Uncertainty and multilevel coordination in fish farming disease control

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Abstract:

In the Norwegian fish farming industry effective proactive and reactive disease control is a key sustainability challenge. Diseases are one of the most important hazards for losses of production and for environmental harm, especially to wild fish. They are important challenges for an industry which, second to oil only, is a cornerstone in the Norwegian export economy. This paper draws on data from a project investigating how modelling and simulation based tools may support disease control in fish farming. Disease management in fish farming is best described as a situation where articulation work and situation awareness rests on the ability to integrate information from a wide spectrum of sources with high uncertainty, but also where acting on information implies mobilizing tightly coupled networks of interdependent actors and technologies representing constraints and opportunities for action. While risk management is typically portrayed and theorized in “closed contexts” like airline cockpits and control rooms, we here discuss “open” decision contexts and we describe some of the complexity faced when the industry and public agencies seek to manage diseases. We describe some of the work of situating information to support concrete decisions, and the need to align information and resources for action within the specific constraints and opportunities provided by these. High uncertainties, both in terms of understanding incumbent threats and the outcomes of different strategies and remedies, and weak signals further complicate the decisions. The mobilization of resources for disease control offers many of the coordination problems seen in response to societal crises (see e.g. McConnell and Drennan, 2006; Auerswald et al, 2006). We also build on the theorizing of coordination within sociology of work, and on decision theory.

1 Introduction

General introduction (mini summary)

1.1 What is fish farming?

Farming fish, especially salmon, but also rainbow trout, cod and other species constitutes a large industry in Norway. The first-hand value of the fish farming industry now totals far more than the traditional fisheries in Norway – NOK 17 and 12 billion respectively. The total export value of farmed fish represented about NOK 20 billion in 2008 (Statistics Norway 2011). In the course of 2010, Norwegian aquaculture produced 944 000 tons of salmon, 55 700 tons of rainbow trout, 19 700 tons of cod, 1800 tons of halibut and 1800 tons of other marine species (Bornø and Sviland 2010).There is however increasing controversy about the environmental effects of the industry, and the industry itself reports high losses, averaging at 13.6 percent during the sea phase in 2010 (Statistics Norway 2010). Parts of this loss can be explained by diseases, for example estimated to 23.5 percent of the losses during the sea phase for the region of Trøndelag og Møre og Romsdal by the Norwegian Food Safety Authority (Tangen et al. 2011).

Approximately ten to fifteen different diseases episodically appear in Norwegian fish farms, but some geographic areas are affected by pancreas disease (PD) on an endemic basis. According to the Norwegian Seafood Federation, the aquaculture industry has been successful in combating many diseases. Their statistic show that reported cases of infectious salmon anaemia (ISA) has been reduced from 98 cases in 1990 to 10 cases in 2009, bacterial kidney disease (BKD) has decreased from 77 cases in 1990 to only 3 cases on rainbow trout and salmon in 2009. On the other hand, most believe that new diseases will continue to appear in the future so eradicating diseases all together is a futile goal. Parasites like salmon lice are also a chronic problem for the industry and a particular problem due to spill-over to wild fish. Though many remedies exist for salmon lice, they all have limitations and side effects that need to be considered.

Disease control strategies is therefore an important issue in Norway as well as abroad. Diseases have economic consequences for the fish farmer, they are a threat to animal welfare at the fish farm and they affect wild fish and other marine life. In the wild, diseases and parasites are normally at low levels, and kept in check by natural predation on weakened individuals. In crowded net pens they can become epidemics. In addition to various diseases, salmon lice are a growing concern both for the farmed and wild fish.

1.2 Our research

This paper reports on on-going research in an interdisciplinary project on how to improve model based decision support in fish farming disease control. While more technologically, biologically or economically oriented sub-projects seek to contribute with better models or model components, we here report on research efforts aiming to understand the decision contexts these models are intended to support.

The SALMODIS-project consists of several sub projects that seek to model physical and biological phenomena, like how pathogens or parasites might be spread by coastal currents, how migrating wild smolts and fish farms are exposed to this infection pressure, how diseases develop within a population of farmed fish and how they are affected by various control measures. Together, these models constitute a foundation to the overall research topic which is integrated decision support.

The research which we report here, seeks to frame the disease management strategies and decisions in a holistic manner, individual farms, neighbouring facilities, local communities, stakeholders, governmental regulation, authorities etc. Based on interviews and case studies, we investigate the management strategies and decisions as intra-organizational and interdisciplinary ventures.

There is a difference between reacting on an emerging disease situation and proactively develop strategies to prevent and control such future situations. While the overall aim of the project is to support *strategic* disease control and therefore on proactive measures, this paper studies both of these interlinked levels. A strategy must take various future scenarios into considerations, which makes knowledge of the abilities to and limitations in responding to disease situations essential. Additionally, the challenges to react to particular disease situations can be said to be a subset of the challenges to develop disease strategies and draws attention to the uncertainties and lack of fundamental understanding of the system.

Given the descriptions of the industry and its disease problems, it is clear that these are decisions taken “under the risk of accidental loss” (Rosness, 2009; see also Størkersen, 2011). Such decisions can lead to actions or events that might have consequences which negatively affect something of value, e.g. personnel, product or environment. As such, our discussions can draw on literature of decisions in safety research, and hopefully also contribute to the discussion of decision making under risk of accidental loss in other sectors. Though we often speak of single organizations or even individual decision makers in this paper, the decision contexts are organizationally open, with a high reliance on other fish farms and companies, veterinarians, specialists, local communities and (importantly) public authorities, both for sensemaking and for action. In this openness of the decision context there are obvious parallels to be drawn to research on societal safety and critical infrastructures. For example, the handling of a major disease problem needs to involve efforts of a diverse agglomerate of actors, much like the handling of a societal crisis described by McConnel and

Drennan (2006), or risk management across infrastructure sectors (Almklov et al, Forthcoming; see also Auerswald et al, 2006).

1.3 Theoretical background

In essence, the SALMODIS project is aimed to improve disease management by inscribing scientific knowledge in tools that can be employed in specific decision contexts. In this respect it is an attempt to bridge the gap observed in agriculture by McCown (2001). He argues that while science in the form of technological innovations is quite easily assimilated, more system oriented scientific knowledge that could support strategic decisions and optimization are not. One of the (many) reasons for this shortcoming is that the scientists tends to stereotype the decision contexts in which their methods are to be implemented. In fish farming disease control there are quite similar gaps between science and practice.

In a safety research context, Rosness (2009:812) makes considerable efforts in systematizing decision contexts. Though our discussion doesn't fit perfectly with his framework, it is certainly in line with his overall invitation to explore "possibilities that arise from thinking of decision making as action adapted to situational constraints". [1]

We believe, like Weick (1993) and others, that "decision" is more often than not a retrospective or rationalistic label put on an on-going accomplishment. In his discussion of the Man Gulch disaster, it is not single decisions that are catastrophic, rather a continuous string of events and actions. Also in our discussion, decisions shouldn't be reduced to discrete acts, but rather as explanations of on-going activities. Actually, interconnectedness between events is one of our key observations. Though we recognize that using the term may have some potential pitfalls of reification, we stick with "decision making" in order to discuss the different phases of the process.

A relevant body of research is the literature on Decision Support Systems (see Shim et al, 2002 for an overview), which introduces both the relevant terminology, but also documents the experiences of designing systems to support decisions. As ICTs are more widespread in all contexts, and for example web based tools can be utilized to support almost any decision, the boundaries as to what is a DSS or not are more blurred than ever. As we proceed here to describe the situational constraints and context of decisions, one important aspect of disease management decisions is that the scientific knowledge on which they are based has a high uncertainty. This "deep" (Kandlikar et al 2005) or

[1] For an application of Rosness'(2009) framework in other types of decisions in fish farming, see Størkersen (2012).

“epistemic” (see e.g. Nilsen & Aven, 2003; Almklov & Haavik, 2009) uncertainty is not reducible to single variance but rather to a problem of *not knowing what you don’t know*. A DSS in this context necessarily has to be able to express this kind of uncertainty in a good way, or at least not suppress it.

While DSS literature typically discusses systematic and structured ways of supporting decisions, all decisions are in some sense unique, and information and possibilities in these systems need to be situated in local situations. Understanding the variability in decision contexts in fish farming disease management has been one of the key mandates for our project. In discussing this, it is also necessary to highlight more informal traits of organization and situational adaptation. To discuss the informal ad hoc coordination work, both in terms of aligning and contextualizing information sources and of mobilizing resources, we borrow the concept of “articulation work” from a classic in sociology of work. (Strauss et al, 1985). The concept has also been employed extensively in the field of Computer Supported Cooperative Work (CSCW) and in Science and Technology Studies (STS). In safety research, it has been recently employed to address the importance of informal coordination processes in drilling operations by our colleague Torgeir Haavik (2011a).

Articulation work is the informal work done to align resources, tasks and information in a specific context. It is the work of making a workable whole out of the more static formal system. In the words of Suchman (1996: 407): “[articulation work is] the continuous efforts required in order to bring together discontinuous elements – of organizations, of professional practices, of technologies – into working configurations.” We will get back to this concept in the course of our argument, but it suffices to say here that we employ it as a tool to address the full spectrum of coordinative work beyond formal organizationally visible coordination mechanisms.

The empirical data in this paper illustrates that social networks are an important source of actionable knowledge (Cross et al. 2001). Approaching others who have information and solutions is pragmatic problem solving. Problem solving requires more than a correct answer, often it is also about defining and interpreting the problem at hand, reviewing available resources, suggesting alternative approaches, weighing consequences and convincing others of the correctness of the decision. Actionable knowledge contains input to all of these issues, and is defined as knowledge that leads to immediate progress on a current assignment or project (Cross and Sproull 2004, p. 446). In an efficient manner it provides answers to complex problems with short time horizons. Task interdependence is the strongest and most consistent predictor of information seeking (Cross et al. 2001) which suggest that creation and interpretation of knowledge is inherently a social process. In fish farming, social networks are put to work by decision makers who copy actionable solutions from someone they know and trust, much because scientific knowledge is considered too abstract, disputed or unavailable.

Table 1 summarizes the theoretical background applied in the subsequent discussion. The table illustrates how different theoretical perspectives illuminates the decision making process in fish farming. In line with open system theory, the decision making process is portrayed in there stages; input, process and outcome.

Table 1. Decision making

INPUT	PROCESS	OUTCOME
Situation assessment (Ben-Bassat and Freedy 1982)	Articulation work (divide, allocate, coordinate, schedule, mesh, interrelate) (Suchman 1996)	Distributed decision making
Information: incomplete and uncertain	Heterogeneous networks of organizations and authorities	Discretionary decision making: Local perspectives and incongruent heuristic
Contextual/experiential knowledge		Actionable decisions and social networks
Incommensurate perspectives (Schmidt 1991)		
Short timeframe: livestock		
Politicising arguments: Uncertainty gives leverage for politics. Evidence trap (Renn 1992)		

2 Case

2.1 Method

The main data for our study of decision making is a series of in-depth interviews with key stakeholders across the industry and authorities. 20 interviews were conducted, each lasting approximately one and a half to two hours. We have also drawn on interviews in previous projects with slightly different scopes (Osmundsen et al. 2012; Størkersen 2011; Fenstad et al. 2009). Our results have been discussed with industry representatives in the project group and key informants (authorities, key stakeholders, and representatives from the industry).

2.2 Results

With the aid of our respondents we will illustrate the decision making process fish farmers undertake to decide on disease control strategies. The stories told by respondents demonstrates that making a decision for a specific control strategy is not merely dependent on themselves and their own farm, but involves a complex array of different stakeholders, and a multitude of consideration beside that which occurs below the surface. When a decision has been made it will eventually lead to a series of events, as the extent of interconnectedness also affect actions.

For the sake of the following presentation, we will portray decision making as a stepwise process where one tries to make sense of a situation, takes the decision and takes action based on what has been decided, although we acknowledge that it is more of an on-going accomplishment in real life (Weick 1993). The fish farmer is dependent on assessing the current situation; information from many different sources needs to be assimilated into an overall 'big picture' in order to decide what to do next (Ben-Bassat and Freedy 1982). The farmer combines the knowledge he has of the fish and its particular needs with knowledge of practical feasible alternatives restricted by available resources, other stakeholders, and in line with laws and regulations.

2.3 Phase 1. Understanding the problem – Uncertainty

The first signs of a potential problem can be fairly weak, perhaps some of the fish is eating less than usual, there are a few more deaths than average, or some of the fish have a behaviour which is abnormal (swimming patterns, location in the pen, surfacing for air etc.). Or perhaps the neighbour a few kilometres down the fjord calls and say they suspect pancreas disease (PD) on their farm. Bear in mind that an average net pen have approximately 200 000 fish and they are all below the surface and hard to inspect directly. It is therefore difficult for the fish farmer to understand what is happening, even though his suspicion is aroused due to small abnormalities or uncertain warning signals. (See Brizon and Wybo (2009) for a discussion of "weak signals".)

The first phase of the decision making process is therefore to identify and understand the problem at hand. The fish farmer will typically call the veterinary and make sure more autopsies are performed, tests are sent to the laboratory, and they may try to introduce health feed to strengthen the fish' immune system. Depending on the type of disease, while the farmer is waiting for a reliable diagnosis, he will alert neighbours and authorities.

Uncertainty marks this phase of the decision process. Determining how the fish got the disease, what type or sub-type of disease they have, and how you may limit the outbreak in the pen and avoid spreading the disease to other farms are often wrought with uncertainty. Measures of precaution are taken to limit the spread, but currents and passing wild fish are beyond the fish farmer's control.

One of the reasons for the extent of uncertainty is that much is unknown when it comes to diseases, treatments and prevention. These knowledge gaps complicates the work which fish farmers and authorities aim to do, and at times makes for strategies based on guesswork and intuition rather than well founded facts. Even though there has been much progress in research results and in the number of well-educated and competent fish farmers and others within the industry, much is still uncertain and unknown. As one of the respondents states;

"I have no idea why we haven't got infectious salmon anaemia (ISA). The neighbours had it for over a year, and they are 2.5 km away. It is mere chance, pure luck; perhaps we have good fish which is resilient, good localities, even though we have been exposed to disease carriers…" (Manager, Fish farm)

During the interviews our respondents referred to an array of explanatory factors for disease out-breaks, ranging from net cleaners, well boats, passing wild fish, quality of hatchery fish, nearby farms, currents etc. They have many theories, ideas and suggestions for explaining the causes for diseases and how to combat them, but they also emphasize that there are few certainties. One of our respondents explains: "*It is difficult to observe what happens under the surface and it takes time to understand what is going on*" (Veterinary, Fish farm). Fish farming is set in an open environment where there is a whole range of conditions which cannot be controlled for, and where seemingly similar situations have a high degree of variation. One illustrative example is how diseases and especially viruses behave differently in water. For instance, one of the respondents exemplifies this by pointing to how ISA and IPN do not infect across long distances, while the PD virus does. Our respondents emphasize that the most important source of knowledge which they can rely on is their own experience and intuition. There are still disease outbreaks they cannot explain. 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 is smoltified, and that it is strong, resilient and healthy before it is put into the pen, sometimes it gets sick and at other times it doesn't". (Manager, Fish farm)

Respondents also recognize the need for improved methods and more sensitive technology to survey infective agents and to identify diseases. A couple of the respondents referred to tests for resistance to lice treatments as a method they felt was untrustworthy.

There is also disagreement between the different actors involved in the industry, i.e. between the fish farmers and the various governmental agencies, and between different research communities on what constitutes 'knowledge'. An on-going and recent debate has been the threshold for lice treatment and how the consequences for using too much chemicals may cause increased resistance. Other examples the respondents brought forth included disagreements on how infection is spread, characteristics of diseases, the reliability of test and methodologies for identifying parasites and viruses.

Research communities disagree on results and the available scientific knowledge, but they also appear as spokesperson for certain strategies above others. Recently, discussions concerning the effect of increased populations of lice on wild fish has been intense, bringing forth researchers with contradictory views on the subject.

In sum, all of these concerns affect how respondents in this study view the credibility of research results. Scientific results and subsequent recommendations are interpreted as contributions to an on-going debate, and evaluated based on whom the author is. Renn (1992) calls this an evidence trap as facts and documented results are devalued related to other resources such as the ability to mobilize support from others, value commitment or power. It is the extent of uncertainty which allows room for political manoeuvring as it is difficult to falsify evidence.

Because the knowledge that fish farmers have access to often is uncertain and subject to controversies and disagreements the fish farmers' ability to choose the optimal strategies for preventing or combating disease is weakened. During the decision making process the fish farmer continuously needs to consider the needs of the livestock. Fish farming is a production which cannot be paused or stopped, a fundamental characteristic which affects decision making. Applicable solutions are needed without delay to make sure the fish stays healthy, and to limit the consequences of diseases.

According to the majority of those interviewed, the main source of knowledge is other fish farmers, often located in the same area or the veterinaries they use on a regular basis. The respondents say they are more sceptical to solutions which nobody they know have experience with, even though they have read about it on the net or in relevant journals. As long as nobody have personal experience with a solution they prefer to "wait and see" as one said. Trust is therefore an important basis for their choice of strategies. If they have heard of others who have used certain strategies with good results they are themselves more willing to try them. Advice from other farmers and from experienced veterinaries are much appreciated and used to form their own strategies.

To merely replicate what one has done before is not guaranteed to work the next time as conditions are unpredictable, and what may work one year doesn't work next time around. Even so, most of our respondents refer to past experience as their main source of knowledge, perhaps because experience has proven to be a great advantage when there are few other reliable sources of knowledge.

Also, availability of knowledge is of no use if the knowledge is not 'actionable'. Abstract research results or elaborate time-delayed statistics needs to be usable in a decision context. If fish farmers are to make use of the information, they need to translate it to fit with their knowledge of where in the biological process their production is, which seasonal particularities they have to consider and what available equipment they have access to. Scientific knowledge is often abstract, and it has to be made actionable before it is put to use. Experience, on the other hand, is already actionable knowledge. It has already been put to use, and includes a definition of the problem, the possible alternative solutions and how to use this knowledge in a practical and feasible manner. Learning from experience means that knowledge is highly contextual, and this may be an advantage in many respects. Contextual knowledge often contains practical solutions and is adapted to the working conditions at the farm. It also allows for action during situation where one needs to 'do' something, and where there is no time to wait for research results or to evaluate the best possible approach. On the other hand, contextual knowledge can also be episodic, meaning that it can be difficult to separate between unknown conditions, special circumstances and tacit knowledge which may be difficult to replicate in a new situation or a new place. But often, there is no other option. As one of the respondents puts it:

"*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.

And there are other consequences from relying mainly on experiential and contextual knowledge. For many, if not all of our respondents this is the way they have built their knowledge about how to run the fish farm. It is a valuable way of learning, especially when there is a lack of scientifically fact-based knowledge and the only feasible way is to attempt to do ones best. But it may also imply that there is not much improvement, or rather that merely building on what has been done earlier implies small improvement to existent solutions. A consequence of relying on experiential knowledge may also be that one is more preoccupied with repairing damages after something has occurred, than working preventively beforehand. The strength of many fish farmers is that they can be quick with solutions when something happens, but perhaps such a way of working entails less focus on prevention. There is little time to think long-term when you are caught up in daily affairs and challenges, so most solutions repairs the current challenge, but are perhaps less relevant for providing long-term solutions and major improvements. However, this may constitute the main difference between small and large companies, as larger size and more available resources may allow for longer term planning.

2.4 Phase 2. Articulating potential actions – Constraints

Reaching a decision on how to handle a disease outbreak, or increased amounts of parasites in the pen does not simply depend on how you assess the current situation and available knowledge. Understanding what is going on rests on the ability to combine information and resources into a workable understanding that is possible to act upon. This is very much dependent on the array of stakeholders surrounding you, existent laws and regulations, geographical requirements, public opinion and available resources. A respondent explained:

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 which is important, so we have to disregard earlier requirements of not handling the fish from its put into the pen and to slaughtering. Now it has to go into the well boat and be treated with hydrogen-peroxide, and perhaps even be flushed. 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 now. (Manager, Fish farm)

Articulation work is a central part of reaching a decision and the fish farmer needs to coordinate his own actions with those of his neighbour, check with the authorities if they are deemed acceptable, schedule the timing with others, share and allocate resources (well boat, capacity for slaughtering) and also convince others that the chosen alternative is the best for the situation at hand. In fish farming decisions are highly interdependent. The strategies a farmer chooses depends on a number of things; especially the local conditions (currents, temperatures, oxygen levels) and his/hers own knowledge of the farm, but also actions taken by other farms in the area, and past actions. E.g. choosing the most effective delousing treatment is dependent on which treatments one used last time to avoid decreased sensitivity or resistance. Having many interdependent decisions to deal with makes it difficult to decide on strategies, and this limits the number of available strategies. As fish farmers are acutely aware of, diseases and lice problems should not be considered in isolation; actions that seek to reduce e.g. lice infections may dramatically reduce the immune system and make the fish more susceptible to diseases.

This type of decision context is also a reality for those in charge of regulating the fish farming industry. Respondents from various governmental agencies[2] describe how they need to coordinate their work with other authorities and with fish farms. Different governmental agencies have at times conflicting goals and lack the legal authority to coordinate their work. A likely example is a case where one fish farm has disease and needs to slaughter, but the neighbouring farm has already booked the slaughter house because their fish is of such a size that the maximum allowed biomass (MAB) is about to be exceeded. From the point of view of animal welfare and environmental risk one should prioritize the sick fish, but the Directorate of Fisheries will issue daily fines if the MAB is exceeded, and have no legal authority to permit exemption. Also in other areas, respondents from the authorities experience that the regulatory framework they work by is at times too static and rigid, and not providing the necessary authority to make sound decisions. In other cases authorities face the dilemma of balancing between societal interest and the farmers' economic interests. To command slaughtering of the fish often have enormous consequences for the farmer, and perhaps also for the local community. The authorities need to take this into consideration while also heeding societal interests such as environmental sustainability. And as respondents stress, they need to decide fast to avoid spread of the disease.

2.5 Phase 3: Action.

A fish farmer needs to consider the interests of neighbouring farms, the agreements and cooperation arrangements he has with others, priorities and interests of authorities, and laws and regulations. Decision making in aquaculture concerns the biological needs of the fish, but also the priorities of the regulating authorities, and the needs of other farmers. When considering these constraints the fish farmer may decide on a different strategy than what he would consider to be optimal for his farm alone.

As Schmidt (1991) asserts, in complex environments, decision making is performed under conditions of incomplete, erroneous, misrepresented, misunderstandable, and incomprehensible information. This requires decision makers to exercise discretion, but in discretionary decision making, different individual decision makers will typically have preferences for different heuristics (approaches, strategies, stop rules, etc.). To arrive at decisions which are acceptable to all involved and the society at large these heuristics needs to be integrated. Formalized cooperation between fish farmers partly remedies some of the challenges of knowledge gaps, uncertainties and

[2] In charge of regulating the fish farming industry in Norway, there are three main governmental agencies with partly overlapping functions, in addition to local and sectorial authorities with smaller jurisdiction.

interdependencies that decision making represents. Free information flow is seen as a fundamental condition to such cooperative agreements. All of the fish farmers interviewed in this study participated in a formalized cooperation with other fish farmers in their area. All saw the advantages of cooperating with others, but the scope and extent of obligation varied. Also, many respondents confirm they have a close dialogue with authorities, especially the Food Safety Authority. Nonetheless, these cooperative agreements and arrangements are voluntary, and respondents question if they will still be upheld when individual interests are threatened. Furthermore, the industry is a complex conglomerate of actors, and beside various governmental agencies with separate and focused responsibilities there is no overarching body which may command coordinated actions.

In many organizations decision making is becoming increasingly distributed. In large global organizations efficient and effective distributed decision making is achieved by the help of modern technology. Fish farms, however, is greatly dependent on local conditions and other farms in the vicinity. Although a significant number of the approximately 1500 fish farms, with about 4000 employees (Statistics Norway 2011) are organised in larger company structures, these can be distributed over large areas often close by other companies' farms. Being increasingly dependent on coordinating their actions with neighbouring farms, each individual farm operates autonomously even within larger organizational structures. Discretionary decision making is therefore a better description. Each farm has a localized perspective of distinct realities, and much articulation work needs to be performed before decisions are made. On the other hand, risks are not constrained by organizational boundaries and migrate between farms. In a sense, then, we have loosely coupled organizations trying to solve tightly coupled problems. A DSS tool that would improve the coupling between the individual decision contexts and decision makers would probably be of great help.

Above we have described the extent of uncertainty, reliance on experience and interdependence that characterizes decision making concerning disease control in fish farming. We would like to stress that even though there are many aspects of and causes for uncertainty concerning disease control, this should not lead our readers to conclude that all is unknown. There is much knowledge on diseases, prevention and available strategies in use by fish farmers, and the industry is continuously improving.

3 Discussion

Constraints on decision making in aquaculture is in particular related to what many see as a lack of knowledge on basic and fundamental issues related to disease control. Fish farmers we interviewed emphasized that they found it difficult to evaluate research results and to make use of such results in the daily running of the farm. Therefore, most of the fish farmers we interviewed emphasized their reliance on prior experience as a main source for information. Experience has the advantage that it is actionable knowledge: it contains the definition of the problem, possible solutions, and description of how to take actions. Research results on the other hand may appear abstract and removed from real problems at the farm. Decision making in aquaculture is much about achieving an adequate awareness of the current situation to be able to choose the response which is optimal considering the array of factors in play. There might, however, be limitations in utilizing this approach in more strategic and proactive control, which might require a deeper understanding of the situation.

It is fruitful to understand decision making in fish farming through a perspective emphasizing the interdependencies and complexities of the decision context. Irrespective of who makes a decision there will always be an element of uncertainty and a network of actors involved in the process. These will weigh the multitude of conflicting considerations, like economic profit, fish welfare and wild fish survival, differently. In addition, the decision process plays out on a political field where the reputation of the industry is at stake. Fish farming companies often involuntary have to share the blame, supporting communal efforts to control diseases. Herein also lay the fundamental dilemma fish farmers face. In order to progress with articulation work, and continuously improve their ability to handle diseases and parasites they are dependent on transparency. Improved access to data and information from nearby farms is a necessity for knowledge growth and integrated decisions. On the other hand, such information may also be used in a negative manner by media, environmentalists, and at times by the authorities. There is therefore resistance towards transparency even though they may also benefit by sharing more information. Increasingly groups of fish farmers have established their own closed databases accessible to only themselves. Because actors and stakeholders have different agendas and interests, transparency is limited. McConnell and Drennan (2006: 66) refer to how contingency planning is difficult because you need to bring together organisations with fundamentally different values, cultures and goals, a point also salient in fish farming.[3]

The term *decision support* conveys a number of possible system levels, ranging from improved general knowledge on basic and fundamental issues to more complex systems of model based decision support systems. Generally, our study shows the need to adapt research results to actionable knowledge anchored in the experiences of the farmers. Trust, both in more general

[3] See also Almklov et al (Forthcoming) who discuss these organizational issues with regards to cross sectorial risk analysis.

knowledge contributions and in models, must gradually be established. How, then, can decision support tools support decisions under risk in this open environment? How can it improve the scientific basis of decisions and reduce overall risk of diseases? Our discussions and examples of articulation work, points to the importance of transparency between levels, disciplines and entities matching the biological and physical interdependencies found in the production systems. We believe that successful DSS tools will highlight connections and interdependencies, rather than black boxing them, and spelling out elements of uncertainties rather than converting them to a number. Given the complex organizational context, with a high diversity of interests and competence between actors, such a system must rely on social and organizational research to uncover interdependencies and mutual/diverging interests and goals. Such understanding should be available apriori, even though we do acknowledge the importance of providing meta-information on origin, authorship and context (Schmidt and Bannon 1992). This is also relevant for decision support in open contexts, like for managing societal safety, in which interdependencies and uncertainty, as well as the diversity of involved actors, are key problems.

This has relevance for decisions under risk in several contexts. The interdependencies and complexities of the decision context must be taken into account. During drilling operations in the petroleum industry, for example, there is a transient interdisciplinary decision making context in which information, resources and tasks must be articulated on the fly in order to proceed safely. (Almklov, 2008) Also here, studies of operational work suggest that transparency and support of articulation work would be an important quality of DSS tools (Almklov and Haavik, 2009; Haavik, 2011).

Our studies show a broad scope of requirements for improved decision support in disease control management in the aquaculture industry. A more extensive use of model based decision support systems seems promising. Integrating existing and new knowledge into models enables studies on complex dynamics, such as the cost-effect relationship between measures to control diseases on farmed fish and their effect on wild fish. In addition, the development and integration of models itself can expose uncertainties and lacking knowledge.

But although the models and their simulated results will have a central role in such tools for disease control, the decision process that they support might be equally important as they provide an arena to share information and collectively develop plans of action. Decision support systems are based on models of the decision to be supported. How concrete this model is depends on how easily constrained and standardized the context is. Due to the high degree of uncertainty in the scientific knowledge on fish disease and the openness of the production system, decisions are not easily constrained and standardized. Thus, the decisions to be supported are quite superficially modelled, and their DSS components must be designed for flexible use.

4 Conclusion

We have described fish farming disease control decisions as open contexts characterized by interdependencies, high uncertainties and heterogeneous networks of actors. In this, and similar contexts, we argue the coordinative efforts described here as "articulation work" are essential. Decision support systems to aid such decisions should at least give leverage for such work, and in the best of cases represent a resource for it.

5 References

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