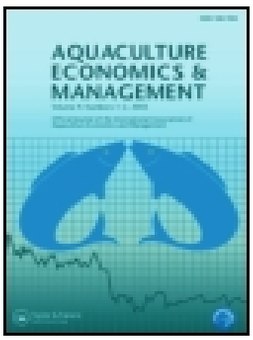

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Fish farmers and regulators coping with the wickedness of aquaculture

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ABSTRACT

Managing and regulating aquaculture is a complicated issue. From the perspective of fish farmers as well as regulators managing aquaculture can be regarded as what political scientists refer to as a "wicked problem." This is because there is a great extent of uncertainty and lack of firm knowledge with respect to the externalities of aquaculture production; e.g., diseases, environmental impacts, and conflicts with other user interests. Furthermore, the dynamic nature of the aquaculture sector contributes to the uncertainty as new solutions emerge, rendering established knowledge obsolete or irrelevant. Designing appropriate public regulations and policy measures is thus important, but difficult. Based on empirical data from Norway, we investigate what respondents from public agencies and the industry perceive to be challenges in governing aquaculture and what we may infer on the characteristics of a good governance approach. We propose that such an approach needs to focus on building competence, collaboration, and be adaptable. Furthermore, it needs to be flexible and cost efficient.

KEYWORDS

Aquaculture; externalities; fish farmers; governance model; regulators; wicked problems

Introduction

Salmon farming is one of the most successful aquaculture industries in terms of production growth and technology development (Smith et al., 2010; Kumar and Engle, 2016). However, aquaculture sectors, including salmon farming, are growing at very different rates worldwide. There are several underlying causes of growth or stagnation across species and countries. Technological innovations, diseases, prices of production factors, fish market prices and market access are important determinants of profitability and growth (Anderson, 2002; Asche, 2008; Bostock et al., 2010; Guttormsen, Myrland, & Tveteras, 2011; Kobayashi et al., 2015; Kumar & Engle, 2016).

Aquaculture sectors also rely heavily on the aquatic environment, and their production activities may have significant effects on the aquatic environment and other user interests or stakeholders; (Asche, Guttormsen, & Tveteras,

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1999; Asche et al., 2009b; Tacon & Metian, 2008; Abate, Nielsen, & Tveteras, 2016). Hence, aquaculture is a natural candidate for government policy interventions and regulations. It also follows from this that public governance of the aquaculture sectors may have significant effects on their economic returns and growth. With poor management and governance structure, the industry will not be able to grow and may even move (Chu, Anderson, Asche, & Tudur, 2010; Chu & Tudur, 2014; Knapp & Rubino, 2016).

A fundamental challenge in many aquaculture sectors is the lack of knowledge on relationships between aquaculture production activities and effects on the aquatic environment and other user interests that all stakeholders can agree on (Pettersen, Osmundsen, Aunsmo, Mardones, & Rich, 2015), including substantial differences within the aquaculture industry due to different firm structures and size (Asche, Roll, Sandvold, Sørvig, & Zhang, 2013). The body of research-based knowledge may be incomplete, contradictory, or difficult to interpret. The dynamic nature of many aquaculture sectors contributes to the uncertainty. Frequent innovations in key production technologies, changes in the scale of farms, the localization of farms, and total production in sectors cause some knowledge to become less relevant or obsolete, and creates the need for production of new research-based knowledge.

A consequence of uncertain knowledge is that some stakeholders may interpret the research-based knowledge as providing support for further growth in production, while others may interpret it as providing support for contraction of production or at least limits to growth. Furthermore, the uncertain knowledge leads to different conclusions about appropriate policies and regulations among different stakeholders, and across time. For instance, regulations and restrictions aiming for control of disease, parasites, and escapees are abundant in the legal framework of salmon aquaculture. New and increasingly detailed regulations attempt to mitigate these problems, but amount to a regulatory framework that is intricate and fragmented.[1] The result is a complex web of regulations and laws between a multitude of governmental agencies and levels of jurisdiction. In both Scotland and Norway, researchers have described the legal framework as fragmented and layered with different strands of regulation developing separately, for different reasons, and at different times (Liu, Olaussen, & Skonhoft, 2011; Liu, Chuenpagdee, & Sumaila, 2013; Alexander et al., 2015; Solås et al., 2015).

Uncertainty and lack of knowledge, dynamic challenges, lack of consensus with respect to interpretations and solutions, and problems that persist and rarely have a final solution are fitting descriptions for what has earlier been termed wicked problems (Rittel & Webber, 1973).[2] In this article, we discuss why managing and governing the aquaculture industry should be described as a wicked problem, or as an area of governance characterized by such problems. We do this by investigating the specific characteristics of the aquaculture industry, and suggest possible features of a good governance

approach. In interviews, both managers of fish farms and regulators in governmental agencies describe how managing and governing the aquaculture sector is about trying to handle problems which are unpredictable, elusive, and volatile. However, rather than being paralyzed, our respondents pursue different coping strategies that are relevant for managing such wicked problems, and we report on these and discuss features of a good governance approach to aquaculture production.

The objective of this article is to investigate the wickedness of aquaculture and show how fish farmers and authorities attempt to cope with this seemingly slippery problem area. The research questions are therefore: *What is wicked about aquaculture, and which coping strategies do central stakeholders apply?* And finally, *what is a good governance approach for aquaculture?*

Externalities of aquaculture production

Externalities are the effects of a firm's production on other firms, households, or other agents that are not fully internalized in the economic decision making of the firm because it does not have to cover the economic losses to others associated with the externality. These costs can be in the form of lost sales or increased unit costs for other firms, increased health costs for households, etc. Fish disease is an example of an externality in aquaculture. If a disease outbreak is caused by the production processes at a farm, the outbreak is an externality if other farms or industries (like wild salmon) or parts of the ecosystem (Naylor et al., 2000) are affected by the disease outbreak and the farm does not have to cover the other farms' economic losses (Asche et al., 1999; Asche, Roll, & Tveteras, 2009; Asche et al., 2016b).[3] Figure 1 shows different types of externalities from a farm to other farms in the sector, and to other sectors and users.

Externalities to other sectors and users can come in several forms, as suggested by Figure 1. Examples are organic emissions that pollute waters

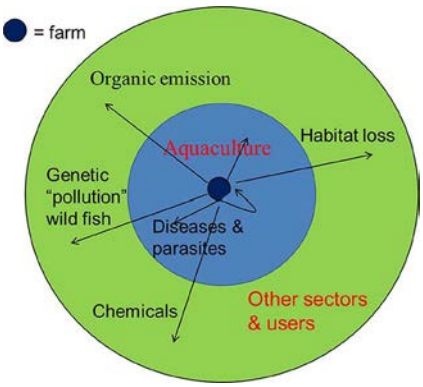

Figure 1. Externalities from aquaculture.

and change the nutrient balance, habitat loss (e.g., mangrove habitat), emission of toxic chemicals used to combat disease, escape of farmed fish that "pollute" the genetic pool of wild fish stocks, etc.

In aquaculture, externalities influence productivity and production (1) directly through diseases and other externalities that cause increased mortality or lower growth rates and (2) indirectly through public regulations and other policy measures motivated by externalities. In theory, externalities provide a rationale for the government to introduce regulations or taxes to mitigate the externalities. However, in practice, designing appropriate measures is difficult for governments due to insufficient information about the mechanisms and magnitudes of the externalities. Public measures to mitigate externalities can often fail because the effects of the measures are too small or too large, or because the measures have unintended effects.

Atlantic salmon farming is an example of a farmed species in which similar production technology is used across countries, but the government measures designed to mitigate externalities differ significantly (Gibbs, 2009). The policy measures implemented in the main salmon producer countries have also been motivated by other policy objectives, which again have been influenced by the political power of different stakeholders. Policy measures aimed to mitigate externalities, or the absence thereof, have had significant effects on the development of production in salmon producer countries. For the United Kingdom (UK), Canada, and the United States (US), strict regulations have led to lower environmentally sustainable growth than could have been possible. In the more liberally regulated Chilean sector, the absence of proper regulations has led to a disease-driven decline in production since 2008 that could have been avoided (Asche, Hansen, Tveteras, & Tveteras, 2009).

Designing good governance for wicked problems

Aquaculture producers interact more with their surroundings than is the case for other industries, through possible disease externalities, their environmental impacts, and use of areas that have effects on other user interests in the coastal zone. Moreover, in many cases it is not in the economic self-interest of aquaculture companies to mitigate negative impacts of their production activities. The external impacts of aquaculture imply that there is an important role for governance in general, and for government regulation in particular. To enable sustained and sustainable growth of an aquaculture industry it is necessary to have the right governance mix, where public regulations have to play a central role. If regulation is too heavy, the industry will never develop or will stagnate at small volumes, as is the case for instance for salmon aquaculture in the United States and Ireland. If regulation is too light then the industry may eventually after a period of rapid growth develop an unsustainable structure or practices that cause it to crash, as in the case of

Chilean salmon farming or Chinese turbot farming. There are also a number of countries that have experienced such bubbles in shrimp farming, and even a few countries where disease almost bankrupted the industry, but where it has been able to recover following improvements in governance.

Salmon aquaculture is, therefore, a good example of how governance and regulation can influence industry growth. Figure 2 shows the development of Atlantic salmon production in the five leading countries from 2005 to 2015. Although there are differences in the biophysical conditions across these countries, it can be argued that the widely different growth paths can be explained to a high degree by governance and regulatory regimes. All the countries have, at the central government level, increased domestic aquaculture production as policy objectives. Norway's production has increased by 115% during the period, while production has not expanded at the same rate in Chile (53%), UK (38%), and Canada (25%) for different reasons. This contributed to an increase in the Norwegian share of global production from 46% in 2005 to 53% in 2015. In Chile, a liberal "industry-friendly" regulatory regime accommodated rapid growth in the early period, and was considered a model by some salmon firms and stakeholders. But it failed to establish the necessary safeguards against diseases as the industry approached production levels and production densities that created a higher disease pressure (Asche et al., 2009a).

Hence, it turned out that the regulations were not industry-friendly after all as they were not able to adapt as the industry expanded and external effects from salmon farms increased. In the UK, Canada and to an even greater extent in the United States, regulations have been much influenced by stakeholders that are critical to the salmon industry or want production curtailed or even abolished. The United States, with a fairly long coastline suited for salmon farming, has given priority to wild salmon stocks over farmed salmon

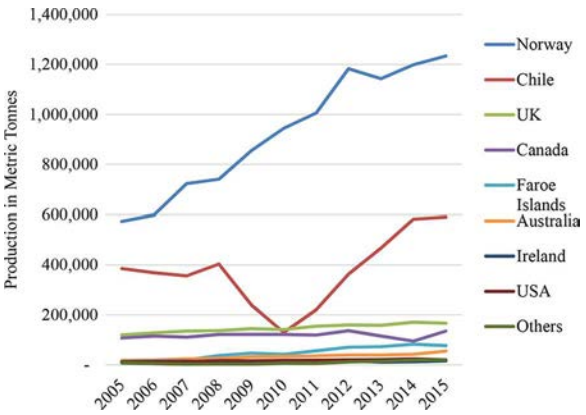

Figure 2. Atlantic salmon – an example of the influence of government policies? (*Source*: Kontali).

to an extent which has significantly limited the geographic scope and scale of salmon farming. In Canada concerns about First Nations (or indigenous peoples) rights and legislation have influenced the localization and scale of salmon farming. There is evidence that regulations have failed on several of the above-mentioned criteria in Canada, the UK and United States, most notably on collaboration and cost efficiency. The consequence of this is that the salmon industry in these countries did not achieve higher sustainable production levels, and is also less competitive and profitable, than would have been possible.

In theory, a government, which maximizes social welfare, will design policy measures and regulations for a sector that account for producer and consumer surplus, including costs and benefits related to externalities from the sector. Externalities may be both negative (e.g., environmental emissions, diseases, and parasites) and positive (e.g., agglomeration economies), but are in both cases effects from aquaculture production activities that are not fully internalized in the economic decision-making of aquaculture companies (Asche, 2009b; Asche et al., 2016). The challenge for the government has been that the uncertain knowledge about externalities means that the estimation of costs and benefits associated with externalities is difficult and provides poor guidelines for the design of appropriate regulations that will maximize social welfare. Furthermore, uncertain knowledge opens up political bargaining processes involving different stakeholders.

The concept of "wicked problems" illuminates the difficulties involved in creating an appropriate regulatory system for aquaculture. The problem is non-linear, volatile, and information is never complete. Moreover, all involved agents have to consider externalities with great uncertainties. As Rittel and Webber (1973) pointed out, wicked problems are difficult to define and delineate from other problems; there is rarely consensus as to their interpretation and solutions, and they persist and rarely have a final solution. Problem perception and definition are often social as opposed to individual constructs (Kooiman, 2003). As social problems, they are often interpreted in political and moral terms. People disagree on what the problems are, their causes, and how to solve them, and they may utilize the uncertainty for political purposes.

To describe a wicked problem thus entails acknowledging how different stakeholders (i.e., politicians, bureaucrats, NGOs and industry) have competing perspectives of what the problem is, that there are ambiguities and disagreements as to the cause of the problem, and measures may not have the intended effect. Earlier, Bavinck, Chuenpagdee, Jentoft, and Kooiman (2013), Jentoft (2007), and Jentoft and Chuenpagdee (2009) have argued that fisheries and coastal management attempt to govern what is called "wicked problems." Furthermore, Berkes (2012) holds that ecosystem-based management in fisheries should be seen as a wicked problem.

These contributions describe the wickedness of aquaculture implicitly, as an equivalent to fisheries. Few of these contributions describe the wickedness of aquaculture explicitly, with Liu et al. (2013) as a noteworthy exception. When discussing aquaculture as a governance and management problem it is necessary to take into consideration the specific characteristics of the industry as a highly industrialized, intensive, and sophisticated production, because these characteristics distinguish the industry from other activities in the coastal zone, be it tourism or fisheries (Pullin, 2013).

One may say that there is a mismatch between problem structure and organizational structure in aquaculture. It is therefore useful to distinguish between characteristics of the system to be governed (aquaculture production) and the governing system (aquaculture administration) (Jentoft, 2007) and to include the interaction between these systems, as it is the alignment or appropriate fit between these two systems that is the objective of this article.

The system-to-be-governed is primarily a biological production system situated in close interaction with a wild environment. The live product determines the pace of the production process, and as Størkersen (2012) has earlier shown, fish farmers heed the safety and welfare of the fish above other considerations, as this is fundamental in preventing illness, death, escape, or environmental damages. In many cases, this fact puts temporal constraints on decisions.

The governing system involves (in a Norwegian context, but also elsewhere) several administrative agencies and is based on a two-level system. In Norway, the Directorate of Fisheries is given the mandate to award licenses for aquaculture production. New licenses have been announced five times since 2002. After receiving a license, the producer needs to find a suitable place for production, and it is the municipal level that has the main role in planning and designating sites for aquaculture production. However, sites need to be approved and its carrying capacity set by the regional level (Food Safety Authorities, Directorate of Fisheries, the County Governor (environmental authority) and the counties). These agencies also administer and uphold regional and national laws and control the aquaculture production in their region. At the national level, directorates and ministries are responsible for overseeing their regional offices and for policy development. At all these levels, the governing system is concerned with the entanglement and at times conflicting priorities of environmental and business concerns. In this article, we limit ourselves to the local and regional levels.

The governing system and the system-to-be-governed affect each other. The governing system determines the framework conditions of production, while occurrences such as escapees, prevalence of lice, diseases, and impacts on the environment have repercussions for existent regulations and laws. The interaction between these two systems is in part also mediated by research, in so far as regulations are adjusted according to new findings in our understanding of the system-to-be-governed.

Materials and methods

The primary data for this study is a series of in-depth interviews with key stakeholders across the industry and authorities. Interviews were conducted in three consecutive research projects. The scope of these projects has been the governability of aquaculture production as viewed from the perspective of fish farmers or authorities. The data underlying this study includes 53 interviews, each lasting approximately 1.5–2 hours. These are interviews with 25 aquaculture companies – 22 fish farms and 3 service companies (veterinaries), and interviews with 28 public authorities (Food Safety Authorities, Directorate of Fisheries, County Governor (Climate and Environmental Department), Counties and Municipalities). Most interviews were conducted in Mid-Norway, but also fish farmers and public authorities in Nordland, Lofoten and the Western part of Norway were interviewed. Interviews were recorded, transcribed and anonymized. Key categories were discerned by the authors and colleagues, and analyzed in relation to decision-making challenges in fish farming. These categories are presented below from both the perspective of fish farmers and from the public authorities. Preliminary results have on different occasions been discussed and validated with industry representatives and regulators. This has been done through presentations and in workshops.

Results

Describing wickedness

The wickedness of aquaculture was described by the respondents in terms of the challenges they perceived in production (the system to be governed), and in relation to governmental agencies and the wider society (the governing system). Even though the aquaculture industry and the research community have built much knowledge over the years, there is still much which is unknown in fish farming. This is due to the biological system one is attempting to manage and industrialize, and its inherent variability, and because fish farming is set in an open environment, where influences across distances and between aquatic organisms and farmed fish cause unexpected outcomes and consequences. As one of the respondents states: "*I hope the level of knowledge increases in the next 10 years, we need more facts on the interconnectedness of things. We need more factual knowledge on lice, and not only applying a precautionary principle.*" (Veterinary, Fish farm 14).

Disease control is a central issue in production. Diseases were described by the fish farmers interviewed as hard to detect, prevent, plan for, and often had unexpected outcomes. The first signs of a potential disease can be fairly minor; perhaps some of the fish are eating less than usual; there are a few more deaths than average; or, some of the fish show a behavior that is abnormal (swimming patterns, location in the pen, surfacing for air, etc.).

An average net pen has approximately 200,000 fish, and direct inspection is difficult. It is therefore difficult for the fish farmer to have exact knowledge of what is happening, even though suspicion is aroused due to small abnormalities or uncertain warning signals (See Brizon and Wybo (2009) for a discussion of "weak signals"). As one respondent states, "*It is difficult to observe what happens under the surface and it takes time to understand what is going on*" (Veterinary, Fish farm 15).

Moreover, to understand how diseases are spread between farms and across long distances is difficult. One respondent illustrates the complexity and unpredictability of diseases, and explains: *"I have no idea why we haven't got infectious salmon anemia (ISA). The neighbors had it for over a year, and they are 2.5 km away. It is mere chance, pure luck; perhaps we have good fish that are resilient, good localities, even though we have been exposed to disease carriers … "* (Manager, Fish Farm 1). During the interviews, our respondents referred to an array of explanatory factors for disease outbreaks, ranging from net cleaners, well boats, passing wild fish, quality of hatchery fish, nearby farms, and currents. They had many theories, ideas, and suggestions for explaining the causes of diseases and how to combat them, but they also emphasized that there are few certainties. As one explains: "*Even though we try to run many tests, use the best vaccines, vaccinate all the fish from day one, follow the recommendations from the vaccine supplier, observe the fish closely, ensure that the fish are smoltified, and that they are strong, resilient, and healthy before being put into the pen, sometimes they get sick and at other times they don't."* (Manager, Fish farm 21).

We see that the fish farmers describe a decision-making context fraught with uncertainty and uncontrollable externalities. Moreover, the farmers must consider not only the production and their fish at the farm, but also wider society and the media: "*Fish health and well-being of the animal is one consideration. But in practice, you have to consider what the media and the authorities deem important. Like now, it is the louse that is important, so we have to disregard earlier requirements for not handling the fish from when they are put into the pen to slaughtering. Now the fish have to go into the well boat and be treated with hydrogen-peroxide, and perhaps even be flushed with fresh water. This means that the strategy we applied to avoid diseases 3–4 years ago is no longer usable because the focus is on the lice."* (Manager, Fish farm 5). This was also confirmed by one of the regulators: "*An optimal environment is the safest way to avoid disease. Stress causes disease. Delousing on low occurrences of lice also causes stress, especially if you use hydrogen peroxide and need to delouse in a well boat. We have received comments from the veterinary inspector that this is not justifiable for animal health. But society has made some conditions here … The media and society in general do not have professional insight into this … but there is no room for discussion. You do not get your message across and few dare to try."* (Public Agency 9).

The wickedness of aquaculture is also reflected in the governing system. Respondents from both industry and public agencies describe the Norwegian aquaculture administration as world leading, but also acknowledge its limitations and faults. Our respondents from the public agencies experience challenges with a complex governing system, distributed and fragmented responsibilities between agencies, detailed legal framework, lack of competence, and limited resources. Their responsibilities are at times competing and incommensurable. In particular, when there are disagreements and ambiguities as to root causes, and possible consequences and intended effects. As one of the respondent states: "*We don't agree professionally, it's that simple. We are more concerned for the wild salmon than they are. It is that simple.*" (Public agency 7).

Both the legal framework and the public administrative system are seen to be under constant pressure to adapt to new knowledge and understandings, and to technological advancements of the industry. One of the respondents explains: "*It is a very complex industry – [] an industry which has developed over a long time and which has been regulated from both the seafood perspective, from the perspective of fish health and welfare, and from production regulations. [] The sum of the different professional and political considerations is a framework that is complex. When you find areas that are unclear you try to remedy this by an increasingly more detailed framework, and finally there is a danger that there is no clear thought on the distribution of either roles or responsibilities*." (Public agency 5). A similar example was brought forward by one of the respondents describing the manner of establishing zones for controlling diseases as one of creating layers upon layers of restrictions on logistics and production. Fish farmers who are caught in several of these overlapping zones have a very difficult challenge of sorting out production and transport.

One of the consequences is overlap between the different agencies and their responsibilities. Closely related areas of expertise may cause confusion or competition between agencies, and examples discussed by the respondents were the matter of lice and escapees, and how this could be interpreted as the responsibility of both the environmental authorities in addition to the Directorate of Fisheries, or use of medication, a concern relevant for both the Food Safety Authority as well as the environmental authorities. Another consequence is inconsistencies in case handling between the same agencies in different geographical areas. Several of the agencies were suspected of lacking a uniform approach to case handling causing disparate decisions on seemingly similar cases across regions. Some saw this as a sign of flexibility and quality because they were heeding local conditions.

However, by most it was seen as demonstrating an administration incapable of upholding a uniform level of competence and allowing local case handlers too much discretion. A third consequence is an inability to improve

the governing system towards a more strategic mode. As explained by one of the respondents: "*The challenge is that there are intentions and ambitions that all agree on, but you are not able to fulfil them because you are not coordinated. To be more specific, all the agencies say that it is favorable to have larger and fewer localities, and to have zones for [coordinated smolt releases and thereby] the start of the production cycle, slaughtering and fallowing. [] But, in the process, we see that to achieve what all agree on as important, each agency is looking at its own agenda. The Food Safety Authority is looking at fish health, the County Governor at discharge … And then everything becomes difficult. Because there is always someone who says no. The result is that one does not achieve what everyone agrees is what you should achieve.*" (Manager, Business Federation).

Coping with wickedness

The uncertainty in both the biological and regulatory system, and the institutional complexity, make aquaculture hard to manage and govern. Being keenly aware of the limitations of governability, fish farmers and regulators pursue different coping strategies.

Fish farmers report that they rely on experiential knowledge, informal coordination, and pragmatic problem solving. Authorities attempt to create cross-sectorial networks allowing for information sharing and mutual adjustments in case handling. Both fish farmers and regulators describe how the interaction with each other is fundamental in maintaining updated knowledge especially considering externalities, and in shaping regulations to fit with the realities of aquaculture production.

Fish farmers referred to a strong reliance on experience as the most important tool in handling what they perceived to be an area of changing certainties, unforeseen consequences, and moving goals. One put it clearly: "*My decision support tool is experience, and that is the most important one*" (Manager, Fish Farm 9). Another respondent explains further: "*The problem is that when things [i.e., diseases] occur for the first time, you have to deal with it, even though you have no knowledge of how. So you need to deal with it even though you do not know what you are doing.*" (Veterinary, Fish farm 6).

Although experience and intuition can be useful tools, others claimed there were too many hypotheses and myths in the industry. As one said, "*We need to get better at separating facts from fiction*." (Veterinary, Fish Farm 13). Respondents described how they were involved in research projects, and that they were following research news with a keen interest. However, some also said they could find it hard to apply research results, because they were abstract and not always adaptable to the specific situation at hand or the means available at the farm. Fish farmers report a need to find actionable knowledge, knowledge they are able to put to use when the situation occurs.

In addition to their own experience, the fish farmers relied heavily on the competence of local veterinaries and other fish farmers. And while some decisions could be taken only with consideration of the individual farm, the need to align your own production with those in the vicinity was acknowledged. As one said: "*Because [fish farmers] are neighbors, and affect each other, it is very important to have both formal and informal arenas for dialogue.*" (Manager, Fish Farm 5). Fish farmers describe widespread informal networks within the industry, and a strong culture of sharing information and discussing solutions as important for their ability to cope with the uncertainties faced in production. Increasingly, especially due to lice problems, but also because of the spread of diseases, such as pancreas disease, formal coordination between farmers in an area is viewed as a necessary management strategy.

Several schemes for cooperation have been established by the industry in various areas, especially for coordinated lice treatments, screening for pancreas disease, registering lice numbers, and coordinated use of transport. The extensive collaboration between farms can partly be explained by a history of common interest in the industry when it comes to avoiding disease (and other problems such as lice and escapees), both due to the possible spill-over effects from the disease itself, and to the effects that a poorer reputation of fish farming may have on regulation etc.[4] Several of these methods have over time been adopted by the authorities, and in some cases also been made into legal regulations (i.e., the SAV2 regulation in Nord-Trøndelag).

Many of those interviewed also engage with the authorities on developing and improving regulations. Recent examples include regulations on counting lice and thresholds for lice treatments, on spreading patterns of the SAV2 virus, and rules on the handling of dead fish. The fish farmers view rules, regulations, and specific geographical legal constructs as important themes to engage in and attempt to influence.

The regulators describe how they attempt to compensate for the limitations in the governance system by formal and informal coordination between the various agencies, and with the industry.

Formally, this was done through meetings on specific topics, such as preconferences on difficult cases, and through phone calls providing information to other agencies, i.e., notifying in advance of a case that was coming in. Informally, case workers would meet on social occasions in relation to conferences and other meetings. In an administrative region, the total number of caseworkers dealing with aquaculture is less than ten, so most will know each other. They reduced the lead-time in case handling by notifying each other so they could work in parallel, and they would indicate potentially difficult aspects so that other agencies could get a head start in solving the issues. In some regions, they used temporary location permits to allow the industry to try out a location and document the potential negative/positive consequences on the environment. This was done to compensate for the lack of certainty

especially in regards to environmental issues, which could be a subject of disagreement between the agencies. If the company could show positive environmental reports during a time period, the permit could be made permanent.

The regulators recognized the need to apply a more comprehensive approach to governing the industry, and expressed a desire to move away from a case-by-case approach. It was also recognized as necessary to apply a broader geographical approach and to view individual applications in the same area concomitantly. However, this was dependent on caseworkers having knowledge of which applications were underway and the plans of individual companies. According to the legal framework, the processing of applications is based on single case handling, but this was remedied through information sharing between the industry and governmental agencies.

Another coping strategy was to ensure that case workers and their leaders were updated on developments in the industry and knowledgeable. Many of the regulators would therefore participate in venues where they could find information about the latest developments in the industry, and they would also arrange or participate in seminars on specific topics related either to changes in the legal framework or the industry. Several of the regulators, especially those in a managerial position, had an extensive network in the industry, with NGOs, and other public agencies, and were conscious of always being present with these to learn of new developments.

All of these strategies can be seen as a way of coping with the uncertainties of aquaculture and the limitations of the governing system. However, several respondents expressed a desire to move towards a more proactive than a reactive governance approach. As stated by one of the respondents, "*Currently we are just running to put out fires*" (Public Agency 5).

Discussion

As seen previously, respondents perceive managing and governing aquaculture as difficult because of a decision-making context fraught with uncertainty and hard-to-manage externalities. Fish farmers attempt to cope by accumulating knowledge and experience from others and through interaction with both the research community and public authorities. Regulators acknowledge that governing the industry straddles regulatory boundaries, as the uncertainty and the extent of externalities are pertinent to all of the public agencies involved in the regulation of the industry. Thus, one gets glitches and overlaps in terms of responsibility and authority between these agencies. The regulatory system may further be described as fragmented and based on a legal framework that has been developed layer by layer across time, and where inconsistencies across geographical areas and lack of understanding of aquaculture production are sometimes apparent.

Both fish farmers and regulators acknowledge that also the wider society and the media have influences on the governability. Problem perception (i.e., lice) thus becomes a social construct interpreted in political and moral terms, moving definitions away from a purely scientific understanding. The extent of uncertainty leaves room for political maneuvering, and both the scientific debate and discussions on how to manage and govern the industry become politicized. This is also because the debate about aquaculture production and its environmental consequences is a value-laden discussion. Hence, although more knowledge and certainty should be aimed for, the complexity of the system to be governed and the value conflicts involved also demonstrates the limits of knowledge in resolving such issues (Olsen, Holen, Hoel, Buhl-Mortensen, & Røttingen, 2016). Based on the results presented here, what implications may be elicited for opportunities to improve governance systems in aquaculture?

Earlier contributions discussing governance approaches to wicked problems highlight the hierarchical and fragmented administrative system in public policy development and delivery (Jennings & Ewalt, 1998; Powell, 1990), and a call for cross-sectorial collaboration as a means to handle the limits in governability has been made (Bavinck et al., 2013; Jentoft, 2007; Jentoft & Chuenpagdee, 2009). As Mahon, McConney, and Roy (2008) argue, there is a need for a flexible and adaptive approach to governance as opposed to one that emphasizes control and stability. Liu et al. (2013) argue that there are possibilities for improvement to be found in both integrated coastal management at the local and national level, and that international standards and guidelines must be further developed. Jentoft and Chuenpagdee (2013) point out that governance should rather be about political brokerage, than exercising authority from the top down. Roe (2013), rather than using the term "wicked problems," discusses "policy messes," and argues that they need to be managed. They cannot be avoided or cleaned up once and for all. This also goes for aquaculture. Although much can be improved in terms of structure, the uncertainty and complexities will persist, and they will need to be managed.

Building on these contributions and the empirical data in this article, we suggest that central elements in successful governance of aquaculture can be summarized as in Table 1.

Table 1. Central elements in successful governance.

Elements	Main areas of concern
Competence	All areas: Competitiveness, sustainability, growth
Collaboration	Sustainability and risk management
Adaptability	Accommodate evolution in industry size, structure and technology over time
Flexibility	Accommodate immediate or short-term challenges or crises (diseases, trade barriers, food safety)
Cost efficiency	International competitiveness, also with respect to land-based animals

These elements are (1) *competence*, (2) *collaboration*, (3) *adaptability*, (4) *flexibility* and (5) *cost efficiency*. As indicated in Table 1 they address somewhat different areas of concern. *Competence* is required both on the government side, in the various ministries and agencies that are involved in the design and implementation of regulations, and in the industry itself. For government, it is necessary to have a proper understanding of the state-of-the-art research on the various biological, veterinary, environmental, food safety and market issues that should influence regulations. If there is not sufficient competence in government, then regulations may be too strict or too lax, often depending on which stakeholder groups are able to exert most influence in the political processes that determine the regulatory outcome.

For fish farmers, competence, both gained through experience and interaction with others, such as veterinaries, other fish farmers and authorities, is central to handling externalities. However, abstract scientific knowledge needs to be made actionable and adapted to the specific situation at hand. This is often done through collaboration with others. *Collaboration* between the government, the aquaculture industry, and other stakeholders is necessary to utilize the total knowledge of all parties and balance legitimate competing interests, and improve overall governance. The empirical data in this paper illustrates that collaboration is an important source for actionable knowledge, and this is in line with earlier research (Cross, Rice, & Parker, 2001), which shows that task interdependence, here described as externalities, is the strongest and most consistent predictor of information seeking.

Collaboration can also be viewed as a risk management tool, as a continuous dialogue with all important stakeholders may reduce the risk of effective hostile campaigns against the industry by disenfranchised parties. *Adaptability* of the regulatory regime is required as the industry grows, industry structure changes, and technology evolves, because regulations that were appropriate for, e.g., a small-scale, low-tech industry serving local markets will generally not be so for large-scale, industrialized aquaculture serving international markets. *Flexibility* is desirable as unforeseen rapidly developing events – for example new diseases, trade barriers, and food safety issues – create new challenges that cannot be accommodated sufficiently by existing regulations. Because aquaculture industries generally operate in highly competitive markets, it is necessary to have regulations that are *cost efficient* in two dimensions: (a) they allow the industry to exploit economies of scale at different levels and use the most efficient mix of inputs to minimize production costs, given due considerations to environmental externalities, etc., and (b) they do not create high costs in monitoring and enforcement of regulations for government agencies and the industry.

There are trade-offs and dilemmas related to the elements of successful governance which we have described above. For example, farmers would require urgent actions following unexpected events (e.g., a new disease type

or type of conflict with other user interest) for which current policies or regulations are inefficient or have not been sufficiently addressed, and which significantly affect their profitability and competitiveness. On the other hand, they would also like to have predictable regulations and equal treatment across geographic areas and production systems. Such dilemmas are a consequence of the wickedness of aquaculture as we have defined it here, and will persist as long as the sector is characterized by sufficient lack of knowledge, dynamic challenges and lack of consensus.

The dynamic nature of aquaculture, due to innovations, growth, and emerging diseases, biological and environmental challenges, means that governments need to change policies and regulations at frequent time intervals. However, the scientific knowledge base that government relies on is often not able to keep up with developments in the aquaculture sector. Science does not provide sufficiently clear guidelines or implications for government. This affects the speed of change in government regulations, and the appropriateness of regulations in terms of increasing welfare. The perceived inadequacies of government policies lead to private initiatives to substitute for this. Such initiatives can have a local, national, or international scope.

Because farmed fish is often exported, private initiatives may cover the value chain from producer countries to final buyers in import markets. Professional buyers and consumers in OECD markets tend to be concerned about the sustainability and environmental effects of aquaculture, and this has contributed to the emergence of third party certification of aquaculture production activities through e.g., the *Aquaculture Stewardship Council* (ASC) and *Best Aquaculture Practices* (BAP).[5] The development of ASC and BAP standards is a result of dialogues between several types of stakeholders – representatives of the aquaculture industry, professional buyers, NGOs, and research institutions. Government representatives are absent from these organizations. These third-party certification organizations and their standards can partly be seen as a response to the challenge of finding a common knowledge base and consensus on the effects of aquaculture production activities, and the inability of governments to develop policies and regulations that satisfy important stakeholders. For aquaculture producers, such standards facilitate access to demanding buyers, but they may also provide a higher price (Roheim, Sudhakaran, & Durham, 2012; Uchida, Onozaka, Morita, & Managi, 2014; Asche, Larsen, Smith, & Young, 2015).

Conclusions

The global aquaculture industry is on the one hand expected by policymakers and societies to increase production and employment, but on the other hand is receiving increased scrutiny due to its real or perceived negative impacts on the natural environment and other user interests. A consequence of the latter

is that many, and particularly developed countries, have become less willing to issue public licenses and develop regulatory regimes that allow the aquaculture sector to increase its production. It is fair to say that relative to its economic value added, aquaculture sectors are the subject of a much larger and critical debate than most other sectors in some countries.

A central problem for policymakers and regulators is the lack of firm knowledge on relationships between aquaculture production and effects on the aquatic environment and other user interests that stakeholders participating in the public dialogue can agree on. This leads to the description of managing and regulating aquaculture as a "wicked" problem in this article. We have presented an analysis of salmon aquaculture, a sector that is at the forefront of the challenges that global aquaculture faces as it grows and becomes increasingly dependent on a license from society to grow further. The analysis of qualitative interviews with respondents from the salmon sector, public authorities, and others shows a lack in the knowledge base, differences in understanding the relationships between production activities and the effects on fish health and the aquatic environment, and the implications for regulatory measures and future production growth.

The world will, in the future, demand more of the nutritious food that aquaculture can provide. For farmed salmon in particular, we observe increasing market prices, well above those that provide normal risk-adjusted returns to capital, signaling that the sector is not able to keep up with demand growth and increase its production at rates that would still provide competitive economic returns to capital owners. There may be several underlying causes for this, but restrictions from society on salmon aquaculture growth are certainly a key factor.

We argue that there are several elements that must be included in successful governance of a growing and innovative sector with changing external effects, such as the aquaculture sector. These elements can be summarized as (1) *competence*, (2) *collaboration*, (3) *adaptability*, (4) *flexibility*, and (5) *cost efficiency*. We have discussed these in the paper, and concluded that a relative absence of one or more of these governance elements will contribute to stagnation and an increased level of conflict between stakeholders.

The "wickedness problem" in aquaculture can never disappear entirely. To mitigate the problem and facilitate sustainable growth requires a mix of measures and investments from policymakers, public sector, and the aquaculture sector itself. This includes investments in research-based knowledge production on relationships between aquaculture production activities and external effects, transmission of new knowledge to government, aquaculture producers, and other relevant stakeholders, and documentation of environmental conditions and effects in the aquatic environment. The public sector's economic resources, organization, and talent attractiveness related to management and regulation of aquaculture is a critical factor. However, for an

aquaculture sector that is developing rapidly in several dimensions, policy-makers and public budgets may inherently lag behind. This implies that it may be rational for the industry itself to invest in new knowledge production and documentation to provide an improved knowledge base for dialogue between stakeholders and public regulations.

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Notes

1. Although there have been a number of studies investigating the two most common sources of economic uncertainty, production uncertainty (Tveteras, 1999) and price uncertainty (Oglend, 2013; Dahl & Oglend, 2014) and price uncertainty can now be handled at organized markets (Asche et al., 2016), there has been limited focus on other sources of uncertainty such as regulatory uncertainty.
2. In a recent book, Roe (2013) uses the term policy messes to address such problems, interestingly suggesting that one should learn to manage them, for example by developing trans-organizational networks of professionals.
3. Aquaculture can also cause positive externalities such as reduced fishing pressure on wild stocks (Anderson, 1985), stock enhancement (Klinger et al., 2013) and improved economic and social stability (Asche et al., 2016).
4. Both interviews and our recently conducted media discourse analysis (Olsen & Osmundsen, 2017; Osmundsen & Olsen, 2017) suggest that there is a rather weak distinction between different producers in the public perception of the industry.
5. For more about the Aquaculture Stewardship Council (ASC) and Best Aquaculture Practices (BAP) see www.asc-aqua.org and bap.gaalliance.org, respectively. Ecolabelling in aquaculture is also discussed in Bush et al. (2013).

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