "Decreasing shellfish densities") also scored well in terms of feasibility, cost and acceptability. However, most other relatively highly ranked measures scored more poorly on at least one criterion, although the 6th and, particularly, the 7th ranked measures ("Increasing observation" and "Decreasing manipulations") also had good scores.

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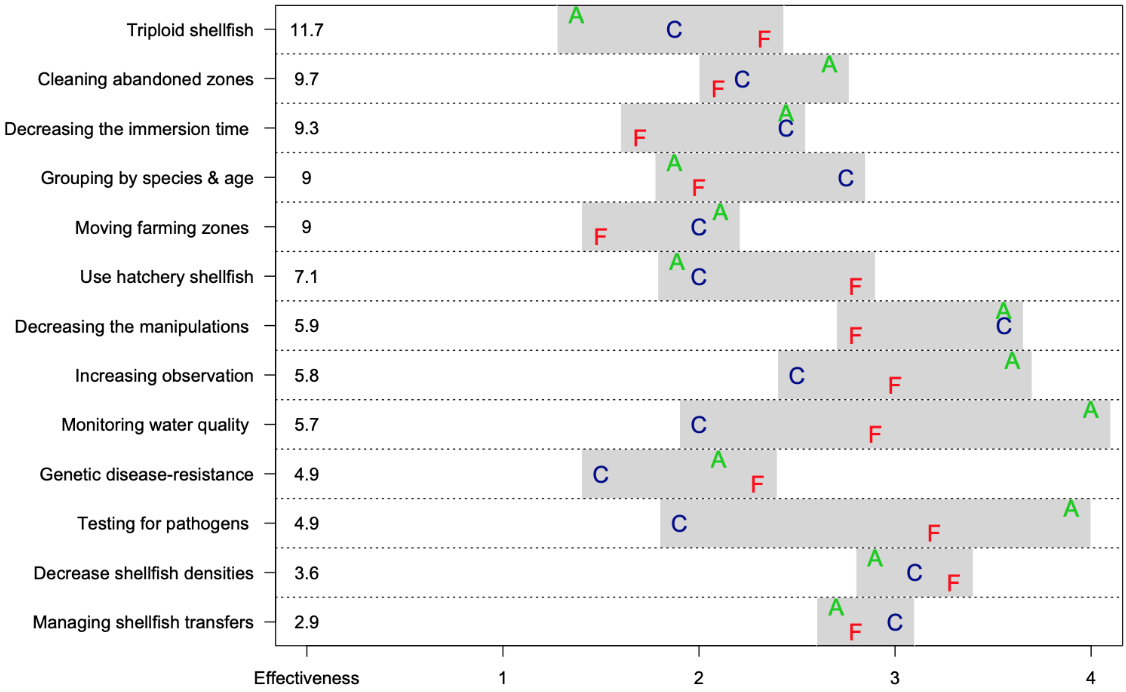

Figure 9. Summary data reported by scientists for all 13 specified measures across all locations. The measures are ranked from those considered least effective at the top to most effective at the bottom. A = acceptability, C = cost, F = feasibility. Score 1 = worst/lowest, Score 4 = best/highest. The grey rectangles highlight the difference between the highest and lowest mean scores among feasibility, cost and acceptability for each measure.

2.3.4. Farmer versus scientist responses

The findings above indicate some similarities and also some differences with regard to the responses of farmers and scientists. Such differences may indicate misunderstandings or alternative understandings on behalf of one or both of these groups, and the identification of different priorities and problems by each group could hamper effective communication and behaviour change. To explore this further, the average responses from farmers and scientists were compared in Figure 10 and Figure 11.

Overall, there is some evidence of consistency among the responses by farmers and scientists (Figure 10), with many responses in in bottom-left or top-right quadrants, suggesting relatively good coarse-scale agreement. It is also worth noting a few points of disagreement in the top-left or bottom-right quadrants. Farmers perceived the measure “genetic disease-resistance" as less effective than did scientists. They also believed that “monitoring water quality” was less costly than scientists, whereas they think that “grouping by species and age” was more costly. However, some criteria show greater variation in the responses of scientists and farmers (Figure 11). Those measures demonstrating most agreement between farmers and scientists included “decrease shellfish densities”, “increasing observation”, “managing shellfish transfers” and “triploid shellfish”,

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for which the average responses to the criteria differed by less than 0.5[1]. In contrast, “Cleaning abandoned farming zones”, “Decreasing immersion time”, “Grouping by species and age” and “Use of hatchery shellfish” had a difference of > 0.5 for 1 criterion and “decreasing manipulations”, “genetic-disease resistance”, “monitoring water quality” and “testing for pathogens” had a difference of >0.5 for 2 or more criteria.

These measures with greater variability between farmers and scientists may be of particular interest as they suggest either misunderstanding between these groups, or that these groups assess these criteria in different ways. For example, the measure “genetic disease-resistance" was perceived as more effective and more feasible by the scientists, as they were the first stakeholders to bring forward this measure. On the contrary, “testing for pathogens” was perceived as a non-costly measure by the farmers whereas in some countries, this measure is funded by the scientists and the competent authority in the context of disease surveillance programs. Regardless of the cause, differences here may suggest that the priorities of these groups may also vary, and this may affect the success of actions to encourage development and implementation of control measures.

[1] Note, for this comparison (Figure 11) the effectiveness rank (which was on a scale of 1 to 13) was rescaled to between 1 and 4, to coincide with the scores given to the other criteria.

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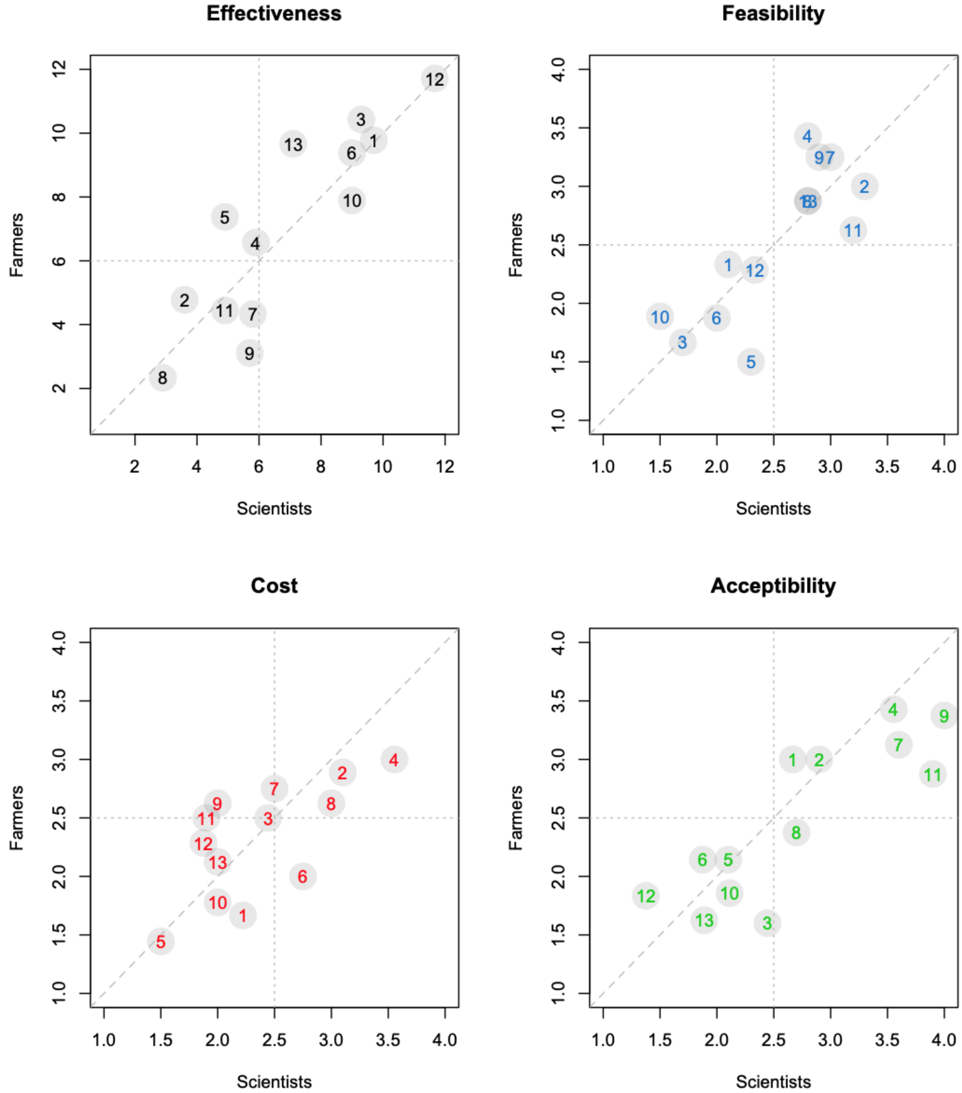

Figure 10. Comparison of responses to the 13 measures in terms of effectiveness, feasibility, cost and acceptability. The vertical and horizontal dotted lines divide the responses into quadrants. The diagonal dotted line indicates the line of perfect agreement. The responses are coded as

1 = Cleaning abandoned zones 2 = Decrease shellfish densities 3 = Decreasing immersion time
4 = Decreasing manipulations 5 = Genetic disease-resistance 6 = Grouping by species & age
7 = Increasing observation 8 = Managing shellfish transfers 9 = Monitoring water quality
10 = Moving farming zones 11 = Testing for pathogens 12 = Triploid shellfish
13 = Use hatchery shellfish

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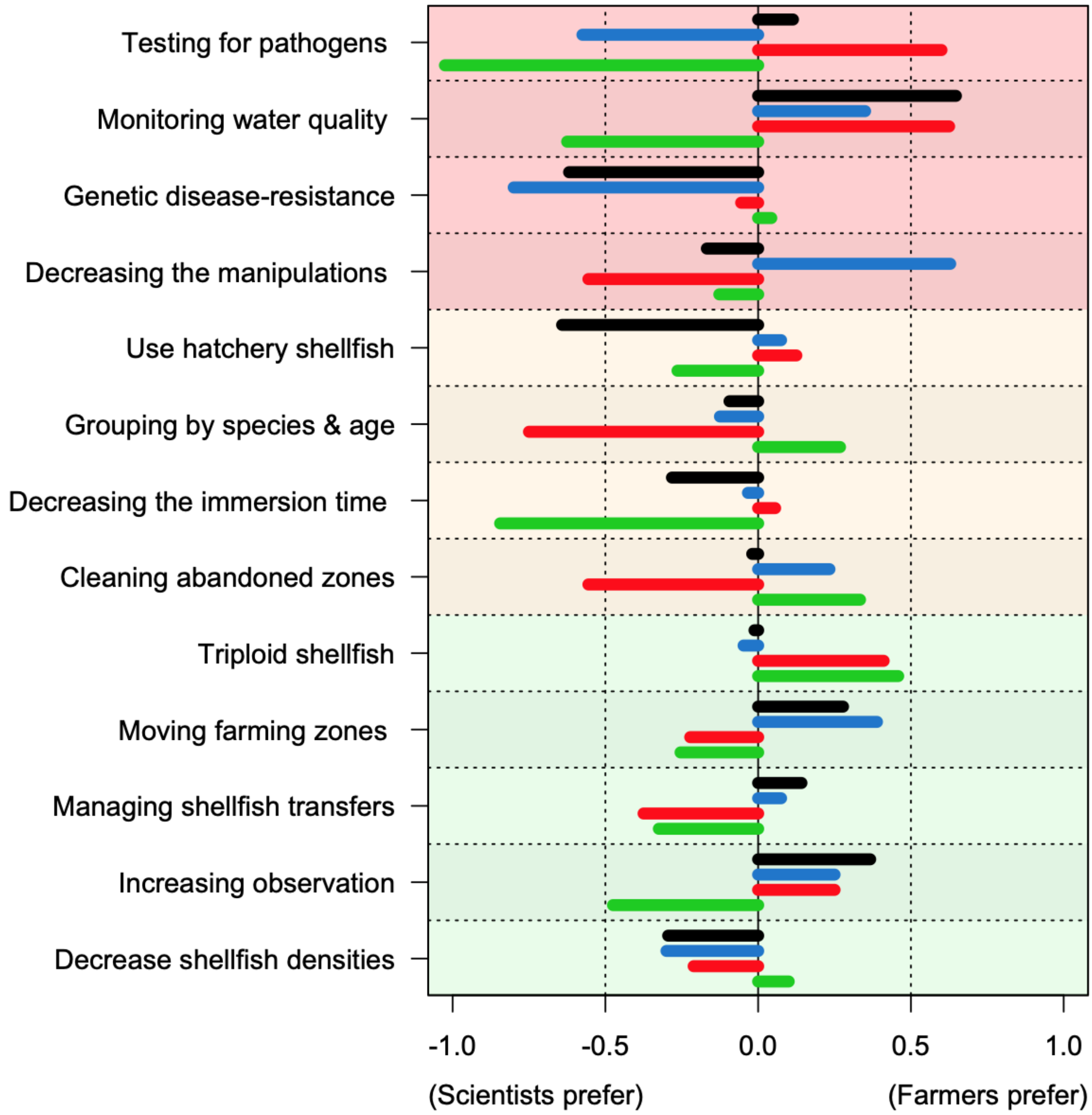

Figure 11. Differences in effectiveness rank and scores for feasibility cost and acceptability between farmers and scientists. Note, for this comparison the effectiveness rank (which was originally on a scale of 1 to 13) was rescaled to between 1 and 4, to coincide with the scores given to the other criteria. Black = effectiveness; Blue = feasibility; Red = cost; Green = acceptability

2.4. Conclusions

Despite some initial concerns, most participants in the Phase 2 focus group discussions reported that they found the process interesting, and this was reflected in the considerable discussion that occurred during the activities. The findings highlight some similarities and differences both between workshops and among different stakeholders. Conclusions drawn with regards to each measure examined are presented below.

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Farming practices & techniques:

- *Decreasing shellfish densities in farming areas*; Overall, there was good agreement that this was likely to be an effective measure, that it would be reasonably easy to do, with moderate to small cost and variable acceptability. This finding was reflected in the interviews, where in the case study in France, farmers reported that decreasing density may reduce disease transmission risk. In contrast, some farmers (e.g. those in Northern Ireland) felt that increasing density may enable enhanced financial security in the face of disease/mortality. Hence, this measure may be more welcomed by some farmers, and increasing uptake in with more reluctant farmers may require identification of alternative methods of enhancing financial security.

- *Decreasing the manipulations of shellfish*; this was seen as having moderate efficacy, overall, but scored well in terms of feasibility, acceptability and cost. However, there was some disagreement between results from farmers and scientists, with scientists less concerned about the cost and more concerned about the feasibility compared to the farmers. This latter finding may reflect farmers' involvement in the day-to-day activities of farming, enabling them to better imagine ways in which this measure could be incorporated in to their practices. Nevertheless, overall this measure was seen as quite feasible by both groups. Despite perceptions that this measure may have only moderate efficacy, it could be a useful target for intervention due to the lack of other major concerns, hence enhancing the potential for implementation.

- *Decreasing the immersion time of shellfish*; this measure was typically perceived to have low efficacy, with particular concerns about the feasibility (which is, in addition, opposite with the previous measure about the decrease of manipulations of shellfish) and, among farmers in particular, the acceptability of such a measure.

- *Managing shellfish transfers*; this was revealed to be perceived as the most effective measure overall, and among farmers and scientists separately. It was also well regarded in terms of feasibility, cost and acceptability. This is already a key-measure in the current EU legislation but its implementation is heterogeneous among the Member States (DG Health and Food safety of the European Commission 2018). Hence,

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provided it can be effective implemented, improved management of transfers could be a highly suitable target for intervention.

- *Increasing shellfish observation during farming*; this measure was viewed, overall, as having moderate effectiveness, with farmers viewing it effectiveness somewhat more favourably than scientists. The measure was viewed quite favourably in terms of feasibility, cost and acceptability.

- *Testing shellfish for pathogen presence/absence*; In terms of effectiveness, this measure was similar to *increasing observation*, although there was somewhat more concern about the cost and feasibility of testing compared to observation. In particular, scientists appeared to report a higher acceptability and to be more concerned about the cost compared to farmers. Given the relatively favourable results for feasibility, cost and acceptability for both this measure (increased testing) and increased observation, these could be suitable candidate for interventions. However, the effectiveness of both relies on the mitigations methods adopted in the face of results of testing and/or observation indicating a disease risk. Therefore, the implementation of these two measures should be considered alongside that of mitigation measures.

Farming places:

- *Moving farming zones in other areas;* this measure had somewhat limited perceived effectiveness and was seen as having some issues in terms of feasibility, acceptability and cost.

- *Cleaning abandoned farming zones;* this measure was ranked low in terms of effectiveness, although it was viewed as having good to high acceptability, possibly due to the potential broader environmental benefits.

- *Grouping the farming zones by shellfish species / age;* this measure ranked relatively low on effectiveness, with issues also identified in terms of feasibility, acceptability and, particularly for farmers, cost.

Water:

- *Monitoring water quality;* overall, this measure was ranked highly for effectiveness, though farmers ranked it considerably higher than did scientists. Both groups viewed this as quite feasible and acceptable, with

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some concerns about cost, particularly among scientist. The relatively better rank among farmers may reflect there general concerns about disease, be it of infectious or non-infectious origins, compared to scientists who, for this exercise at least, were likely to be more focussed on infectious causes of disease. It also reflects farmers concerns with managing environmental issues, as raised in Phase 1.

Shellfish:

- *Developing genetic disease-resistant shellfish*; the use of genetically disease-resistant stock was ranked higher in terms of efficacy by effectiveness, who viewed it has having quite good effectiveness, compared to farmers, who tended to report much lower effectiveness. Scientists also viewed this measure as being more feasible, perhaps reflecting their greater interest and faith in scientific/technical approaches.

- *Using only hatchery produced shellfish*; Overall, the use of hatchery shellfish was seen as having relatively poor effectiveness (particularly by farmers), and although being quite feasible, was thought more problematic in terms of cost and acceptability.

- *Increasing the use of triploid shellfish/oysters*; this measure was ranked as least effective across the board, and acceptability, in particular, was viewed as an issue.

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GENERAL CONCLUSION AND PERSPECTIVES

In both areas studied in the case studies, France and Northern Ireland, farmers considered diseases/mortalities in quite general sense, focussing on an economic point of view. Reputation was also mentioned in the two case studies, either for the individual farmer who reported a shellfish mortality event, or for the oyster as a product, with a negative image for the consumers. Economic and psychological impacts were particularly mentioned by the French mussel farmers, who experienced massive mortality events since 2014. In contrast, Irish mussel farmers did not discuss widely these latter impacts. This difference of perception between the mussel farmers may be explained by the different epidemiological situations in the two countries.

Generally, farmers did not believe that disease is an overall threat for the shellfish industry, and notably they were not sure diseases are a contributing factor to mortality, and even the extent to which infectious and non-infectious (e.g. environmental pollutants/water quality) is involved. This was reflected in Phase 2, with environmental measures, such as “measuring water quality” ranked as highly effective. Importantly, this factor tended to be ranked more as effective by farmers than scientists, perhaps reflecting the broader view of the farmers, and the more pathogen-focussed scientific perspective.

Nevertheless, oyster farmers in both regions mentioned key pathogens including Ostreid herpes virus OsHV-1. Irish oyster farmers also cited notifiable diseases (*Bonamia ostreae* and *Marteilia refringens*) despite these affecting a different oyster species (flat oyster, *Ostrea edulis*) that the one mainly farmed for human consumption in this region (Pacific oyster, *Crassostrea gigas*). This highlights the complex inter-relationships between such factors as, because flat oysters are present near the Pacific oyster farming areas, the presence of these pathogens in the flat oysters causes movement restriction of Pacific oysters. Discussion of particular pathogens sometimes did not reflect disease burden but rather the regulatory requirements. For example, Irish mussel farmers mentioned *Marteilia refringens,* a notifiable disease at the OIE and EU levels, despite not experiencing mortalities due to this pathogen.

Concern about environmental factors extended to the future impacts of climate change. In particular in Northern Ireland, which has suffered limited effects of infectious diseases, farmers were not really worried about disease nor mortality risk under the current temperature regime, but they were aware of potentially emerging diseases under climate warming scenario. In contrast, the French shellfish farmers, who are already exposed to severe infectious disease impacts, did not feel concerned by emerging or exotic diseases.

In Northern Ireland, the implemented mitigation and control measures were reactive, whereas French shellfish farmers mainly implemented measures to manage the economic impacts of mortality consequences on their individual businesses; these measures had little or nothing to do with management of the disease itself. Indeed, some measures, such as increasing stocking density to stave off financial losses (particularly reported by Irish farmers), may actually increase disease risk.

However, proactive measures to prevent disease introduction should also be considered. Those measures commonly believed, in both phase 1 and 2, as important included enhancement of surveillance as an early alert system to detect disease outbreaks and ensuring minimum-stress conditions during farming (e.g. decreasing the shellfish farming manipulations).

Despite evidence of regional beliefs, there was also considerable variation with single locations, most evident between the different stakeholders' categories. Part of this variation may be explained by the differences in the priorities of different stakeholder groups, and the stakeholder networks within and between participating countries. In particular, the Irish network was concentrated around producers whereas the French, Spanish and Italian networks were more fragmented, with less (in number and frequency) interactions between the different stakeholder categories (see VIVALDI Deliverable N°6.6).

A key novel perspective developed in this work package highlights the critical importance of variation in beliefs and priorities across location, mollusc species, and stakeholders. The results strongly suggest that these differences should to be taken into account for prevention measures/strategies to be successfully and sustainably implemented. For example, flexibility should be provided for the application of some measures perceived as not being feasible in some locations and leave the opportunity to replace this measure by another one. In other words, focus should be given to the obligation of results (i.e. preventing disease introduction or spread) instead of best endeavours obligation.

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TABLE OF ANNEXES

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ANNEX 1: Topic guide – Northern Ireland

Semi-structured interview format

The purpose of the semi-structured interview format for this section is to understand the perception of the stakeholder about the disease risks and their management.

The interview will begin with exploring key themes and allowing the stakeholder to openly communicate their priorities and thoughts without being directed towards an answer. More specific questions relating to each theme may be asked depending on the quality of answers as the interview progresses. These are drafted below each theme. Ultimately this will allow an understanding of the stakeholder's knowledge and perception of shellfish disease.

Stakeholders in Northern Ireland

Production Chain

- National shellfish producer organisations
- Fishermen
- Hatchery, nursery or ongrowing farmers
- Purification Centre
- Processors
- Distributors
- Retailers

Politicians

- Department of Agriculture, Environment and Rural Development

Public Institutions

- Food Standards Agency
- Reference laboratories
- Customs

Education, Training and Research Organisations

- College of Agriculture, Food and Rural Enterprise (CAFRE)
- Queens University Belfast

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- Agri-Food and Biosciences Institute

Knowledge Transfer and development Organisations

- Certified or private analytical or diagnostic laboratories
- National experts

Wider Society

- Quality Assurance Schemes

Topic Guide

1. **Shellfish Disease – An identification of the key diseases the stakeholder prioritises**
   - Is shellfish disease a threat to your enterprise?
   - What do you consider are the most threatening shellfish disease for your production?
   - Can you tell me some information about this disease?
     - Characteristics? Consequences? Contributing factors?
   - Has your production suffered from shellfish disease in the past? If yes, tell me about this.
     - Do you believe it is a real concern for your enterprise? Why do you think this?

2. **Review of Disease Risk**
   - Do you review the risk and types of diseases that may affect your enterprise?
   - How often would this review take place?
   - Why do you undertake a review?
     - Event occurrence, testing results, climate change patterns, regulatory direction/stipulations?
   - Have you a format or method for this review process?

3. **Disease Preventive Measures**

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- Do you think you have an influence on preventing or mitigating shellfish disease in the industry? What is the extent of this influence you can have?
- What disease preventative measures do you currently undertake?
- Why do you undertake these particular measures?
    - Regulatory or quality assurance schemes stipulation or to increase the resilience of the production system to disease
- What is the purpose of these measures, i.e. what are they mitigating against?
- How do you implement these measures in your production system?
    - Why do you do it this way? – Training or tradition or experience passed down?

4. Perceived Benefit

- Do you believe these mitigation strategies are necessary for your enterprise?
- What are the benefits of taking such action?
- Are there any negatives for undertaking such action?

5. Factors influencing disease management

- What factors do you deem important for disease management
    - Economics, acceptability, perceived benefit, understanding
- How would you prioritise the factors mentioned in disease management?

6. Consumer Purchasing Power

- Do you consider consumer purchasing power as a risk to your income?
- Do you think increased consumer awareness of shellfish disease would influence purchase? For example, do you think your company would suffer if the consumer knew herpes virus was established in the Northern Irish Shellfish Industry?

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7. Other aspects which may not been addressed:

Specific questions relating to important factors in disease occurrence and management if they have not already been addressed:

- Climate change and how this impacts on disease risk and occurrence etc.
- Mention of the following factors in disease understanding or risk assessment:
  - Climate Change and changing disease risk
  - Change of supplier or importing country
  - Internal movement or distribution to production systems
- Diseases which are relevant to the UK and Ireland:
  - *Crassostrea gigas*: Herpes virus (Ostreid herpesvirus 1ųvar) and *Vibrio splendidus*
  - *Mytilus edulis: Vibriosis, Marteilia spp.* and *Mytilicola spp.* (red worm)
  - *Ostrea edulis: Bonamia ostreae and Bonmamia exitiose*

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ANNEX 2: Topic guide – France adaptation for farmers

In the context of a European project, VIVALDI, we try to understand the perceptions of the stakeholders of shellfish diseases, the way they mitigate their effects, and the reasons why they implement or not particular measures.

I use a tape recorder to record the interviews. This is a tool very helpful for me as I can better follow the discussion today and it prevents me from distorting what you say when I will transcribe this interview. Don't worry, the analysis of the interviews is totally anonymous and the tapes will be erased when used.

N° survey :	Date :	Place :
Name :	Duration of survey :	

1. General presentation - business characteristics

1.1. Could you describe your professional experience?

1.2. Could you describe your enterprise?

Farmed shellfish species, enterprise size, production stages, sales, production techniques, specialization or diversification...

2. Shellfish diseases

2.1. What is the greatest difficulty you have experienced in your enterprise?

2.2. Are shellfish diseases a threat for your enterprise?

2.3. Could you categorize these issues according to their importance? **(use of CARDS)**

□ *Economic difficulties;* □ *Financial difficulties;* □ *Major climatic or meteorological event;*

□ *Personal event having affected the company;* □ *Diseases affecting the production;*

□ *Environmental issues*

2.4. Are you afraid of a particular disease?

If yes, which one? And why?

2.5. Do you think shellfish diseases are a threat for the whole shellfish industry?

2.6. Did you, in your enterprise, already face a disease?

If yes, which one? Could you tell me the story?

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2.7. Are you afraid of a new disease (climate change, transfers, national or international situation)?
If yes, what kind of disease (exotic or emerging disease) and why?

2.8. Are there any signs that you can see when a batch is infected?

3. Disease management measures

3.1. Do you think your enterprise did well?
If yes, how? What measures did you implement?

3.2. Were you helped for this? (colleague, family, stakeholders)

3.3. Do you think your neighbours are in a similar situation?

3.4. Do you feel you are more or less affected than they are?

3.5. Are there any measures you would like to implement or that you know about to prevent diseases?
If yes, which of these would you like to implement? If no, why?

3.6. On the contrary, are there any measures you have heard of but do not want to implement?
If yes, which one and why (cost, feasibility, efficacy, administrative constraints)?

3.7. Finally, what is your overall future production strategy to avoid the disease development?

4. Information sources

4.1. Do you feel you are sufficiently informed about shellfish diseases and measures to limit their impact?
If yes, by whom? How? If no, according you, what would be the best person or organism and the best way to have this information?

5. The other stakeholders

5.1. Do you think other stakeholders could help you to face shellfish diseases and their impacts? Do you believe in them?
If yes, which stakeholders would you like help from? How?

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If no, why? So, you feel that the other stakeholders are of no help, so you only rely on yourself? When you say "you", is it you as an individual or in a collective way?

In order to collect different points of view, could you help me to identify other producers who I could survey?

5.2. Could you give me the name of a person who you know being concerned by shellfish diseases?

5.3. Could you give me the name of a person who you know NOT being concerned by shellfish diseases?

After completion and analysis of all the interviews, we will present the results and we would like to discuss them with shellfish farmers, during a meeting which will be held in the region. Would you agree to participate?

Thank you a lot for your time.

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ANNEX 3: WP6.2 Phase 1 – Northern Ireland case study: detailed results

This is manuscript will be submitted for publication in a peer-reviewed journal.

Preventing and Mitigating Farmed Bivalve Disease: A Northern Ireland Case Study

Abstract

Shellfish production forms a large proportion of aquaculture production in Northern Ireland. Disease represents a serious threat to the maintenance and growth of shellfish cultivation with severe consequences to production output and profitability. In Northern Ireland, production generally benefits from a good health status with the absence of notifiable diseases, except for localised cases of *Bonamia ostreae, Marteilia Refringens* and oyster herpes virus. In this paper we qualitatively explore the prevalence, risk, impact, mitigation and experience shellfish farmers in this region have in relation to disease. 25 semi-structured interviews were conducted with stakeholders within the sector. The interviews were transcribed verbatim and Nvivo 12 was used for an inductive thematic analysis. Our results highlighted that the industry has varying attitudes and experiences with disease. At current temperatures, disease is not an issue and this provides vast market opportunities for the region. However, instances of disease have led to substantial consequences to financial income, production output and reputation in the past, whilst control and mitigation remain reactive. It is imperative proactive disease prevention and control are employed and enforced to sustain NI's reputation as a healthy shellfish region, particularly under increasing global temperatures and intensified production systems. A cultural shift to disease appreciation, risk analysis and surveillance through research, education, training and collaboration is essential.

Introduction

Aquatic food makes an important contribution to human health and development as an essential source of high quality proteins, vitamins and micronutrients (Lauria et al., 2018; Jennings et al., 2016). They are sourced from the capture fisheries (wild) and aquaculture (farming) sectors (DAERA, 2018). Its security is of increasing concern as wild stocks plateau and begin to reach their maximum sustainable potential (Jayasinghe et al., 2016; Oidtmann et al., 2011; Cressey, 2009). These concerns are exacerbated by the fact the human population is rapidly growing towards an estimated 9.8 billion people by 2050 (United Nations, 2017). As a result, aquaculture production has become increasingly important in meeting demands for aquatic food and has become the fastest growing food producing sector in the world (FAO, 2014; Oidtmann et al., 2011). It has been estimated that aquaculture production will need to more than double to 140million tonnes by 2050 if we are to continue to meet the future demands for fish and shellfish as a food product (Waite et al., 2014).

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The European Union is one region which provides a large market for aquaculture products and is the world's largest importer of seafood. However, despite this demand, and the increasing global rate of aquaculture production, growth within EU countries has stagnated over the last 20 years. The spread of disease has been one of the factors attributed to this stagnated production, and in some cases, responsible for social and economic disruptions at a national level (Oidtmann et al., 2011). Within the EU, there are 28 member states, each country shows different growth patterns due to varying regulatory settings on licences, use of water, veterinary medicines, emissions, species, production methods and environmental conditions (EP, 2009). The largest proportion of production is shellfish, contributing 60% of total EU aquaculture production (Murray et al., 2012). The diseases associated with bivalve production include Bonamiasis caused by *Bonamia ostreae* and more recently the emergence of Oyster Herpes virus that has dramatically affected the culture of the Pacific oyster *Crassostrea gigas* (Segarra et al., 2010). It is imperative to explore each member state individually if the EU is to provide area specific solutions and optimise the overall productivity and profitability of the sector and contribute to global food security for now and future generations.

Within the European Union, it is widely acknowledged that the Island of Ireland has all the features for a thriving aquaculture industry and can become a prosperous producer and exporter of aquatic food. In particular, Northern Ireland has a unique disease free status and suitable temperature regime which makes it attractive for aquaculture production. This potential was recognised by the NI executive who set out ambitious targets to grow the sector in their Going for Growth Strategy (AFSB, 2015). Similar to the EU, shellfish production for human consumption forms the largest component of aquaculture in this region with 46 farms currently licensed for the cultivation of mussels (*Mytilus edulis*) and Pacific Oysters (*Crassostrea gigas*) (Figure 1). However, shellfish production volume has decreased substantially (69%) from 2010 to 2016 (Table A3.1).

Table A3. 1: Production and value of the aquaculture sector in Northern Ireland

	2010		2016	
	Tonnes	**£('000)**	**Tonnes**	**£('000)**
Finfish	1155	3100	1136	6300
Shellfish	11081	7700	3468	7900
Both	12236	10800	4604	14200

Disease is one of the biggest threats to the maintenance and growth of the sector (Jennings et al., 2016; Marquis et al., 2015; Oidtmann et al., 2011; Murray et al., 2012). At present, NI is declared free of a number of shellfish diseases. However, notifiable diseases exist for: *Bonamia ostreae* in Lough Foyle and Strangford Lough, Oyster Herpes Virus (OsHV-1-µVar) (only Lough Larne is free) and as of 2017, *Marteillia Refringens* in Belfast Lough and Dundrum bay (DAERA, 2018). These diseases have had devastating consequences to farmers within the region in terms of productivity,

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financial return and reputation (Peeler et al., 2012). It is imperative to understand the risk from disease and provide innovative solutions and long term management to the sector. This is particularly important for NI as they set out to increase production in line with the targets set by the NI executive (Table A3.2). Such growth is commonly associated with an introduction of new species and systems; and an increase in international trade. These factors exacerbate the spread and emergence of current and emerging diseases (Oidtmann et al., 2011). This study aims to qualitatively identify and review the vulnerabilities of molluscs farmed in Northern Ireland to these pathogens based on the experiences and perspective of the stakeholders. The study has a particular focus around key topic areas including, key pathways for disease introduction; environmental conditions when disease strikes; and the likelihood and consequence of disease outbreaks. These results can be used to assess the scale of risk to investment in mollusc production; key risk factors for disease; and consider if these could potentially be controlled and mitigated against to reduce the risk to production posed by disease.

Table A3.2: NI Executive Fish and Aquaculture Targets for 2020 (AFSB, 2013)

Fish and Aquaculture 2020 Targets		
Grow turnover	By 34%	To £90m
Grow value-added	By 45%	To £22m
Grow external sales	By 36%	To £75m
Grow employment	By 9%	To 600 full time equivalents

Methodology

Participant Recruitment

Stakeholders in the shellfish supply chain within Northern Ireland were recruited to take part in a semi-structured interview via stratified random sampling. Recruitment methods involved sending invitations via post and email to the farmers licensed to conduct shellfish cultivation and the agencies or government departments directly involved in sampling, licencing, enforcing or supporting the sector within Northern Ireland. The participants were divided up into sub-groups (strata) based on (1) their activity in the supply chain; (2) species cultivated; (3) location. Subsequently the participants were randomly selected from each strata until saturation was achieved. In total 25 stakeholders made up of shellfish farmers, government, food inspectors and independent agencies were interviewed. All participants provided informed verbal consent and the study was approved by the School of Biological Sciences Ethical Committee at Queen's University Belfast.

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Interview questioning guide

Based upon a review of previous literature and the opinion from a number of experts involved in the aquaculture supply chain (n=3), the interview instrument was constructed. The interview guide was piloted for clarity, comprehension, reliability and timing with three individuals and refined prior to implementation. The questions were designed to elicit participant's perceptions regarding their experiences with shellfish production including: their activity in the supply chain; the prevalence and threat of disease to their production; and mitigation measures (

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Table A3.).

Data Collection

Interviews were conducted face-to-face (n=24) and by telephone (n=1) between July 2017 and July 2018 by an interviewer (MF; a Food Quality, Safety and Nutrition Scientist) who had completed previous courses on qualitative data collection and interview techniques. Interviewees were given a brief overview of the project and reassured there was no right or wrong answers; they could opt out at any time; and their data would remain confidential and anonymous. Verbal approval for audio recording was sought before the interviewer proceeded to ask a series of guided open-ended questions (Table A3.3). The interview concluded when all topics had been covered and no new information emerged. Interviews were audio recorded with a mean duration of 45minutes.

Data Analysis

Audio recordings were transcribed verbatim, checked for precision and coded thematically using the qualitative program Nvivo 12 (QSR International Pty Ltd, Victoria, Australia). As the emphasis was on the perceptions of the stakeholder, the study took a constructive approach to evaluate the aquaculture industry from the subject's point of view and assess the meaning of their experiences. The transcripts were coded and independently checked for coding consistency before consensus on the validity and reliability of the application of codes to the data was reached. Minor revisions were made to the terminology of some codes. Data saturation had occurred as no new codes emerged from the interviews. Subsequently, codes were grouped into themes and categories which represented a common principle. They were then inspected for overlap to ensure there was a clear distinction within and between each of the categories and themes and selected quotes which exemplify each challenge and facilitator before confirming the data was presented objectively.

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Table A3.3: Questioning route of semi-structured interviews

1. Brief overview of the project and interview
2. Can you tell me a bit about your production system/ activity in the supply chain?
3. How did you begin working within the aquaculture sector, motivation, and start-up?
4. Can you tell me a bit about disease and if it affects your production system?
    - Characteristics, consequences and contributing factors
    - Changes in disease frequency or type
    - Impact and degree of mortality
    - Consumer Perception
5. What kind of preventative measures do you implement for disease?
    a. Factors including in biosecurity plan
    b. Monitoring, biosecurity, analytical tests and methodologies
    c. Voluntary or Regulatory – has there been any training or guidance provided
    d. Review of disease risk and how often
    e. The cost of mitigation – is it necessary or economically viable to implementing enhanced measures
    f. Certification schemes
    g. Water classification
6. Summary of interview discussion. Is there anything else you would like to add?
7. Thank you for taking time to participate in the survey

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Results

The stakeholders involved in shellfish aquaculture mentioned four different shellfish diseases: *Oyster herpes virus*, *Bonamia ostreae* and *Marteilia Refringens,* related to cultivation in Northern Ireland. There were a number of different attitudes related to the prevalence of disease:

(1) Not an issue.

"Disease isn't an issue" (Participant M1).

(2) The risk of disease is uncertain.

"It is fair at the minute it was higher at a time and you don't know what is around the corner either." (Participant O8)

(3) Not sure if disease is a contributing factor to mortality or not.

"We wouldn't [have disease]. Well I don't know. If I find oysters dead like I don't know what killed them. To me it could be stress..." (Participant O5)

(4) Disease has been detected in the water body but it hasn't caused an issue.

"They found Marteilia Refringens in Belfast. So that seems to be a buzz word at the moment. But experience with this, yeah they found it but it doesn't seem to be doing any harm to the place." (Participant M1)

Impact of Disease

In the oyster sector, a disease outbreak causes rapid mortality to production.

"Well you could be sitting here next September and I could be sitting there with maybe 100,000 Euros worth of stock to sell between now and end of November or October. I could lose that in a week. That would be sad. You know." (Participant O3).

This mortality has huge economic repercussions for the shellfish production business.

"The amount of money we have sunk into that…it's just thousands, thousands. And then one year we got a disease and it wiped me out. Just when I thought I was getting it under control. I started up and had no money for about three years. I had zero. And just when I'm starting a

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disease came and wiped me out. Two years then I was back with very little money. And now I have got to build it up again." (Participant O3).

On the other hand, disease has not caused similar consequences to the mussel sector, despite the presence of *Marteilia Refringens* in Belfast Lough and Dundrum bay.

"We have a scientist actually doing monitoring the Loughs at the moment, the Dutch authorities send him over every year…he was saying about this Marteilia Refringens, he has seen it pretty much everywhere but that it doesn't seem to be something, if the water warms up, then we might have a problem with it, but in Ireland you know at current temperatures it doesn't seem to take hold. I know last year because it was a little warmer we saw it. (Participant M1).

In the disease free areas, the shellfish farmers benefit from access to worldwide markets.

"I am Bonamia free so I can send them anywhere." (Participant O1)

Similarly, when disease is latent and not causing mortality, this provides the sector with an opportunity to capitalise on their increased production. This was particularly related to periods when disease outbreaks was causing mortalities in other production sites.

"…one year, not last year, the year before. Every other bay in Ireland had massive mortalities apart from Carlingford. So we were just selling everything and just getting top quality prices for it…They needed it and they paid for it and they paid the top dollar." (Participant O3).

However, some farmers in locations which have been declared disease free voiced frustration over difficulties in sourcing good quality, cheaper seed from French hatcheries.

"So being a disease free bay is a problem for me. Because I can't have access to good quality seeds, the ones that grow better, the ones that are cheaper. I have to work with UK or Irish seed with comes from smaller hatcheries, with difficulties and what I got, it's not very good…the ones coming from France are coming from a selection program you know they get the best of them. So that's my problem today, I am not starting, I am not competitive I can't be competitive…" (Participant O2).

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Consumer perception was also discussed as a potential impact in relation to awareness and understanding of shellfish diseases. In general stakeholders did not believe disease came under their radar.

> *"It doesn't really come under their radar…straight over their heads, an oyster is an oyster to them" (Participant O7).*

However, some explained consumers may unjustifiably associate shellfish disease as harmful to humans.

> *"It is not harmful to them but there is always the association, it is oyster herpes disease, I am going to eat this diseased creature." (Participant 07).*

Nevertheless, the common belief was that those interested in eating shellfish will eat it and those forming negative associations are not the target consumers anyway.

> *"Well the world seems to be divided into two types of people. Some people who they will just not touch oysters or eat oysters or anything like that there and that is fair enough, I am not going to start going into that road…really the oyster herpes virus, it was proven that it was no risk to humans…but again there is some people who would say aww no I am not, it is like mad cow disease in cattle these things, or like the salmonella in eggs away years ago, you probably wouldn't mind that, but everything gets a rattle now and again, but there is people then who just wants to eat them and that's just the way it is, you have to go over to France or Europe, anywhere in Europe to see just how anxious, the Chinese are great customers, they will just eat everything…but someone who wants to be picky and one thing and another but in all honesty they weren't going to eat oysters anyway." (Participant O8)…"*

Risk Factors

The stakeholders in the supply chain revealed a number of risk factors they believed were related to the prevalence and intensity of disease. The purchase of imported seed from regions were a disease is prevalent was the most commonly cited route of introduction.

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"…because the gigas have so many diseases in them it is starting to hit us, it has been hitting the French, now it is hitting us because it has been transported over." (Participant O1).

Similarly, stakeholders believed they are vulnerable of illegal and unregulated movements of shellfish from a production area were disease exists by other water users into the shared water body.

"Now, you can actually go underground or go to French farmers because Native oysters or gigas oysters will reproduce there naturally in the water so they collect them and sell them and that's where disease comes from." (Participant O1)

The ploidy of the seed also played a role, with triploid believed to be more susceptible to disease.

"Triploid, yeah. But they are more susceptible to disease but they command a better price." (Participant O3).

Temperature was a significant factor important in the prevalence of a disease outbreak. For oyster herpes virus 16^{0}C was cited by all oyster farmers as the critical temperature which activates oyster herpes virus and initiates summer mortalities.

"…it's to do with the temperature of the water, it needs to be over 16.5…." (Participant O3).

"…oyster herpes virus doesn't help anybody and if we get water temperatures in excess of 16 degrees centigrade we can see substantial mortality here so we are not out of the woods, the further north you go the less of an impact it has because it is triggered by water temperature and that is why the French are here." (Participant G2).

It is also believed temperature is an important factor for *Marteilia Refringens,* with the current temperature regime limiting the opportunity for the pathogen to cause disease outbreaks.

"…about this Marteilia Refringens…if the water warms up, then we might have a problem with it…" (Participant M1).

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Parallel to temperatures, climate change has been cited as a risk factor for the prevalence of disease and the opportunity for new species or pathogens to survive.

"Climate change is a big one so it is at the minute we have the benefit that we are cooler than France, and if that whole thing moves up if it moves up we are going to be hit with the same diseases as France, the same prevalence of disease but are they going to get worse because they are going to get hotter they will be getting hotter than us I have caught fish in Carlingford Lough from Spain, Spanish trigger fish and that was several years ago." (Participant O7).

Although the mussel farmers did not believe the predicted two degree increase in global temperatures would be enough to cause significant concern in relation to disease.

"I don't believe two degrees in Ireland, in the water is going to cause too much problem. It could cause it elsewhere but not for the mussel industry. The oyster industry will have a huge problem with it because of the herpes virus and there is another one of those viruses but the mussels aren't susceptible to that." (Participant M1).

However, stakeholders did believe there was potential of new and emerging diseases with warmer climates and the importance of keeping the temperature below two degrees increase.

"Aww, like I said to you about the water warming up, you are learning about new diseases, it all depends, they are on about global temperatures you know, keeping them below two degrees." (Participant M1).

"The other problem now is the vibrio oyster and new disease which kill the oyster when they are commercial size which is quite a bigger problem actually than the herpes virus." (Participant O2).

Mitigation and Control Measures

The approaches taken for disease management and control vary and are generally reactive. Some farmers did not believe there was options to help prevent disease.

"Tough luck just…if it happens it happens" (Participant O3)

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"…to be honest it is one of the lessons you learn about this, there is always going to be mortality because oysters have no immune system, so you can't, well there is just too many of the things, but there is nothing you can do like animals where you can spray them or dose them or anything like that there, they just die and that's that…" (Participant O8).

However, others recognised the role management procedures can have in preventing the entry, spread and consequences of disease. Ensuring stress free conditions was deemed important.

"…but what you try to do is try to make sure the conditions are right that they are happy sitting there growing." (Participant O8).

The density of production was also discussed with different stakeholders revealing conflicting views. Some farmers believed low densities helped to reduce the spread of disease.

"…with the oyster herpes virus is if the bay is low density, you know like a bay with not much production are not much affected it's like a class with many kids or a class with not many kids. If one kid gets sick in a crowded place they all get sick. And it is the same with the site. So it is all to do with the culture practice really like." (Participant O2).

"The problem you can have, if you don't plan ahead, you put so many oysters into a bag and then disease is more than likely to come in over peak growing time." (Participant O7).

Whilst others believed over-producing reduces the overall impact of a disease outbreak.

"…what you find as a response to the herpes virus mortality that people actually produce so much seed that they don't mind losing 50% of seed on the first year because what is left will keep growing until the end. You get your mortalities the first year. If you don't get it the first year you try to save it you should expose the oysters as soon as you get disease anyway so you are better off to lose them now so people use twice more seeds and lose half and the production and its back to normal." (Participant 02)

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Movement restrictions and their importance in preventing the entry of disease into the waters was mentioned.

> *"There is a protocol in place if you are taking stuff from anywhere to put into your bed it has to be of the same disease status the water has to be the same disease status so if there is something that is in this water that you don't have you can't take that across but you can take it back." (Participant O7).*

Surveillance methods are important as an early warning sign for the potential of a disease outbreak, particularly in areas were disease has been detected. This involves monitoring disease in the regions the seed is imported from and carrying out more rigorous inspection of the stock at times of high risk.

> *"We check, see if we have mortality in France after in the summer, after here check all the bag, few bag here, not each day but maybe every 15 days or sometimes when I go on the shore I check different bag to see if we start to see mortality on the oyster on. We follow that all through summer." (Participant O6).*

If farmers detect any unusual mortalities they are expected to report this the the competent authorities as a part of the disease surveillance process in the region. However, this is dependent on the adherence of the stakeholders involved.

> *"Not really, no. We wouldn't. Well I don't know, if I find oysters dead like I don't know what killed them. To me it could be stress. Like every oyster I find, I suppose you're supposed to report it but you wouldn't be bothered to be honest. If you find a dead oyster you throw it away like. You know like it could be stress or anything I don't know or something, predators." (Participant O5).*

The quality of seed was also cited as an important factor for the resiliency to disease. In particular, Pacific oysters from a selection program in Frances were considered the most robust to oyster herpes virus.

> *"The key success in the farm, the quality of seed would be number one.*

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You know if you want to do farming you have to start with nice animals, good, healthy population. If you start with oysters that have problems with growing and no resistance to disease – the ones coming from France are coming from a selection program you know they get the best of them." (Participant O2).

A common theme was a lack of concrete knowledge regarding shellfish diseases. In some cases, stakeholders voiced frustration over the overly cautious decisions made based on incomplete information and no evidence of consequences of particular diseases, e.g. *Marteilia Refringens.* The lack of reliable detection methods was also cited as a weakness in the system.

"…There is another school of thought saying it is in the Foyle or it is in Belfast Lough and we can't see any damage being done just pick them out it is not doing any damage so why bother with them…" (Participant M3).

"The story with herpes virus I don't think they know very much what they are talking about in the department to be honest. This new virus, it is a variant that was detected in 2008-2009, everywhere in the world, many places at the same time. And it's a unique virus to the oysters, I mean it has a genome like that…this virus it is very stable so it doesn't mutate and it is part of the oyster population. I believe that it was present already in the Irish water a long time and French water a long time before it struck…in 2012 we don't know so much. So what we did was this program, to monitor the bay, like mortality in the bay, there was no mortality in the bay actually and they say you cannot import seed from a bay which are non-disease free which is a bay where the virus has been detected, to a disease free bay. The thing is, they consider because you cannot detect that its disease free, that there is no disease there. But I don't agree with that I think it is not because you cannot detect it that the disease is not present. It's just your detection method may not be appropriate first or maybe because various other latent stage in the oysters can be detected because it's too difficult to detect them and that's it. (Participant O2).

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However, there is risk of 'letting the genie out of the bottle' if we allow certain activities and movements without fully understanding the potential consequences.

"…but then there is other people saying if let the genie out of the bottle then it is out of the bottle you don't get it back in." (Participant M3).

Similarly, some stakeholders revealed apprehensions over the reliability and effectiveness of detection methods, surveillance and enforcement measures.

"The thing is, they consider because you cannot detect that its disease free, that there is no disease there. But I don't agree with that I think it is not because you cannot detect it that the disease is not present. It's just your detection method may not be appropriate first or maybe because various other latent stage in the oysters can be detected because it's too difficult to detect them and that's it." (Participant O2).

"What about Monopoly? It arrived in about 4 or 5 years ago? Did they do a check on it to make sure it was ok? They introduced a snail into Belfast Lough, from France…And I says, who gave this permission...And again its fisheries responsibility to come and check imported stuff." (Participant O1).

Discussion

To the best of the author's knowledge, this is the first study to use a constructivist approach to provide an insight into how the stakeholders in the NI aquaculture supply chain perceive disease and their experiences with it within their production system. The rich descriptive data characterises shellfish production in Northern Ireland and highlights the sector faces uncertainties to production as a result of disease.

Mollusc Production in NI

Northern Ireland shellfish farms are located along the coast of Northern Ireland and are distributed across six coastal loughs, namely: Belfast, Carlingford, Larne, Strangford, Dundrum Bay and Lough Foyle. These regions differ slightly in terms of disease status. Mussels rely on wild caught spat for production and are laid on bottom for on-growing. The main cultivation for Pacific oysters used in

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Northern Ireland is bag and trestle cultivation. This method involves putting oysters in mesh bags and placing them on metal framed structures called trestles in the inter-tidal zone. Pacific oysters (*C. gigas*) are not native to NI waters and thus the sector relies heavily on imported seed, predominantly from hatcheries in France and, to a much smaller extent the United Kingdom. The main exporter for Pacific oysters is France, although there is growing markets in Asia and the Middle-East. This structure is similar to that reported in other regions of the UK (Clegg et al., 2014).

Mollusc Diseases

The study was concerned with the diseases that could impact upon Northern Irish shellfish production. Bonamiasis, Marteiliosis and Oyster herpes virus were the three diseases identified by stakeholders involved with aquaculture production in this region (Table A3.4). This reflected the status of shellfish diseases reported by the Department for Agriculture, Environment and Rural Affairs (DAERA, 2018). These diseases represent only two, *Bonamia ostreae* and *Marteilia refringens*, of the seven pathogens listed in the OIE's list of notifiable diseases for shellfish (Table 4). This was expected, as the remaining four are not associated with mussel or pacific oyster production or require warmer waters to survive. Although the other pathogens were not named by stakeholders, they were aware of other potentially 'emerging' diseases under climate warming scenarios. The third pathogen, oyster herpes virus, is not listed by the OIE. However, it has been detected throughout NI shellfish growing waters, with the exception of Larne Lough. As a result of its prevalence in NI (and throughout the UK), it is notifiable within this region. The OIE is currently in the process of adding this pathogen to the list of notifiable diseases for the EU following severe problems with the pathogen, particularly OsHV-1µVar in the oyster population throughout Ireland, England, USA, Mexico, Australia and New Zealand in the summers of 2008 and 2009 (Murray et al, 2012; Segarra et al., 2018; Renault, 2011).

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Table A3.4: Shellfish diseases in Northern Ireland

Bonamia ostreae	*Marteilia refringens*	Oyster Herpes Virus
Description		
Lethal infection of the haemocytes of flat oysters, *Ostrea edulis* and the native oyster A lag time of 3 months is observed from introduction to detection Mortality in infected populations is variable, 0-90% Causes mortality at lower temperatures of 12°C and at higher salinities No known treatment	Protistan parasites Can cause mortalities in mussels (40-100%) or pacific oysters (80-90% mortality) Death occurs in the second year after initial infection Survives best at reduced salinities Surveillance is necessary	Virulent disease of Pacific oysters, *Crassostrea gigas* Two strains exist - OsHV-1 reference strain (original) - OsHV-1 micro variant (µVar) (a mutant strain) Causes 'Summer Mortality' - Particularly in juveniles (60-80%) Issue in France, Ireland and England - Particularly in summers of 2008 and 2009 Occurs at temperatures above 16°C
Prevalence		
o NI was disease free until 2005 when samples were positive in Lough Foyle o Also detected in Strangford Lough o Within the UK, prevalence is low, typically 1-3% in wild areas and 20-30% in farmed areas with relatively low levels of mortality o Associated with winter mortality in Ireland and France	o Detected in 2017 during routine testing in Belfast Lough and Dundrum Bay o No clinical signs of disease o Infected area is under confirmed designation and movement restrictions are in place	o Larne Lough is the only disease free bay o The virus has not been detected in Dundrum Bay but it has been removed from the surveillance program due to an industry request detailing sourcing and operational difficulties o Once established pathogen eradication may be impossible

Bonamia Ostreae

Bonamia ostreae is a shellfish pathogen which has been detected in Lough Foyle and Strangford Lough within NI (DAERA, 2018). The pathogen does not cause mortalities in Pacific oysters. However, it is a deadly pathogen to native oysters causing mortality outbreaks in France and Ireland at temperatures of 12ºC (Arzul et al., 2011). Prevalence in infected populations can be up to 80% and in combination with *M. Refringens* it has been associated with a >90% decline in *O. edulis* population in France (Arzul et al., 2011). Pacific oysters are thought to act as carriers and reservoirs for the disease (Lynch et al., 2010). Thus, movement restrictions to disease free areas exist for Pacific oysters from the infected water bodies in Lough Foyle and Strangford Lough. The other

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shellfish harvesting waters in NI did not consider *Bonamia* as a disease threat to their production but discussed the market opportunities it presented in allowing them to send their production anywhere throughout the world.

Marteilia Refringens

Marteilia Refringens is a protistan pathogen responsible for Marteiliosis disease in a wide range of shellfish including native oysters (*O. eduilis*), blue mussels (*Mytilus edulis*), Mediterranean mussels (*Mytilus galloprovincialis*) and Pacific oysters (*Crassostrea gigas*). The development and transmission of the disease is related to water temperatures in excess of 17^{o}C (OIE, 2012). In 2017, *M. Refringens* was detected in Belfast Lough and Dundrum bay. The farmers mentioned the presence of the disease but none of the stakeholders had experienced any mortalities as a result of the pathogen and didn't believe it was doing any harm. In the literature, Marteiliosis has been associated with mortality in oysters (80-90%) and mussels (40%, up to 100% in native populations) (OIE, 2012) and in combination with *B. ostreae* was responsible for the major decline of *O. edulis* in France (Arzul et al., 2011). It is suspected the limited activity from the pathogens is due to the typically cooler temperatures which restricts the extent to which the pathogen can become established in NI. However, there is recognition within the sector that warming trends could potentially allow Marteiliosis to become a serious risk to both mussel and oyster production. This view is substantiated by the literature which relates mortality from the disease to warmer waters and reduced salinities (OIE, 2012; Robelo and Figueras, 1995). The large population of farms in shellfish harvesting sites does give the disease the potential to spread through all areas of the water body when high temperatures are reached. The fact mussel movements appear localised within one body of water may be a reason why farmers in the other harvesting water bodies did not consider the disease as a risk to their production. However, it is important to note Marteiloiosis does pose a substantial risk to the aquaculture sector in NI as it causes mortalities in both mussels and oyster populations when the conditions are right. Therefore it is crucial to prevent its spread across NI water bodies.

Oyster Herpes Virus

Oyster herpesvirus is a virulent disease which affects the Pacific Oyster (*Crassostrea gigas*). There has been dramatic effects of the virus reported in oysters throughout Europe, Australia, America and New Zealand (Renault, 2011; Segarra et al., 2010). The most recent virulent variant of the virus, OsHV-1 µVar has been linked with the extensive mortalities of both adult and larval in Ireland since 2009 (Clegg et al., 2014; Dégremont et al., 2013; Peeler et al., 2012; EFSA, 2010; Segarra et al., 2010; Malham et al., 2009). Stakeholders in NI linked oyster herpesvirus outbreaks to the importation of seed, and the large movement of spat, part grown and fully grown Pacific oysters between regions, particularly France. This is similar to other investigations of the virus in Ireland (Peeler et al., 2012). All stakeholders cited a temperature of 16^{o}C and above as critical for oysters and the trigger point for the virus. This supports the work by Clegg et al., (2014) who defined

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summer mortalities as multi-factorial, with the virus a necessary but not sufficient cause of mortality. Shellfish farmers in NI are at a unique advantage in comparison to those on the continent as they believe mortality has been generally limited by the low temperatures of NI waters. However, as noted and discussed by Murray et al., (2012), diseases should not be discounted given the widespread instances of mortality observed in Ireland in the past. Other risk factors were discussed by the farmers which mirrored those illustrated in the literature: hatchery in which the seed is sourced (Clegg et al., 2014); horizontal transmission of infection from unselected asymptomatic adult to juvenile *C. gigas* (Dégremont et al., 2013); increase or sudden change in temperature; husbandry practices including the introduction of possibly infected spat and the movement and mixing of population age groups; prior exposure to the virus; management practices including the age the oyster is first infected and the condition of the oysters; and temperature and other environmental factors (Clegg et al., 2014; EFSA. 2010; Garcia et al., 2011). There is no realistic prospect of eliminating the virus (Peeler et al., 2010) thus legislation has been introduced to prevent the spread of the virus to unaffected areas within the United Kingdom whilst allowing trade to continue between infected areas (European Community, 2010). Larne Lough is the only waters certified disease free, however as a result they are facing difficulties in sourcing good quality, cheaper seed.

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Table 3.5: Diseases listed by the World Organisation for Animal Health and by EU Directive 2006/88 (adapted from Oidmtmann et al., 2011)

Diseases listed by OIE	Diseases listed by EU Directive	Susceptible Diseases
Disease exotic to EU		
Bonamia exitosa	*Bonamia exitosa*	Australian mud oyster (O. angasi) and Chilean flat oyster (O. chilensis)
Perkinsus marinus	*Perkinsus marinus*	**Pacific oyster** (C. gigas) and Eastern oyster (C. virginica)
Perkinsus Xenhaliotis californiensis		
	Microcytos mackini	**Pacific oyster** (C. gigas), Eastern oyster (C. virginica), Olympia flat oyster (O. conchaphila) and European flat oyster (O. edulis)
Disease not exotic to EU		
Abalone		
Marteilia Refringens	*Marteilia Refringens*	Australian mud oyster (O. angasi) Chilean flat oyster (O. chilensis) European flat oyster (O. edulis), Argentinian oyster (O. puelchana), **Blue mussel** (M. edulis), and Mediterranean mussel (M. galloprovincialis)
Bonamia ostreae	*Bonamia ostreae*	Australian mud oyster (O. angasi), Chilean flat oyster (O. chilensis), Olympia flat oyster (O. conchaphila), Asiatic oyster (O. denselammellosa), European flat oyster (O. edulis) and Argentinian oyster (O. puelchana).
Additional		
	Oyster herpesvirus microvariant (OsHV-1 µVar)	Pacific oyster (*C. gigs*)

Impact of Disease

Mollusc disease has had substantial consequences to the oyster industry in the past, whilst the mussel farmers have been protected by the temperature regime in NI. These consequences include mortality, economic loss and reputation which have been highlighted by multiple authors on the topic of shellfish diseases (Peeler et al., 2012; Oidtmann et al., 2011). Consumers perception was another topic discussed in this study. The fact consumers perception can affect the market was recognised by the stakeholders, particularly as the product is typically minimally processed and consumed raw or lightly cooked as a whole (Lees, 2000; Murchie et al., 2005). The example of oyster herpes virus was used whereby oyster herpes virus has proven not to be a risk to humans.

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However, not all consumers fully understand or accept this and if they learn of the disease association, they may 'boycott' the product. This lack of trust within consumers is a consequence of other scandals within the food industry, such as BSE or 'Mad Cow Disease' in Ireland. Nevertheless, stakeholders did not believe this was a significant issue for their market of shellfish eaters. This supported the findings from Olemdo et al. (2013) who stated consumers seem to be more informed about the benefits arising from consumption of seafood rather than on the risks.

Risk of pathogens

The Island of Ireland was cut off from Britain and the continent before Britain was cut off from Europe by water in the landslide age. This created a salt barrier that prevented species moving across Europe getting to Ireland. Consequently, Ireland has a small number of native species in comparison to the continent and, as pathogens follow the species, the region also has a smaller number of pathogens. This unique disease free status has enabled Ireland as a geographical unit to have substantial export trade and, any emerging diseases must find a route of introduction into the region (Murray et al., 2012). The most commonly cited introduction of disease into NI shellfish harvesting waters was the movement or import of shellfish from areas were infection was present, particularly for oyster herpes virus. This reflects the literature which defines the movement of infected hosts as the most effective way of moving pathogens (Dubé et al., 2011; Brown et al., 2006; Mortensen et al., 2006). In NI, Pacific oysters are imported from France and the United Kingdom and thus the sector is vulnerable to diseases which exist within these regions. The mussel sector relies on wild caught spat so there is relatively few imports of this species. However, in 2016, the Irish Supreme court ruled fishermen/farmers from NI could no longer fish for mussel-seed in their waters, a situation known as the Voisinage Arrangement (Symmons, 2018). Consequently, the availability of wild spat is becoming an increasingly limited resource for mussel farmers and may lead to the use of imports to sustain current production. Stakeholders also identified other farmers and water users as a threat to their production as shellfish harvesting occurs in shared water bodies which allows other anthropogenic routes for disease entry. These potential routes have been described in the literature to include: the transport of infected live aquatic animals, fomites or water; lorries that carry shellfish and aquatic species for import or export; and shipping carrying pathogens within ballast water or shellfish attached to hulls (Murray et al., 2012; Oidtmann et al., 2011). Fraud, has also been highlighted as a route of introduction for disease into shellfish waters. It is believed *Bonamia* exists in Lough Foyle as a result of an illegal movement of seed from infected waters in the Western coast of Ireland, thus other shellfish farmers suffer the consequences of the disease as a result of one farmers illegitimate activity. A significant factor cited for the prevalence of disease was temperature, particularly in terms of oyster diseases. This supports the literature which highlights the role of increasing water temperatures on disease prevalence and mortality events, particularly in relation to the activation of latent oyster herpes virus (EFSA, 2010; Sauvage et al., 2009). Although, Garcia et al. (2011) noted OsHV-1 was often detected when temperatures rose quickly but was no longer detected once temperatures stabilise. In the mussel sector the risk of

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disease was not considered an issue with the current temperature regime, but trends of increasing global temperatures may active *M. Refringens.* Moreover, these environmental changes associated with climate change may also create conditions which allow pathogens to survive and move naturally by water currents or wild vector species from zones of infection. However, it is more likely these changes will create increased risk from pathogens already present in the water in their latent forms, than introduce new pathogens as Salma and Murray (2011) explains the transport of shellfish species and pathogens over distance by natural routes is unlikely.

Mitigation and Control Measures

Once a disease is introduced into shellfish harvesting waters, there is often water connectivity between farmed and wild aquatic animal populations. This close interaction allows the pathogens to spread between farmed and wild aquatic animal populations. Consequently, wild populations can become a permanent reservoir of the infection and allow the pathogen to become established. At this point pathogen eradication may be impossible (Oidtmann et al., 2011). This explains the farmer's belief that nothing can be done to prevent a disease outbreak from pathogens which exist in the harvesting waters, it is just luck. It also highlights the importance of preventing any further aquatic animal diseases entering into NI harvesting waters.

At a global level, an inter-governmental body known as OIE, has a mandate to improve transparency and international co-operation in the control of animal diseases, including shellfish. This body has developed two international standards for aquatic animal health: the Aquatic Animal Health Code and the Manual of Diagnostic Tests for Aquatic Animals (World Organisation for Animal Health OIE, 2010, 2011). The Aquatic Animal Health code lists the diseases which must be reported to the OIE by its members if it occurs within their territory (Table 4). This list has evolved over time and is reviewed annually. However, there is weaknesses in the time process to update the list as is evident with oyster herpes virus reviewed in this study, (i.e. the virus is still undergoing the process to become notifiable since severe outbreaks of OsHV-1 µVar in 2008 and 2009) (Murray et al, 2012; Segarra et al., 2018). The OIE standards provide generic and disease specific guidance on how to diagnose, prevent and control these diseases (Oidtmann et al., 2011). It allows countries with a disease free status of one or more listed diseases to restrict the introduction of live susceptible species or trade in products which are not approved disease free. An important element of this biosecurity procedure involves effective surveillance for early detection. Both passive and active surveillance procedures were discussed by the farmers. In terms of the sensitivity of passive surveillance the stakeholders revealed there can be reluctance to report the suspicion of a disease since its detection can lead to financial and reputational loses for their business. This has been reinforced by Oidtmann et al. (2011) who stated the sensitivity of the system is highly dependent on ensuring stakeholders are educated on the clinical signs of disease; allocating responsibilities; and offering incentives for reporting and/or penalties for failing to report disease. The active surveillance procedures mentioned by the industry involved sampling and

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diagnostic testing carried out by food inspectors and government departments to confirm disease or disease free status and compliance to licence conditions. These inspections and checks are in line with the requirements listed in EU Directive 2006/88. At the farm level, stakeholders outlined the strategies documented in in their biosecurity plan to help prevent the introduction and spread of disease. This documented plan is a requirement of the aquaculture licence within NI which defines the acceptable standards of operation, monitoring, reporting and follow up actions for their site. It was generally accepted that good farm biosecurity can help prevent the entry of new diseases and reduce the intensity of existing disease, however it does not guarantee disease eradication or control. A number of management practices were also highlighted, some of which were contradictory. Density was a topic discussed by all the stakeholders. Some thought the greater the density, the higher the risk and intensity of disease. This reinforced the findings of Murray et al. (2012) who stated a relatively low density and small scale production may reduce environmental pathogen loads and the intensity of disease in infected shellfish. Whilst others believed the key is to over produce, the weaker seed will die and what is left is strong, robust shellfish which will survive the two years growing period to reach a marketable size. Similarly, it was voiced that the seed sourced from French hatcheries have survived prior exposure to the disease and come from a robust selective program which provides increased protection in the event of an oyster herpes outbreak. This thought process is similar to the results of Clegg et al. (2014) who noted a strong association between hatchery of origin and mortality. The study observed seed imported from French hatcheries displayed lower mortality compared with seed imported from non-French hatcheries, when placed in bays which were historically infected with OsHV-1µvar. This is potentially due to prior exposure to the virus (in this case OsHV-1 µVar), either of the seed itself or of the related broodstock. Other studies have noted similar results of innate immunity in bivalve species (Gestal et al., 2008; Renault, 2008). Mollusc bivalves lack immunological memory, thus the protective effect of prior exposure is not the result of a specific immune response, but likely genetic (Dégremont et al., 2007; Sauvage et al., 2009; Huvet et al., 2010) with shellfish surviving a mortality event being naturally selected for resistance to disease (Dégremont et al., 2010; Pernet et al., 2012). Stakeholders believed seed from hatcheries in France had the greatest resistance to oyster herpes disease. This reinforces Dégremont et al., (2010; 2013) who revealed the considerable progress this region has made towards the selection for OsHV-1 µVar resistant oysters, particularly in the context of summer mortality in adults. Seed ploidy was also discussed. Triploid seeds were believed to be of better quality and more robust for cultivation which supports the observations of Clegg et al. (2014), Samain (2011) and Gagnire et al. (2006), but is contradictory to an Irish study carried out by Peeler et al. (2012). A more robust research design is required to confirm which seed has a greater resistance to disease as different co-founding factors were not accounted for or controlled in these studies.

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Conclusion

The study provided insights into mortality events affecting farmed shellfish production in Northern Ireland. Disease causes uncertainties to shellfish production in this region. Bonamia ostreae is confined to Lough Foyle and Strangford Lough. Bonamiasis can occur at relatively low temperatures in the native oyster population. Whilst this is not a species farmed for human consumption in the region, its presence causes movement restrictions of Pacific oysters (host species) to other locations for aquaculture production. M. Refringens requires higher temperatures than the current averages in NI shellfish growing waters. It has only recently been detected in Belfast Lough and Dundrum Bay, so experiences with it are limited and non-consequential. Oyster Herpes virus has had the most devastating consequences to farmers. The high prevalence of this disease has been attributed to the reliance on French hatcheries and temperature spikes above 16⁰C. Continuation of warming trends could make the environment more conductive to shellfish disease outbreaks, particularly Marteiloiosis and oyster herpes virus. Warming might also provide opportunities for other pathogens which have not been identified in the study. The outbreak of a disease is multi-factorial with stakeholders naming temperature, hatchery source and cultural operations as key risk factors associated with resiliency and disease mortality. However, further research is necessary to clarify the effect each of these factors plays and others which may exist. Effective biosecurity measures are essential to prevent the expansion of localised presence of disease and the introduction of new diseases. In general the current mitigation and control of disease is reactive and based on active and passive surveillance of pathogens. There needs to be a cultural shift to disease appreciation. Proactive disease prevention and control are crucial to eradicate and control disease and maintain a sustainable shellfish farming industry in this region. This should include risk analysis of current and emerging diseases coupled with economically viable and effective surveillance and mitigation measures. Research, education, training and collaboration are essential to ensure aquaculturists understand and appreciate the risk of disease and are equipped with quick, robust and economically efficient mitigation options and the skills to utilise them. This will prove increasingly important as the industry faces issues associated with increased risk of disease, e.g. climate change and intensified production systems.

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ANNEX 4: WP6.2 Phase 1 – French case study: detailed results

- **Survey response**

The French stakeholders were interviewed between September 2017 and June 2018. For oyster farmers, the rate was 63%, with 31 respondents out of 49 contacted oyster farmers agreeing to participate (of the 18 the that did not participate 3 refused, and 15 had retired or ceased relevant activity). For mussel farmers, the participation rate was 51%: out of 67 farmers contacted by phone, 16 persons accepted an interview, 4 refused and 32 were cancelled because they were retired or has ceased their activity.
Contacting shellfish farmers was complicated by the fact that the sampling list was not up to date; shellfish farmers may often change their activities to adapt to the changing contexts of production. The snowball sampling approach was not often successful as many farmers were reluctant to give colleagues name. Nevertheless, participants appeared, overall, to be keen to engage in the study.

All other stakeholders agreed to participate: local and national decision-makers (N=3), local and national representative bodies of the shellfish farmers (N=2) and the representative scientist from Ifremer (N=1).

- **Perceptions about shellfish diseases:**

  - Shellfish farmers

For each sample of farmers, about 70% of the respondents consider that disease or, more specifically, mortalities were the most serious issue they faced. Farmers indicated that they were not worried about a particular disease, as they perceived that different diseases all have the same consequence, i.e. mortality of bivalves. Rather, their concern focused on the outcome of mortality, rather than its different potential causes.
The primary concern mentioned was that of environment quality, *i.e.* water quality:
" […] but I think that today, pollution, we are sure, at least I am sure, I often fly over the area by helicopter and sometimes, we see different colors of the water, at the mouth of the Charente [river] and the week after, all have died… this is strange" (Q#21)

"thus, there is maybe a water quality problem, a disease problem which activates upon, there is also maybe a genetic problem about the animal which start to weaken or which we pushed too much, we made it as a mean machine, and the mean machine is exhausted" (Q#14)

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“I don’t know if this is a disease, to be clear, you used this term twice or three times but I am not sure this is a disease and if this is a disease what is causing it, this is the main issue. Thus, roughly, our observations on the field are that we clearly have the feeling that environment is deteriorating and we are looking rather for consequences than finding the causes.” (Q#45)

Oyster and mussel farmers showed a varying perception about diseases. Oyster farmers spoke about the crisis in 2008-2010 and mentioned two diseases: Ostreid herpesvirus 1 (OsHV-1), their worst memory, and *Vibrio aestuarianus*, the most worrying as it occurs at the end of the rearing cycle thus it can’t be compensated. Mussel farmers mentioned a more recent crisis in 2014 and 2016. They only mentioned mortalities related to the bacteria *Vibrio Splendidus* clade and parasitism due to *Mytilicola* sp.

Almost two thirds (61%) of the oyster farmers and almost all the mussel farmers (94%) interviewed believed diseases were a threat for the whole industry. But their attitude was different: 90% oyster farmers whereas only 56% mussel farmers believed they had coped with the crisis period. Oyster farmers had taken a step back on the situation and integrate the diseases, and subsequent mortalities, in their business plan, whereas mussel farmers were still in the middle of the crisis, having high financial issues and less possibilities to compensate the losses because mortalities affects the mussels at the end of the rearing cycle (which lasts only 1 year). In addition, they often had specialized enterprises, operating in only one farming location, which limited the possibilities for diversification. They also doubted that the cause of the mortalities was not fully identified (opportunistic bacterial disease?).

- Disease impacts

The perceived impacts of shellfish diseases varied according to the stakeholders (Table A4.1).

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Table A4.1. Perceived impacts of shellfish diseases by the different stakeholder categories, France, 2017-2018

Stakeholders	Economic impacts	Psychological impacts	Ethical impacts
Oyster and mussel farmers	X	X	X
Local farmer representative	X		
National farmer representative	X	X	
Local competent authority	X		
National competent authority - Economics	X		
National competent authority - Health	No real impact	No real impact	No real impact
Scientist representative	X		

- Disease management measures

Oyster industry has got used to oyster mortalities (lasting for 10 years) and coped them by combining short-term and long-term management measures. Oyster farmers wondered about the efficacy of prevention measures. In contrast, the mussel industry currently faced massive mussel mortalities and was suffering from the situation, with fatalism and high uncertainty. Preventive management measures were far from their thoughts (Table A4.2).

Table A4.2: Differences between oyster and mussel farmers regarding the implemented disease management measures

Oyster farmers	**Mussel farmers**
Short, middle and long-term measures - Combination of measures with different terms	Mainly short term measures – Emergency measures – “healing” measures
Room for manoeuvre: farming practices, sales, production types	Low room for manoeuvre
Know that the financial compensations have expiry date	Count on financial compensations
Actions on disease consequences (getting back to a production balance) and not on causes (multifactorial and non identifiable), except for actions related to farming practices Wondering about the efficacy of preventing measures	None action on causes, only actions on disease consequences Fatalism and high uncertainty Not even a preventing measure cited

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- **Information, communication and interrelations with the other stakeholders**

Half of the oyster farmers and almost all the mussel farmers mentioned the insufficient information about shellfish diseases and the measures to implement. They had notably high expectations from scientists and their local representative body. The topics they would be interested in were: interactions between environment, animal and pathogens, knowledge about the current research topics. Oyster and mussel farmers wanted simpler communication between all the stakeholders.

Concerning the role of current stakeholders' system to prevent diseases, only one third of the interviewed oyster farmers trusted the actual system. They notably trusted the scientists and the local technical center, and to a lesser extent, their local representative body and the local competent authority. About two fifths (39%) of them declared they only rely on themselves.
"*Not at all, I don't expect anything. I don't see what they will do best*" (Q19 – Oyster farmer #2)

Half of the interviewed mussel farmers trusted the actual system. They notably trusted their local and national representative bodies. The majority (75%) of them declared to only rely on the mussel community, contrary to the oyster farmers.
"We realized that when there are troubles, the industry was quite solid, the [local shellfish farmers' body] took care well of [the mortality crisis]" (Q20 – Mussel farmer #6)

The local farmers' representative body hoped for a system more: organized, coordinated, flexible, reactive, accurate and thorough, mostly held by the farmers. The main stakeholders cited were the scientist, the local competent authority and, in a lesser extent, the local technical center.
"I think the industry has an important role to play. […] in a well-defined frame, and probably not alone" (Q21 – Local farmers representative body)

The national farmers' representative body also believed that the stakeholder system should be held by the industry, with a structured sanitary network coordinated by the national and local farmers' representative bodies. The role of this system should be to centralize standardized information, which should be accessible to all the stakeholders.
"I think that the main issue is that everything is split" (Q22 – National farmers' representative body)

The local competent authority hoped for a more legitimate farmers' representation. This interview was conducted the same week as the elections of the local representative body; this context may have influenced the discussion.
"*One objective, I think, [is that] it's up to the [local farmers' representative body] to regain some legitimacy […]. I have the feeling that it is not really representative"* (Q23 – local competent authority)

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The national competent authority in charge of industry economics believed that the industry should better absorb the shellfish disease issue, from the individual farmers to their representative bodies, local or national.

"*I think that involving [the farmers] as much as possible is in our interest. Things managed by them and for them*" (Q24 - national competent authority – Economics)

The national competent authority in charge of shellfish health wished that the industry should become aware of its responsibilities and reassessed itself, and a stricter administration. This interview was conducted just after the fact-findings mission conducted by the EU with the aim of providing an overview of how EU legislation on aquaculture is implemented in four Member States, and notably in France.

"*I often turn to the industry because they do not become aware of their situation […] but the Administration does not have enough weight and does not carry out its regalian functions*" (Q25 - national competent authority – Animal Health)

Overall, the stakeholders seemed to be polarized in their perception of the usefulness of the current stakeholders' interaction system. On one hand, shellfish industry and its representatives seem to be confident in the system, without whishing any modification of the current system because businesses continue to operate anyway. They stood for a better and simpler communication between all the stakeholders. On the other hand, the competent authorities believed that the industry did not reassess itself and seemed to be discouraged, without involving themselves anymore in these questions. Maybe an external intervention may contribute to break this circle?

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ANNEX 5: Quotes in original language (French)

Q1: "*On parle des maladies en général enfin… on parle surtout des mortalités et pas forcément de la maladie en elle-même* " (National Farmers' representative)

Q2: " *Dans mon, esprit, mortalité, maladie, c'était… oui je faisais la connexion… il y a des mortalités parce qu'il y a des maladies* " (Local Farmers' representative)

Q3: " *Parce que quand on me dit les moules elles ont été malades, je dis non… si demain vous décédez qu'est que l'on va retenir de vous que vous étiez malade ou que quelqu'un l'a tué d'un pistolet ou n'importe quoi ? le résultat est le même à la fin* " (Mussel farmer #1)

Q4: " […] *mais je pense qu'aujourd'hui la pollution, on en est sûr, enfin en tous les cas moi j'en suis sûr, j'ai survolé le bassin en hélico souvent et à certaines périodes on voit les différences de couleur d'eau avec la sortie de la Charente et puis la semaine d'après tient c'est tout crevé…c'est bizarre.* " (Oyster farmer #21)

Q5: " *Je ne sais pas si c'est une maladie, très clairement, vous l'employez depuis deux ou trois fois mais je ne suis pas sûr que ce soit une maladie et si c'est une maladie par quoi est ce que qu'elle est induite, c'est surtout ca la problématique. Donc en gros notre constat sur le terrain c'est que l'on a clairement l'impression et le sentiment que l'environnement se dégrade et que l'on cherche plutôt les conséquences plutôt que de trouver les causes.* " (Oyster farmer #45)

Q6: " *Les coquillages sont des indicateurs, ce sont des sentinelles* " (Local farmers' representative)

Q7: " *Une [maladie] qui se développe au niveau des frontières et puis qui pourrait effectivement arriver en France, c'est sûr qu'il y a tout ce qui concerne les maladies en général*. " (National competent authority representative - health)

Q8: "*Celle qui n'est pas encore arrivée car on se rend compte qu'on est pas bien armés pour être en capacité de l'éviter*. " (Scientist representative)

Q9: " *La plus grosse incidence elle est financière au niveau des prêts qu'il a fallu faire.* " (Mussel farmer #2)

Q10: " *C'est-à-dire que si on les brasse il faut les vendre aussitôt parce que sinon… Oui avant on stockait, on machinait. Mais maintenant dès qu'on les brasse il faut les vendre. Avant c'était mieux.*

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Donc du coup, on se pose la question de la vente, avec la GMS des choses comme ça, avec du débit derrière qui demande du stock." (Oyster farmer #20)

Q11: " *Nous on a perdu des parts de marché de ce côté-là parce que les GMS on a pas pu les livrer*." (Mussel farmer #4)

Q12: " *D'élever quelque chose qui meurt ça m'a gêné. Après on s'habitue plus, mais cette première année était quand même particulière. "* (Oyster farmer #4)

Q13: " *Après quand on discute avec les gens on se dit on est complètement ridicule de dire « j'arrive à faire sauver 10% des huitres ». Parce qu'aucun élevage n'accepterait ça.* " (Oyster farmer #4)

Q14: " *On n'en s'en rend pas compte mais derrière, les années d'après on se rend compte de la motivation psychologique, quand c'est un coup une année ça va mais quand c'est à suivre, on voit bien qu'il y a un problème. Et je dirai dans ce truc-là, bon faut être passionné dans nos métiers, si il n'y a pas de passion ça ne dure pas longtemps. Et je dirais que c'est la passion qui part ensuite, l'envie de transmettre*. " (Oyster farmer #38)

Q15: " *Sur les mortalités de juvéniles, comme le cycle est long, […] l'impact sur la trésorerie est beaucoup moins important que si c'est sur des huîtres adultes qui meurent en fin de cycle […]. Là l'impact financier est beaucoup plus fort*. " (Local farmer representative)

Q16: " *La filière ostréicole a été aidée dans les premières années de crise, le schéma s'est installé et s'est à peu près stabilisé. Il y a bien eu des impacts sur les entreprises mais disons que celles qui ont tenu le coup a priori tiennent encore le coup. Sur la filière mytilicole, les entreprises sont plus fragiles, c'est un produit à moins grande valeur économique, on peut moins jouer sur les prix et il y a une concurrence sur les produits importés*. " (National competent authority representative - economics)

Q17: " *L'impact sur les espèces en tant que telles n'est pas, lui, flagrant. A long terme. Il y a plein d'espèces de coquillages qui sont exploitables*. " (Scientist representative)

Q18: " *Je n'ai pas perçu de réel impact sur la filière […] Je ne suis pas certain que ça ait freiné cette espèce de course en avant qu'il y avait dans la filière, c'est-à-dire on augmente la production, on augmente la densité*. " (National competent authority representative - health)

Q19: " *On a modifié nos façon de travailler sur les sites, par exemple de janvier à Mars, dans les périodes les plus froides on redescend nos produits de Bretagne, on les calibre et on les prépare et on les remet sur les parcs ici ou en Bretagne […]. On diminue les manipulations lors de la pousse, on*

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va les stresser le moins possible et les placer dans des endroits protégés des passages et des courants. " (Oyster farmer #2)

Q20: " *La filière est très frustrée par rapport à la recherche parce que la recherche a un pas de temps beaucoup plus long que la profession*. " (National competent authority representative - economics)

Q21: " *Non pas du tout, je n'attends rien. Je ne vois pas ce qu'ils feront de plus*. " (Oyster farmer#2)

Q22: " *On s'est aperçu que quand il y a des problèmes, la profession était assez soudée quand même, après le CRC […] ils s'en sont bien occupé*. " (Mussel farmer #6)

Q23: *" Je pense que la profession a un rôle important à jouer. […] Dans un cadre bien posé, et sans doute pas tous seuls*. " (Local farmers' representative body)

Q24: *" Je pense que le principal problème c'est que tout est fractionné. "* (National farmers' representative body)

Q25: " *L'un des objectifs à mon avis […] c'est justement au CRC […] de retrouver un peu de légitimité. […] j'ai quand même la sensation que ce n'est pas vraiment représentatif. "* (Local competent authority)

Q26 : " *Je pense que les impliquer [les professionnels] au maximum c'est dans notre intérêt… chose gérée par eux et pour eux*. " (National competent authority - economics)

Q27 : " *Je me tourne souvent vers la profession car effectivement ils ne prennent pas conscience de leur responsabilité […] mais l'administration non plus n'a pas suffisamment de poids et n'assure plus ses fonctions régaliennes*. " (National competent authority - health)

ANNEX 6: WP6.2 Phase 2 – Facilitator guide

The focus group discussions should be completed within 45 minutes.

FGDs will be based on a series of participatory exercises. Initially the participants will be presented with a set of Post-It notes with the names of 13 specific preventive practices on them.

The aim of the focus group discussions is for participants to rank the practices according to their effectiveness, then score them on their feasibility, cost and acceptability (see below).

General notes:

- Your role as a facilitator is to ensure participants understand each activity, that the discussion is productive and results are generated and that the participants keep to time.
- Participants may disagree with each other. Where this occurs, see if consensus can be reached through discussion. If this is not possible, record the majority opinion on the matrix and note down the alternative views on your comments sheet.
- Practices can be ranked equally in terms of effectiveness. Where this occurs, double-check that the participants really believe they will be equally effective and ask them to rank one above the other if at all possible.
- Please try to ensure all participants contribute. If some participants dominate the discussion at the expense of others, be sure to directly ask the quieter participants to express their thoughts.

Groups:
We hope to have groups comprising similar people (same country or at least first language, same shellfish type and similar roles). However, this may not always be possible.

Step 1 – reviewing practices/measures (up to 5 mins)

- Review the measures presented on the Post-It notes.
- Ensure all participants understand the practices.
- Ask if the participants want to include any other practices that they considered very important by the group. If additional practices are identified they will also be written on Post-It notes. Try to limit these to 1 or at most 2 additional practices.

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- Ask if the participants want to exclude any practice they consider not relevant at all – note that the matrix has space for 12, or at most 13, practices.

Step 2 – Effectiveness (8 mins)

- Ask participants to rank the practices in terms of their **effectiveness** in controlling infectious diseases.
- Asked that they ignore all other factors (such as acceptability, cost and feasibility).
- "Please rank these practices in terms of their effectiveness (i.e. ability to prevent disease entering a farm) from most effective at the top to least effective at the bottom. At this stage assume that other factors, such cost and the difficulty of undertaking the practices, are NOT an issue; just focus on how effective each practice is".
- If there are points of disagreement/discussion about the ranking please note these on your comments sheet.

Step 3 – Feasibility (8 mins)

- Asked participants to score each practice in terms of its **feasibility** (i.e. how easily/readily can it be undertaken)
    - + = very difficult,
    - ++ = somewhat difficult,
    - +++ = somewhat easy,
    - ++++ = very easy.
- Ask participants to ignore the all other factors, such as acceptability or cost of each practice.
- Record these scores in the relevant column, next to each practice.

Step 4 – Cost (8 mins)

- Asked participants to score each practice in terms of its likely **cost** of implementation and conduct (i.e. cost to set up and cost to maintain will be considered separately, if appropriate).
    - + = negligible cost,
    - ++ = small cost (noticeable, but reasonable cost),

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    - +++ = moderate/high cost (would place a considerable strain on finances),
    - ++++ = prohibitive cost (rules out implementation in most circumstances).
- Ask participants to ignore the all other factors, such as the cost of each feasibility and acceptability.
- Record these scores in the relevant column, next to each practice.

Step 5 – Acceptability (8 mins)

- Asked participants to score each practice in terms of its **acceptability** (i.e. can it be applied equitably regardless of scale of operation, is it harmful to the environment)
    - + = not acceptable,
    - ++ = somewhat acceptable,
    - +++ = quite acceptable,
    - ++++ = very acceptable.
- Ask participants to ignore the all other factors, such as the cost of each practice.
- Record these scores in the relevant column, next to each practice.

Step 6 – final comments (up to 5 mins)

- If there is time, ask the participants to review the completed matrix and make any changes if necessary.
- Ask if they have any final comments, and record these on your record sheet.

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ANNEX 7: WP6.2 Phase 2 – Summary of results for each workshop

1. Pilot: VIVALDI workshop, AQUA2018 Conference, Montpellier (France), 29th August 2018

During the VIVALDI workshop in Montpellier (France), participatory FGDs with members of stakeholder groups were conducted to explore their perceptions regarding the most suitable shellfish disease control and prevention strategies. A total of 11 FGDs were constituted, which took approximately 45 minutes.

Participants belonged to different stakeholder categories: research organisations (17), hatchery/nursery (6), competent authorities (6), knowledge transfer (5), shellfish producers (4), training/education (3), shellfish industry representatives (2) and other categories (3). They worked with different shellfish species: oysters (29), mussels (16), clams (15), scallops (3), cockles (3) and abalone (1).

- Ranking results :

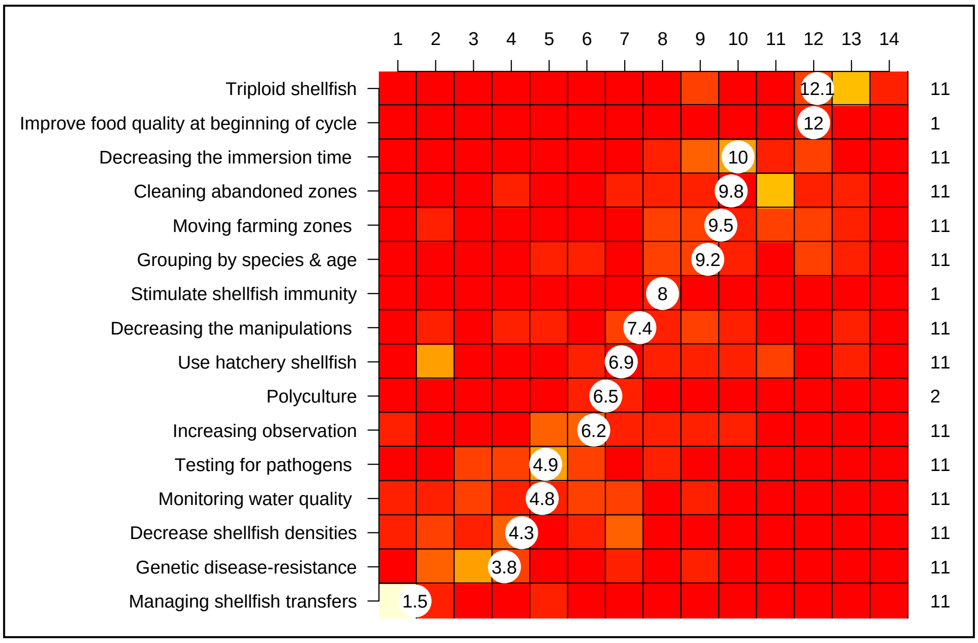

Figure A7.1. Ranking of the preventive measures by the perceived efficiency

"Managing shellfish transfers" was consistently ranked as the most effective measure, followed by "genetic disease-resistance", "decreasing shellfish densities", "monitoring water quality" and

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“testing for pathogens”. Use of “Triploid shellfish” was ranked as having low efficacy, as was “improving food quality at the beginning of the cycle”, a measure introduced by one group

- Feasibility

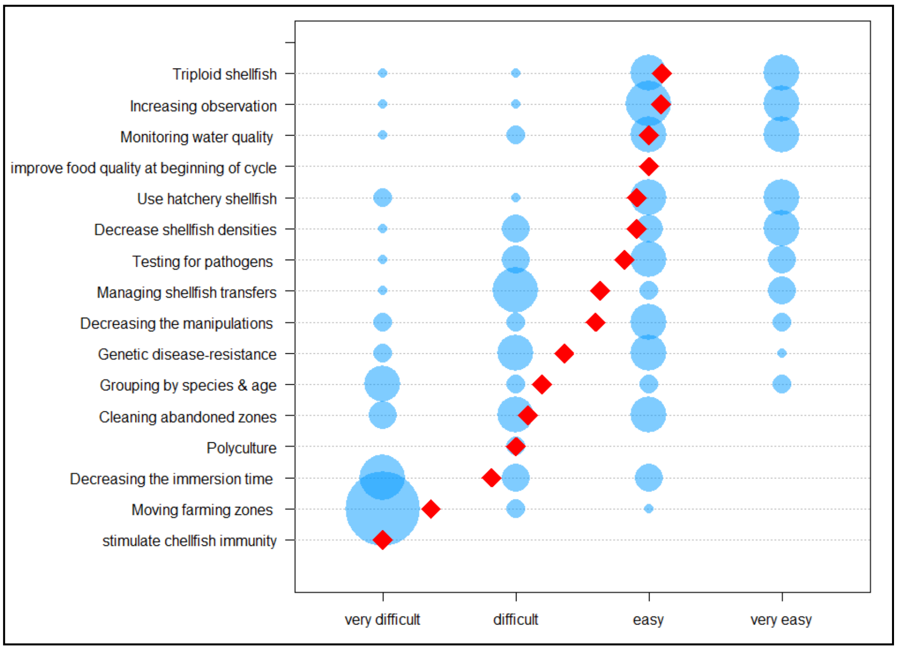

Figure A7.2. Perceived feasibility of the preventive measures

Those factors considered most feasible included use of “triploid shellfish”, “increasing observation” and “monitoring water quality”; “improved food quality at the beginning of the cycle”, a measure introduced by one group, was also considered to be easy by that group.

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- *Cost*

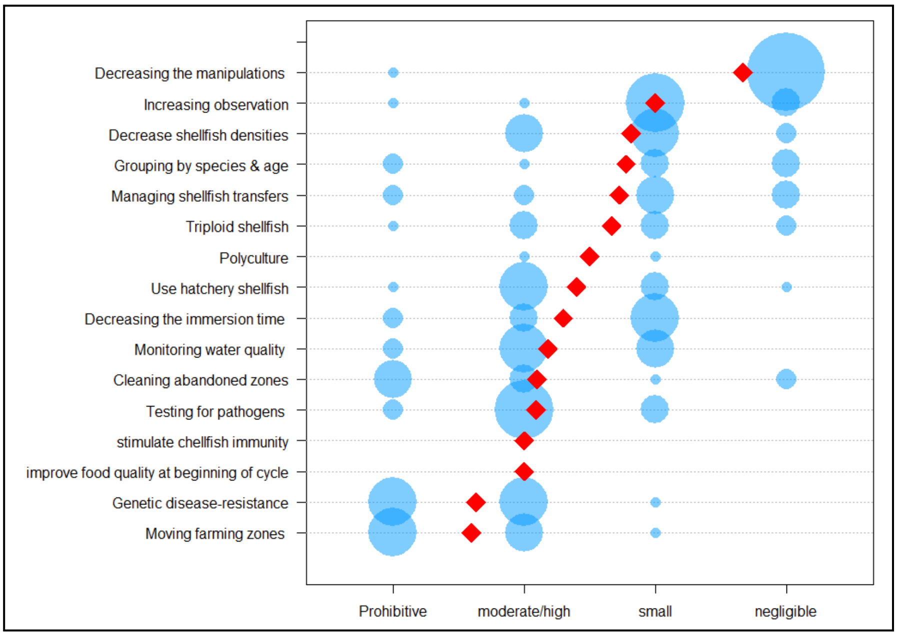

Figure A7.3. Perceived cost of the preventive measures

Measures with small or negligible costs included “decreasing manipulations” and “increasing observation”. “Moving farming zones” and “genetic disease-resistance” were considered by most groups to have high or prohibitive costs.

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- ***Acceptability***

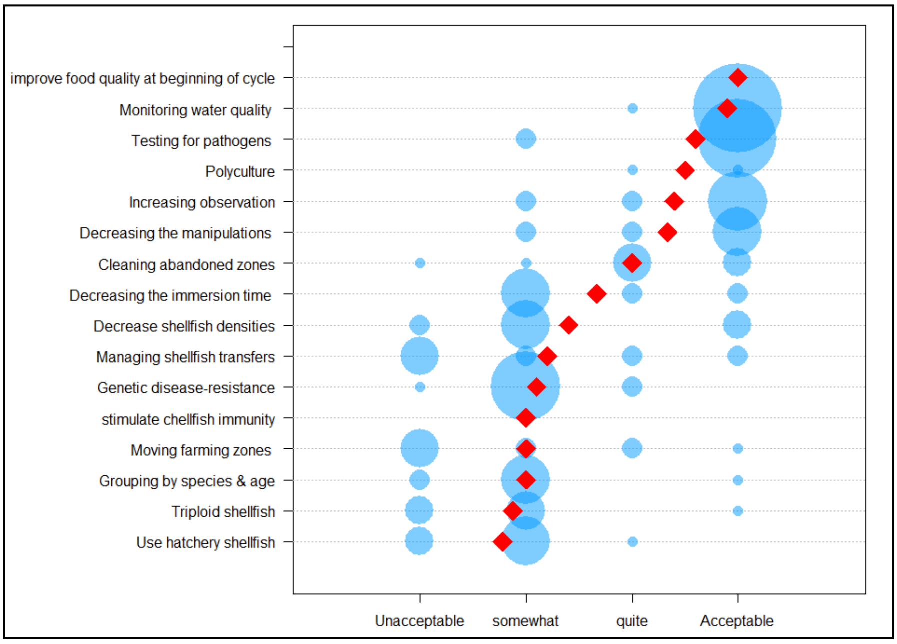

Figure A7.4. Perceived acceptability of the preventive measures

Those measures thought to be most acceptable included those requiring enhanced surveillance (“Monitoring water quality”, “testing for pathogens” and “increasing observation”. Two measures introduced by one group were also viewed as quite or very acceptable: “polyculture” and “improved food quality at the beginning of the cycle.”

Summary results (Figure A7.5) showed that management of shellfish transfers, genetic disease-resistance and decrease of shellfish densities were perceived as the most effective measures to prevent diseases, and were considered quite feasible but having more moderate levels of acceptability and, for genetic disease-resistance, relatively high cost. Participants at this workshop perceived monitoring water quality and testing for pathogens as very acceptable measures, quite effective and feasible but with a moderate cost. At the bottom of the ranking, the use of triploid shellfish was considered to have the lowest effectiveness and as one of the measures with the lowest acceptability.

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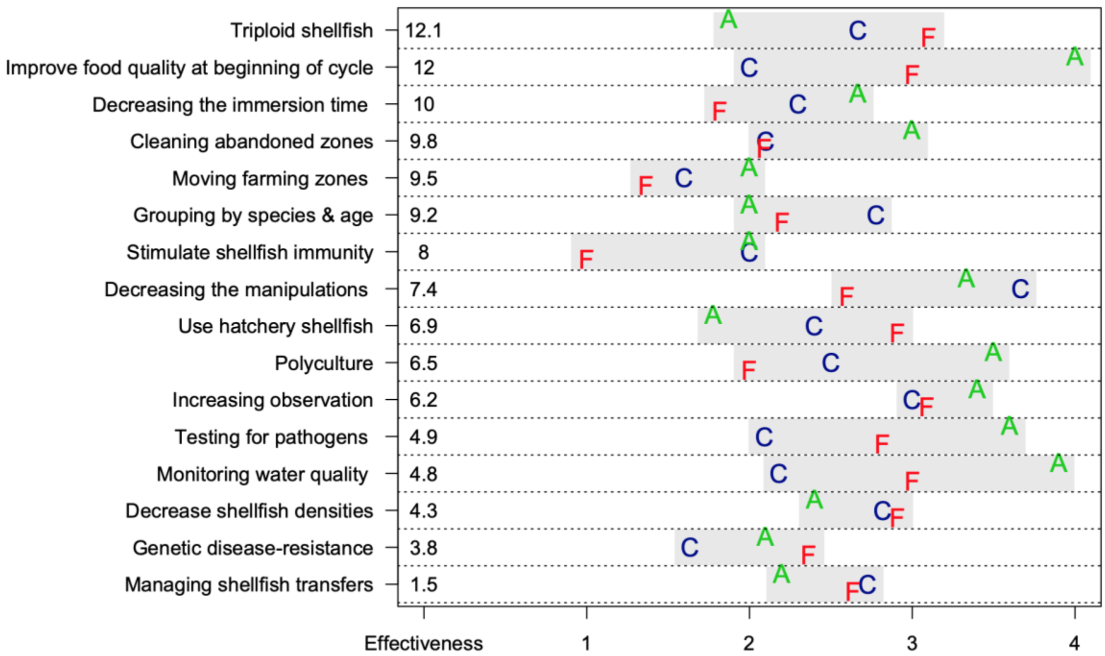

Figure A7.5. Summary of the perception of the preventive measures

- Limitations

The feedback of the participants of this pilot-test pointed out three limitations. First, more time should have been needed for the FGDs activities, as 2 groups out of 11 could not finish the scoring in the available time. Hence, further implementation of these FGDs was planned to take 1 hour instead of 45 minutes. Second, some difficulties of understanding the criteria “acceptability” were reported. For further implementation, the following definition was provided: “acceptability from your own particular point of view, as a [*stakeholder type*]”. Third, some participants felt that the preventive measures to rank were too much oyster orientated.

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2. Italy

Stakeholders

6 producers, mainly mussel farmers using longline systems. Only one participant produced both mussels and oysters. All were members of the association and the FGD was held during one of the association meeting in the end of November 2019.

Due to the relatively low number of participants at this meeting, the participants chose to undertake the FGD as a single group. Hence, the results presented below are those for that group.

Results

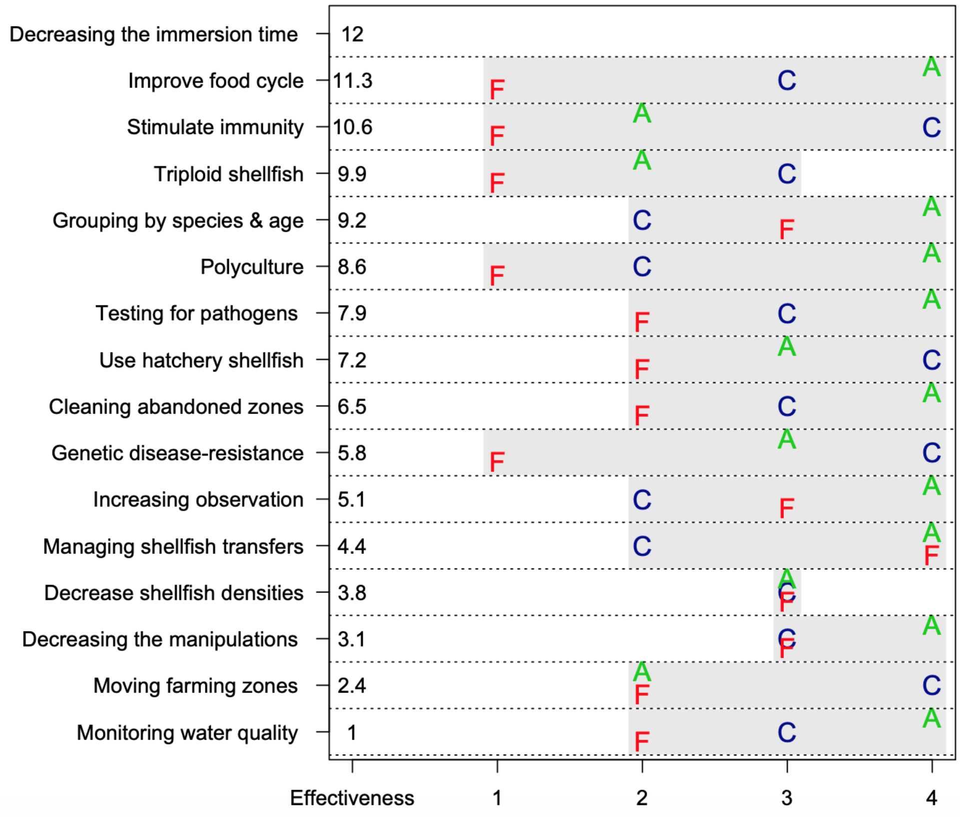

Figure A7.6. Summary of the perception of the preventive measures

"Monitoring water quality" was considered the most effective measure, followed by "moving farming zones". Subsequently, the next most effective measures were those requiring management adaptations, including "decreasing manipulation", decreasing density" and "managing transfers". The group considered "decreasing immersion time" to be impossible, so did not consider it further.

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3. Spain

Stakeholders

Farmers from Galicia were invited to a meeting at CSIC, Vigo in 23 November 2018. Eighteen people participated in the workshop. Rather than undertake the exercises in groups, the participants decided to each complete the activities individually. Hence, the results below summarise the results from the 18 farmer participants.

Ranking of Measures

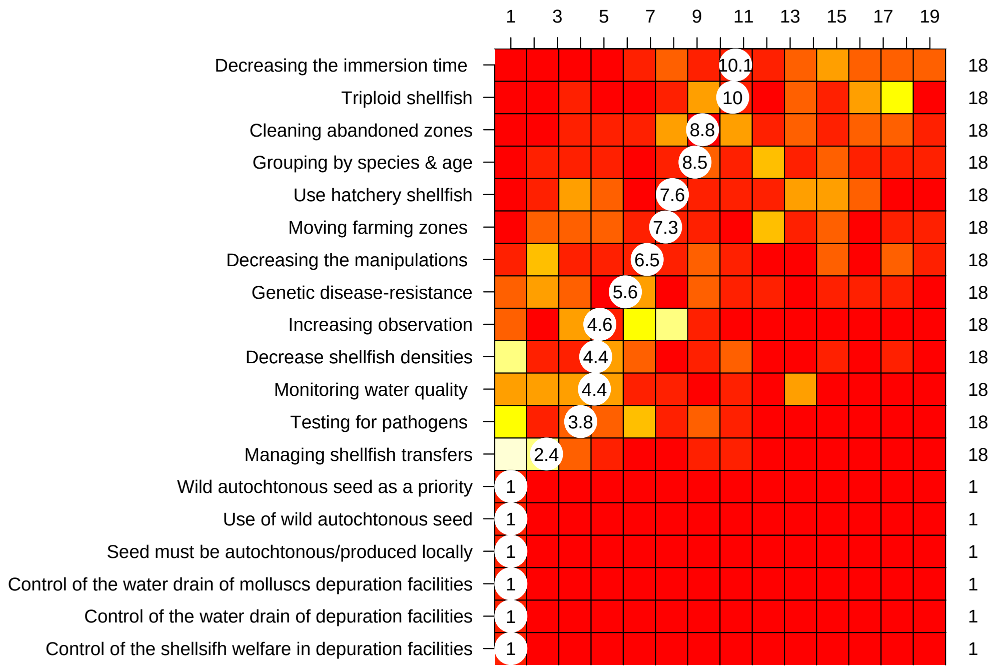

Figure A7.7. Ranking of the preventive measures by the perceived efficiency, Spain

Those methods considered most effective (the bottom 6 in Figure A7.6) were those introduced to the ranking procedure, in each case, by a single participant. Hence, these are likely to represent opinions of a small number of people but could be considered further in future studies. Of the 13 measures presented in the exercise, the most effective were "managing shellfish transfers", those implying increased surveillance ("testing for pathogens", "monitoring water quality" and "increasing observation"), as well as "decreasing shellfish density". The least effective were "decreasing immersion time" and use of "Triploids".

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Perceived feasibility

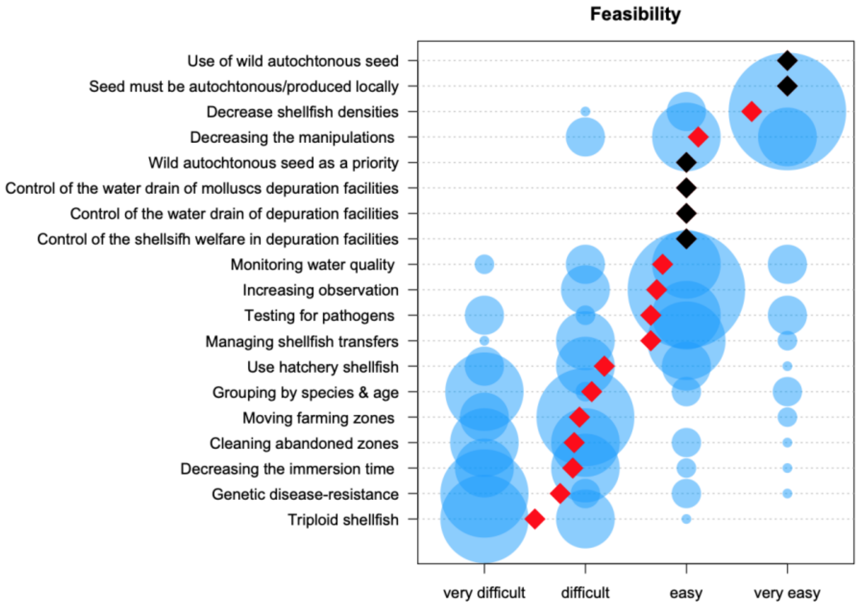

Figure A7.8. Perceived feasibility of the preventive measures, Spain

Perceived cost

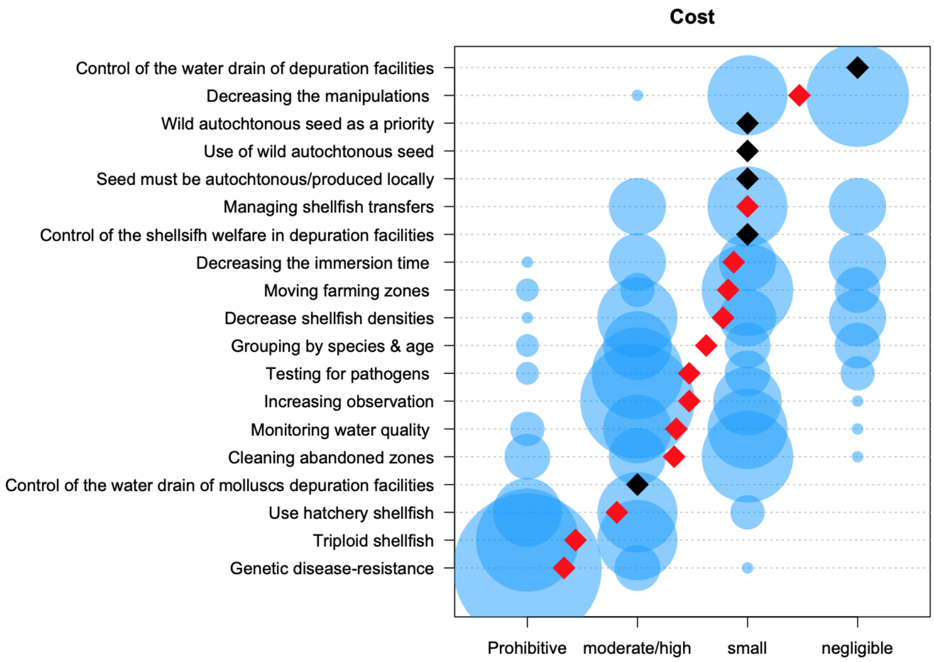

Figure A7.9. Perceived feasibility of the preventive measures, Spain

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Perceived acceptability

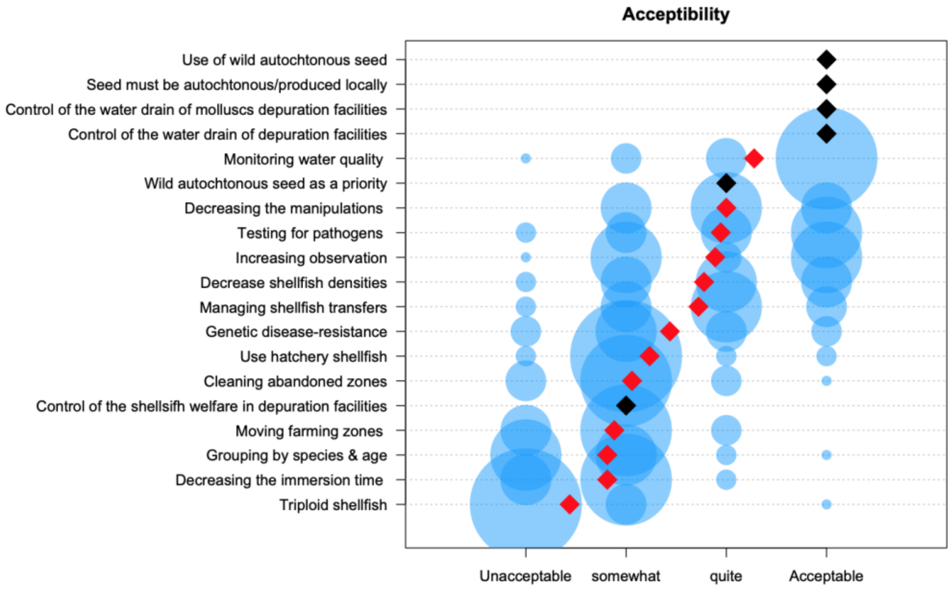

Figure A7.10. Perceived feasibility of the preventive measures, Spain

Summary

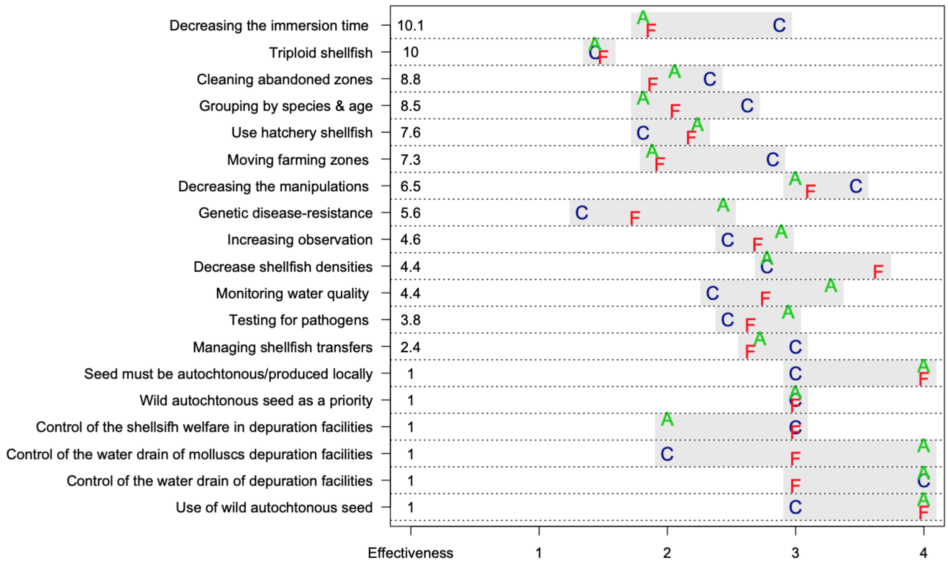

Figure A7.11. Summary of the perception of the preventive measures, Spain

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4. France – Normandy

Stakeholders

The participants at this workshop were from a range of disciplines including: farming and fishing, government (local competent authority), producer bodies, regional technical center, education/training organisations, local funding public bodies and research institutions (n=30). The workshop took place in November 2018 at the regional technical center SMEL, Blainville-sur-mer, Normandy.

Ranking of Measures

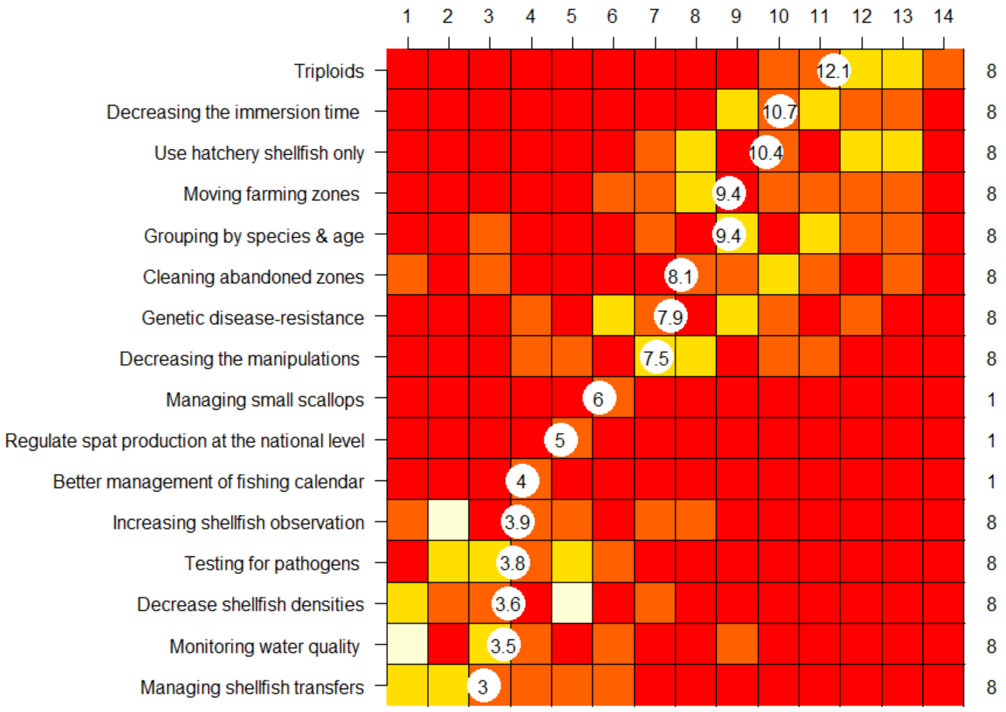

Figure A7.12. Ranking of the preventive measures by the perceived efficiency, Normandy, France

On average, the most effective measures were believed to be "managing shellfish transfers", followed by "monitoring water quality" and "decrease shellfish densities". "Triploids" was considered as the least effective measure.

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Perceived feasibility

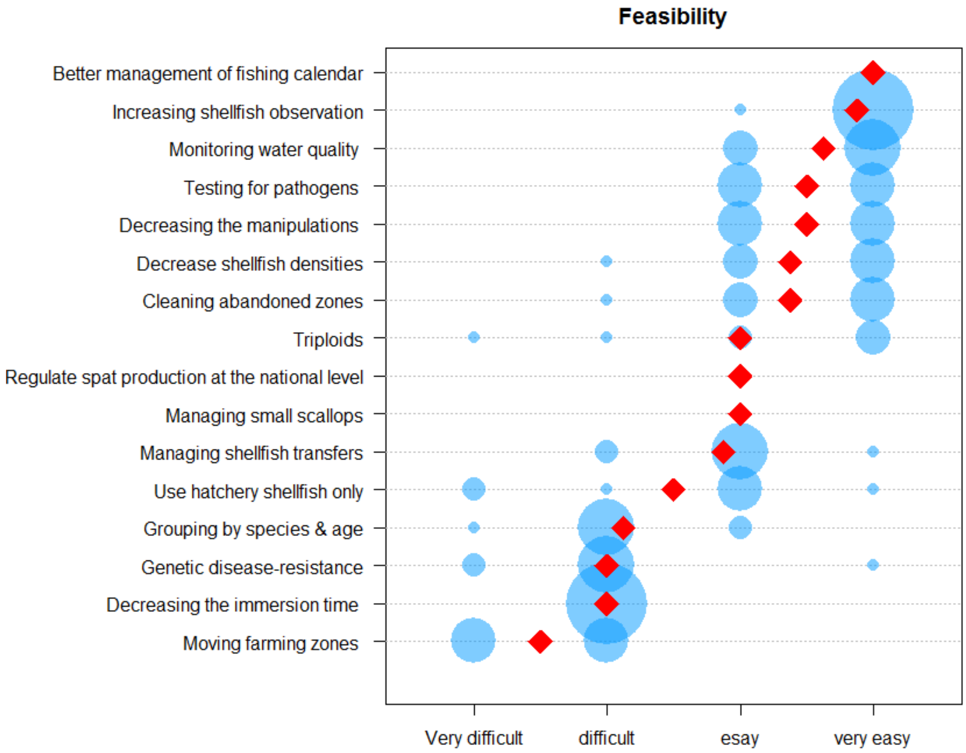

Figure A7.13. Perceived feasibility of the preventive measures, Normandy, France

A group of seven measures were considered to be between easily to very and easily feasible: “better management of fishing calendar” (which was added by the participants), “increasing shellfish observation”, “monitoring water quality”, “testing for pathogens”, “decreasing the manipulations”, “decreasing shellfish densities” and “cleaning abandoned zones”. The most difficult option was “moving farming zones”, and “decreasing immersion time” was unanimously considered to be difficult. Although a few groups disagreed, most groups considered “genetic disease resistance” and “grouping by species and age” also to be difficult.

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Perceived cost

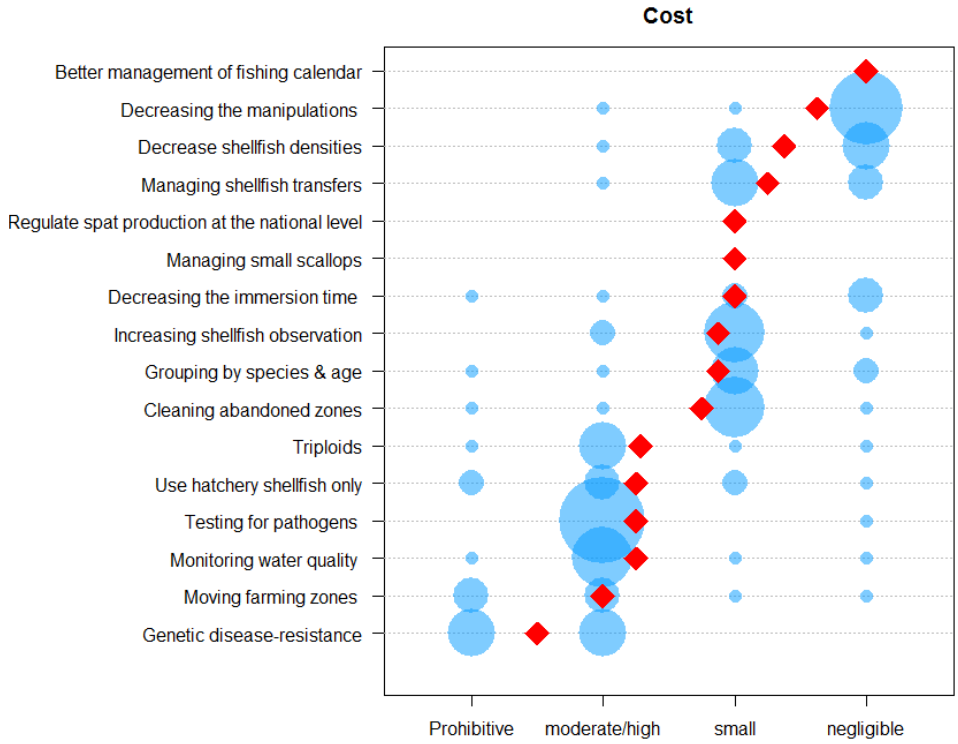

Figure A7.14. Perceived cost of the preventive measures, Normandy, France

The measure with the most negligible cost, on average, was “better management of fishing calendar” (which was added by the participants), followed by “decreasing the manipulations”, which was perceived to have negligible cost by all by a few groups. The measure “genetic disease-resistance” was perceived with a cost from high to prohibitive. Measures considered to have moderate to high costs included “Moving farming zones”, “Monitoring water quality”. “Testing for pathogens”, using hatchery only shellfish” and “Triploids”

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Perceived acceptability

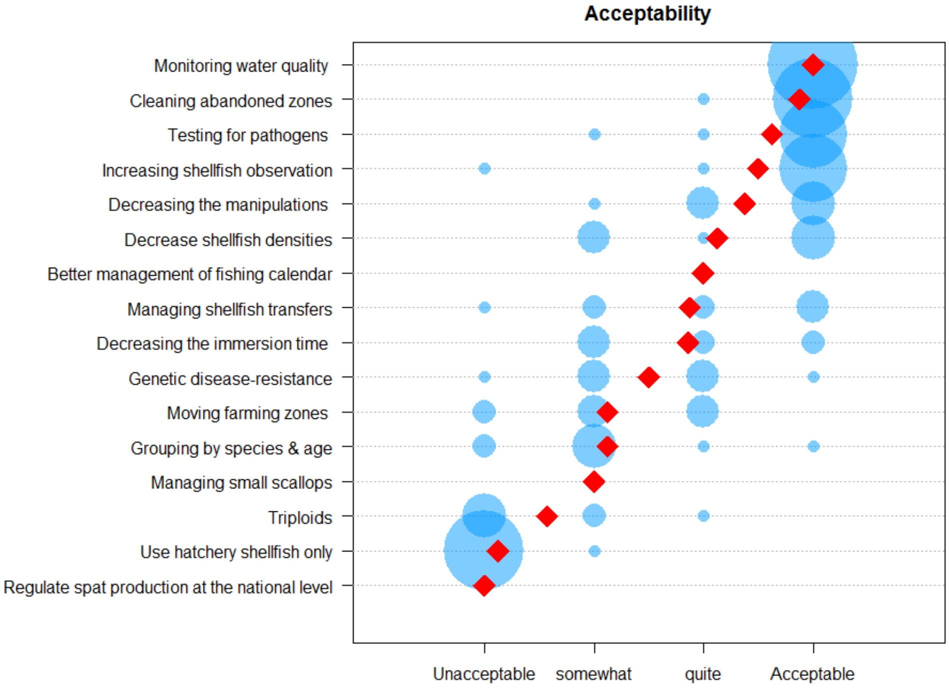

Figure A7.15. Perceived acceptability of the preventive measures, Normandy, France

Unanimously, the more acceptable measure was "monitoring water quality". Half of the 13 measures were perceived on average as quite acceptable or acceptable. The two unacceptable measures were "regulate spat production at the national level" (which was added by the participants) and "use hatchery shellfish only".

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Summary

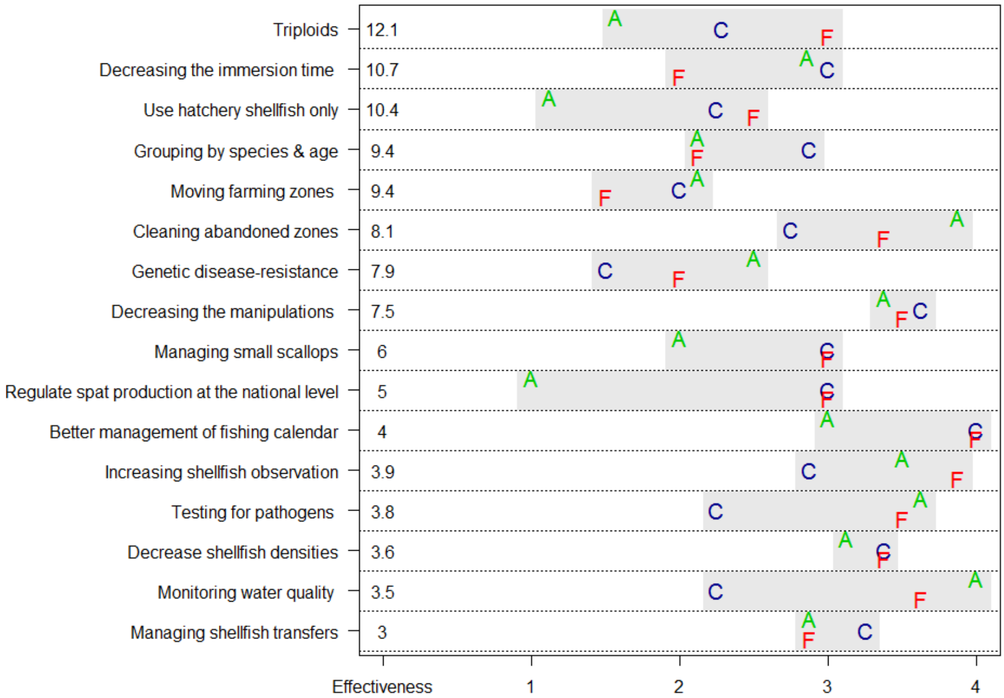

Figure A7.16. Summary of the perception of the preventive measures, Normandy, France

Overall, "managing shellfish transfers" was ranked most effective with good scores of feasibility, cost and acceptability. Similar findings were observed for "decrease shellfish densities". "Monitoring water quality" was perceived as one of the most effective measures but as somewhat costly. Similar findings were observed for "testing for pathogens".

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5. Northern Ireland

Stakeholders

The participants at this workshop were from a range of disciplines including: farming, processing, government, producer bodies, food inspectors and research institutions (n=8). The workshop took place in November 2018 in the Senate room of Queens University, Belfast.

Ranking of Measures

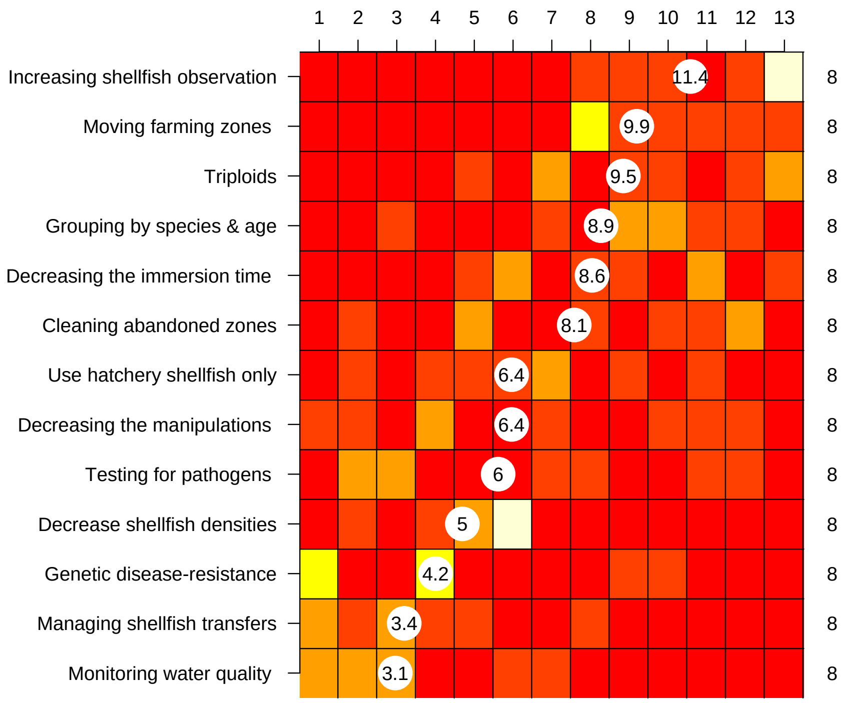

Figure A7.17. Ranking of the preventive measures by the perceived efficiency, Northern Ireland

On average across all the participants the most effective procedures were believed to be monitoring water quality and minimising/ regulating / managing shellfish transfers, followed by developing genetic disease resistant shellfish. Those described to be least effective were increasing shellfish observation during farming, moving farming zones into other areas and increasing the use of triploid shellfish/ oysters.

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Perceived feasibility

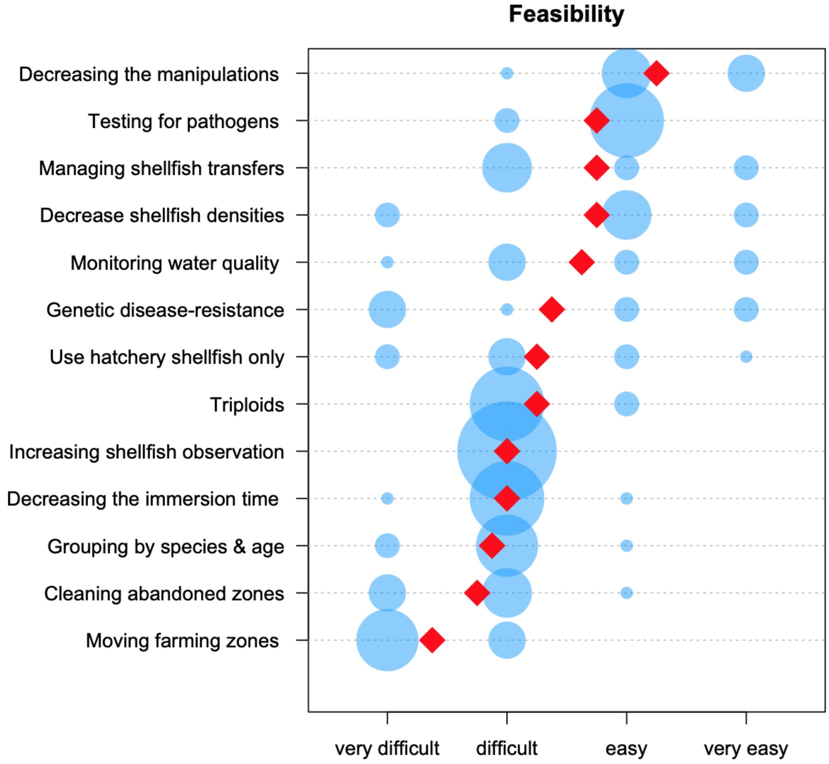

Figure A7.18. Perceived feasibility of the preventive measures, Northern Ireland

The most feasible intervention was decreasing the manipulations of shellfish with testing of shellfish, decreasing shellfish densities and minimising / regulating shellfish transfers also being quite feasible (although opinion was quite divided with regard to managing transfers). In contrast, moving or cleaning abandoned farming zones were perceived to be the most difficult options.

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Perceived cost

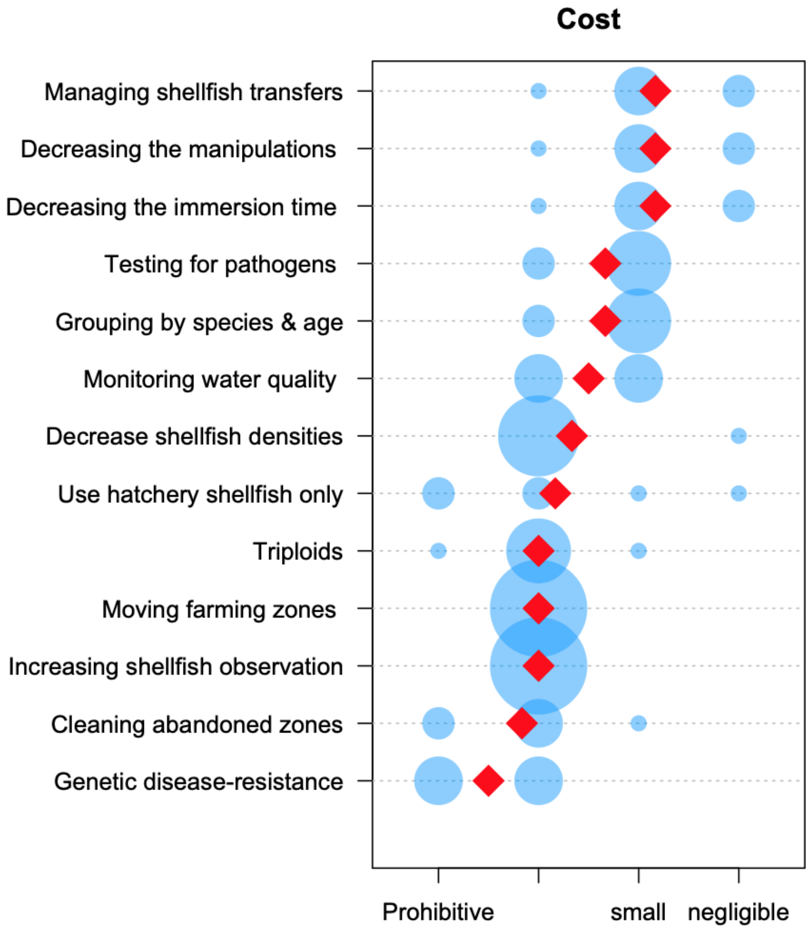

Figure A7.19. Perceived cost of the preventive measures, Northern Ireland

Developing genetic disease resistant shellfish was, on average, perceived as the most costly to implement alongside cleaning abandoned farming zones (with many respondents believing these to be cost prohibitive activities). In contrast, the least costly options were decreasing the immersion time of the shellfish, decreasing the manipulations of shellfish and minimising / regulating shellfish transfers.

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Perceived acceptability

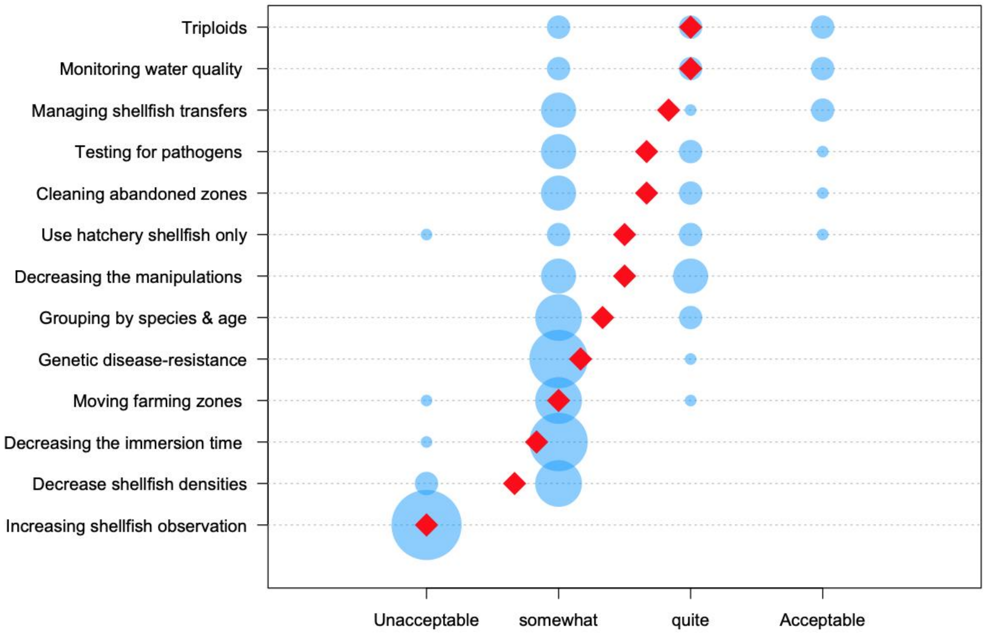

Figure A7.20. Perceived acceptability of the preventive measures, Northern Ireland

Overall, the acceptability of the procedures appeared was relatively low, with the use of triploids and water quality monitoring as the most acceptable. Increasing shellfish observation did not appear to be acceptable, which perhaps links with the ranked effectiveness of this procedure relative to the cost. There appeared to be a some correlation between the costs of the procedure to its acceptability. Those procedures that appeared to be most acceptable were those that were being conducted normally such as managing shellfish transfers.

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Summary

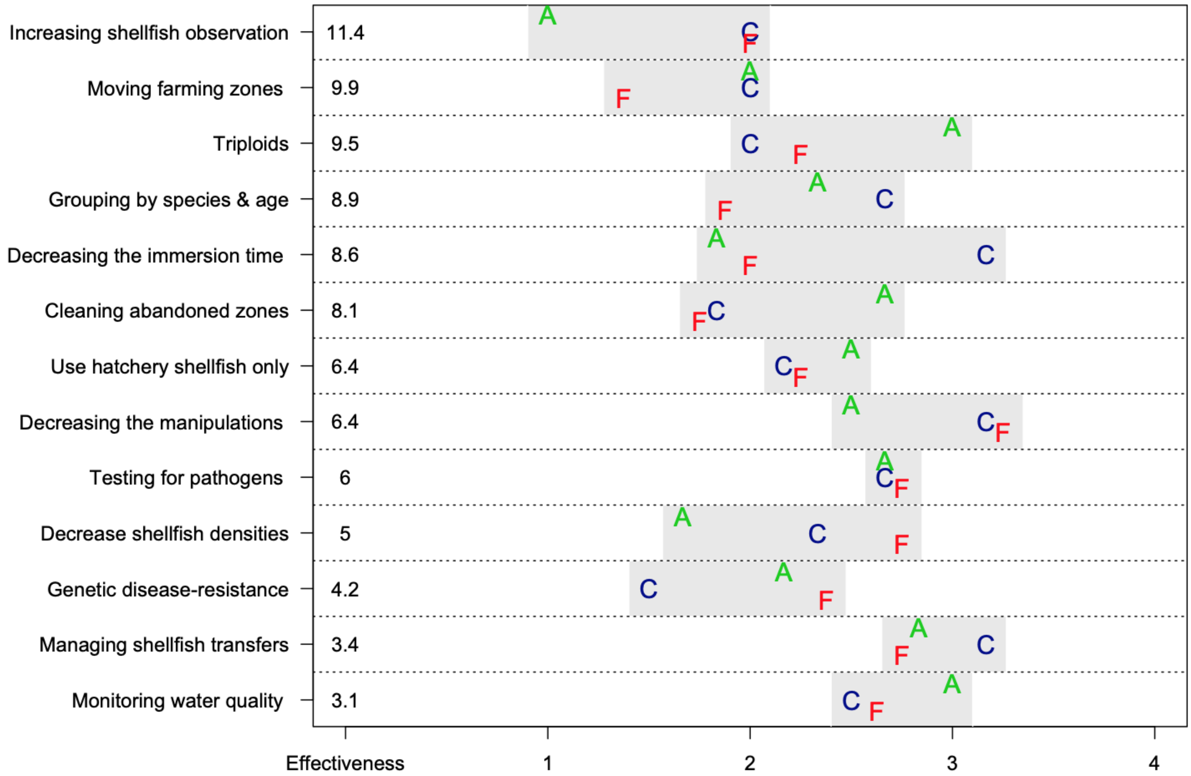

Figure A7.21. Summary of the perception of the preventive measures, Northern Ireland

The focus group was dominated by regulators and researchers compared to shellfish farmers which may have influenced the outcomes. It appeared there was a reluctance to introduce new procedures or methods due to the cost to the industry. Cleaning abandoned farming zones was not feasible in Northern Ireland as there are currently none available and moving farming zones was not feasible due to license requirements. It was deemed that using only hatchery produced shellfish was too costly and especially for mussels.

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