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ARTICLE

To Adapt or Not Adapt: Assessing the Adaptive Capacity of Artisanal Fishers in the Trondheimsfjord (Norway) to Jellyfish (*Periphylla periphylla*) Bloom and Purse Seiners

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Abstract
Worldwide increases of jellyfish has occurred during the last several decades. A dense population of a large scyphozoan jellyfish, *Periphylla periphylla*, has established itself as top predator in the Trondheimsfjord in Norway, impacting traditional fisheries. On this background we discuss the adaptive capacity of artisanal fishers and stakeholder involvement in environmental management. A serendipitous discovery was that fishers report that their capacity to adapt to the presence of jellyfish in fact was sufficient. What they could not adapt to, within the context of jellyfish proliferation, was top–down decisions from the national government allowing purse seiners into the fjord to harvest Sprat *Sprattus sprattus* and Atlantic Herring *Clupea harengus* rest quotas and thereby also large bycatches of the local codfishes. This harvest was perceived more detrimental to their fishery than was the jellyfish invasion. Relative to fisheries management's choice of regulatory mechanisms during times of climatic change, we argue that by involving stakeholders intimately, the resulting policy advice will be experienced bottom–up and, thus, more legitimate and serendipitous results of a critical nature are more likely to surface.

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The last decade has seen mass occurrences of jellyfish blooms globally (Brotz et al. 2012), undesirable effects being reported by commercial fishermen in, among others, Japan, the Mediterranean, South America and Norway (Uye and Ueta 2004; Quiñones et al. 2013; Palmieri et al. 2014; Tiller et al. 2014)[1]. Scientists have speculated that the warming of the oceans is a vital component in the success of these jellyfish blooms (Kawahara et al. 2013). The blooms affect artisanal fishers, i.e, fishing, per Johnson (2006), that is "anchored in household and community based social and economic organization." These small-scale artisanal fisheries occur in the inner Trondheimsfjord and are locally anchored with small catches that are both for consumption and small-scale sale. Impacts in local communities include loss of income, increased hazard to safety, and a rising fear of fishing being eradicated in areas where the infestation is particularly great (Quiñones et al. 2013). The increase in jellyfish populations is also having a negative influence on fish stocks because they prey on the spawn of commercially important fish species. This increased pressure on fish stocks brought about by increased jellyfish numbers is troublesome given that fishing efforts are also increasing, driven by the increased global demand for seafood (Pauly et al. 2002) coupled with population growth and the future need for food security from the marine sector (Garcia and Rosenberg 2010). At the same time, global commercial fish stocks are declining after years of overfishing. Estimates are that 24–36% of global wild fish stocks have collapsed and that 68–72% are overexploited or collapsed (Worm et al. 2006; Pauly 2007; Pauly 2008; FAO Fisheries and Aquaculture Department 2010). Additionally, the European Union through its distant water fleet (DWF) has transferred infrastructure subsidies to developing nations to gain access to their exclusive economic zones (EEZ). These subsidies, however, also contribute to overcapacity in the host country by reducing fishing cost and thereby are contributing to overfishing (Barkin and DeSombre 2013; Le Manach et al. 2013). However, there is a political priority in many nations, including Norway, to protect the traditional industries of coastal communities, specifically the cultural heritage of what some consider remnants of former hunting and gathering past, namely artisanal and commercial fishing (Barnard 1983; Barkin and DeSombre 2013; Ministry of Trade Industry and Fisheries 2013).

This coupling of declining fisheries, natural system uncertainty including jellyfish blooms, and increased stress on marine areas means that fisheries managers are regularly faced with making difficult management decisions while weighing social and ecological concerns against each other in a political setting (Bunnefeld et al. 2011; Tiller et al. 2014). Anticipating the effects of these decisions on the entire socio-ecological system is difficult given that management decisions are introduced into complex contexts with humans, the environment and economy interacting at multiple temporal and spatial scales. The adaptive capacity of stakeholders to respond to changes to the socio-ecological system is sometimes difficult to foresee by managers, and often there are outcomes that management does not anticipate that can have critical effects on stakeholder groups. Within this context, we discuss the management of increasing jellyfish populations globally. We also examine a local artisanal fishery affected by high concentrations of *Periphylla periphylla* and a declining population of Atlantic Cod *Gadus morhua* (hereafter, "cod").

We argue that the coupling of quantitative economic and biological data with qualitative stakeholder data will give a more complete picture of the impacts of stressors, such as jellyfish blooms, from a global perspective down to the impact on local communities (e.g., Trondheimsfjord, Norway), in line with a significant and growing body of literature on stakeholders and co-management (e.g., see www.sciencedirect.com and search words "stakeholder" or "co-management"). The importance of this inclusive approach is to go beyond a top–down approach to include local knowledge and understanding and to incorporate stakeholder adaptive capacity, or social resilience, when assessing their vulnerability to emerging ecological stressors (e.g., jellyfish blooms) and how they might affect fisheries and the cultural heritage of the artisanal fishing in the area. Furthermore, involving stakeholders can also uncover serendipitous discoveries of importance that also affect the stakeholderś ability to adapt to new situations. According to stakeholder theory, on which we ground our findings, this is critical in management approaches because giving management advice is viewed more legitimately from the vantage point of the stakeholders most directly affected when they have been involved in the process. The results of this involvement is therefore that compliance to regulatory changes, as an indicator of the institutional, as opposed to environmental, effectiveness of such measures (Zürn 1998; Kütting 2000; Tiller, R. G. 2010), are more likely to happen (Österblom et al. 2011). In looking at the occurrence of increased *P. periphylla* population and the flow-on effect on cod stocks and the fishermen, we therefore explored the interrelation among cod, jellyfish and fishing based on a time series data of cod and jellyfish in the Trondheimsfjord in concert with fishermen questionnaires—coupled with information from Råfisklaget about actual price changes of cod in the last decades. We also used systems thinking and Bayesian belief networks (BBNs) to map stakeholder perceptions of causality in light of the theory of stakeholder participation. This information in turn was used to determine how stakeholders can be used in research situation, and how their real life information correlates with biological data on the same topic.

Here, we first give the theoretical and methodological backdrop of the topic, followed by background information about

[1]For thorough interdisciplinary background information on the case of the fishermen in the Trondheimsfjord specifically, consult Quiñones et al. (2013) and Tiller et al. (2014).

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the growth of *P. periphylla* population globally in the context of multiple drivers (e.g., climate change and warming oceans) and a overview of the situation in the Trondheimsfjord, Norway. We then present a time series of biological data for a specific geographical location in Trøndelag, Norway, where the perceptions of local fishermen on the developments of jellyfish in the area, and their adaptive capacity, have been recently explored through participatory workshops (Tiller et al. 2014). This information is coupled with follow-up questionnaires to the most active (fulltime) fishermen in the area where they have provided the data based on their own logbooks and observations with regards to the changes in catch and catch composition in the last decades. This information is then combined with aggregated data from the Directorate of Fisheries (The Norwegian Fishermen's Sales Organization; "Norges Råfisklag") about the changes in landings and prices for cod in the same period and area. The discussion focuses on perceptions of the effect of inclusive governance from the vantage point of the stakeholders in response to these biological changes and how theory expects a bottom–up approach to coastal management to affect the compliance to management decisions by creating legitimacy in the process. We also present the serendipitous finding that the stakeholders perceive their adaptive capacity to jellyfish to be high; however, their adaptive capacity and the cod population have been more detrimentally affected by a top–down decision to allow purse seiners into this ecologically protected fjord system to harvest "rest quotas" (i.e., the allowance of ocean going fishing vessels have to transfer up to 20% of their quota for a given species to another vessel in their company or to a collaborator within the same vessel group, provided the vessel has fished >30% of their quota prior to selling it to another vessel; Lovdata.no 2005). With both jellyfish and purse seiners preying on the fish stocks targeted by these artisanal fishermen, they feel like they are caught between a rock and a hard place, and are unable to adapt.

THEORY

The complexities of fisheries management arguably necessitates socio-ecological integration, which has shown to lead to stakeholder trust and legitimacy in fisheries management decisions, and an improvement in the rate of compliance as well (Österblom et al. 2011). A stakeholder in general has been defined by the literature as "any group or individual who can affect, or is affected by, the achievement of the organization's objectives" (Freeman 2010). This is a broad definition and leaves the concept of having a stake, or invested interests, unequivocally open to include virtually anything, any topic, and the jurisdiction of a given stakeholder open to anyone. We distinguish between the management and the engagement of stakeholders, referring to their involvement in the actual decision making process. In management, we are looking at persuasive strategies, the mapping of groups of importance, and the assignment of importance to those stakeholders that are in need of attention. In engagement, we are referring to a strategy of involving the stakeholders in the decision making process and making them real participants with mutual responsibility in the results, rather than just recipients of attention. It is therefore necessary to look closer at stakeholders to determine who they are and to what degree they are affected by an objective, such as jellyfish invasions in the current case.

Searches for the keyword "stakeholder" or "co-management" through an online database shows greatly increasing results of studies on these topics over the last 2 decades (www.sciencedirect.com). There may be multiple reasons for this trend, but we argue that this increase in academic interest in the topic of stakeholders is due to a lack of stakeholder compliance to top–down decisions (including in the context of marine-based management). In Europe, for example, the failures of the Common Fisheries Policy (CFP) through a lack of profitability and a plenitude of overfishing, has been blamed on a lack of decision-making transparency and legitimacy with stakeholders, which has created a lack of compliance (Österblom et al. 2011). The lack of stakeholder compliance is of great interest from a political science perspective. Governments of democratic nations continuously make laws that influence stakeholder groups by shaping and regulating them. In order for these groups to be able to influence this system, however, they must abide by the rules and regulations established by the political and social setting within which they operate. In other words, the political culture wherein stakeholder groups manoeuvre is a reflection and a reinforcement of the political context thereof.

Norway is considered a state that is open to a variety of different interest groups accessing management, though there is no pretence of all groups having equal access to power. Organizations in this system are the link between their members and the government and actively participate in committees that are set up, whether they are advisory or permanent. Ultimately, however, they may still be overrun by a strong government in the decisive phase, resulting in decisions being made that are still contrary to what the members of the organization may have preferred (Dryzek et al. 2003). Participation by stakeholders in the committee system of the national government is one of the areas of inclusion that can be found at the heart of Norway's structure, especially in the case of the Ministry of Trade, Industry and Fisheries. These committees involve representatives from a variety of interest groups, as well as politicians and administrators. Often the goal is to produce a report on an issue, to be later used in preparation of parliamentary proposals, which would be commenced with having an open hearing. Having a case out on a hearing means that the government would like comments from affected stakeholders to a proposal they are working on at the moment, and the background for it would normally be to map out potential economic and administrative consequences of a given decision (Ministry

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of Trade Industry and Fisheries 2007), giving the stakeholders a voice and encouraging legitimacy and transparency. The incorporation of stakeholder groups throughout the decision-making process in the fisheries sector is therefore intense in Norway, and many groups are involved at different levels and at different times. This is in line with findings showing that Norway has had some success with regards to stakeholder trust and legitimacy in fisheries management, as demonstrated by an improvement in the rate of compliance (Österblom et al. 2011). Findings also show though a difference between fisheries organizations in Norway, the main fisheries organization, The Norwegian Fisherman's Association ("Fiskarlaget"), having greater power and influence with the government than does the smaller organization of coastal fishers, the Association of Coastal Fishers ("Norges Kystfiskarlag"; Tiller 2008).

METHODS

Given that stakeholder feelings of policy legitimacy and compliance is of critical importance to the sustainable development of fisheries globally, we used an integrated approach of systems thinking and Bayesian Belief Network (BBN) modeling in developing the stakeholder-driven scenarios and gaining critical insight into the adaptive capacity of the stakeholder group. Systems thinking as a method was used to develop shared mental models of the system, as perceived by the stakeholders involved. This step provides a conceptualization of the system based on the given stakeholder group-level beliefs and experiences and helps identify potential drivers and consequences in the context of the study (i.e., the management of increasing jellyfish populations globally, and in the case study, *P. periphylla* concentrations coupled with declining cod populations and the effect this has on commercial fishermen in the area). This systems thinking process also helps in identifying important elements within the system conceptualization that have influence over, or are influenced by, other elements within the same system. A benefit is that it allows exploration of a complex system at the local scale (in this case, the Trondheimsfjord) based on the expertise of the stakeholders themselves. The system conceptualization was also used to identify and select a priority issue that was further explored using BBN modeling and which uncovered other aspects of the issue. This priority issue represented an element or theme that emerged from the system thinking process that the stakeholders believed strongly about (i.e., *P. periphylla* in Trondheimsfjord). Vensim, a software specifically designed for systems modeling and developed by Ventana Inc. (Vensim.com), was used to develop the system conceptualization during each workshop.

There is a strong motive for engaging with stakeholders in order to access the expertise that they possess (i.e., knowledge-based data), which is characteristically strongly qualitative. For example, the fields of climate change adaptation and resource management have strong human dimensions and therefore draw heavily upon this knowledge-base. However, quantifying this narrative-rich knowledge base for the purpose of making management decisions (e.g., adaptive management scenario testing) is difficult. On these grounds, BBN modeling was selected as the methodological framework for further exploration of the priority issue. In addition, it was chosen because it facilitates participatory modeling and is well-suited to representing causal relationships between variables in the context of variability, uncertainty and subjectivity. Furthermore, BBN modeling is a method that is extremely well suited for coalescing knowledge into a single modeling framework, even if the knowledge comes from a variety of sources (e.g., stakeholders) and is of a variety of completeness. It is particularly effective in eliciting stakeholder opinion through participatory engagement for two reasons. First, the visual aspect of developing the causal maps that characterize Bayesian network models are easily understood and readily accomplished (as confirmed in our experience) by the stakeholders. The impact of this should not be understated because this fosters trust during the stakeholder engagement process. Second, the robust mathematical framework of Bayes theory underpins these models. This aspect, while not necessarily obvious to the stakeholders, provides a mathematical basis for incorporating the beliefs of the stakeholders into the model, something that traditional statistical approaches (e.g., null hypothesis testing) does not allow. It has also demonstrated an ability to use subjective expert opinions to both derive the structure of, and variables within, a BBN (Richards et al. 2013).

The methodological process of developing BBNs through stakeholder engagement is outlined in detail elsewhere (Richards et al. 2013; Tiller et al. 2013). Briefly, however, the structure of a BBN is a network of nodes that are connected by arcs. Each node is treated as a variable and therefore must have more than one state (e.g., if car color is the variable, then the states could include white, red, blue, etc). Furthermore, these states must be mutually exclusive (a variable can only have one state at a time), consistent (i.e., the states must relate to the same variable), and exhaustive such that the states cover all possibilities (e.g. for car, the variable color would require all possible colors be assigned as individual states, or alternatively, the states defined in a way that covers all possibilities: white cars and not white cars). Arcs connect variables and show the direction of causality through the direction of the arrow at the end of the arc. This direct connection between variables represents conditional dependence, which is a fundamental tenet of Bayes theory upon which BBNs are based. Feedback pathways are not allowed in Bayesian networks and therefore the entire network must be acyclical (i.e., one direction of causality). The implications for this constraint include the inability to model the influence of reinforcing (positive feedback) or balancing (negative feedback) pathways on the system being modeled. Such feedback pathways are important for understanding the temporal evolution of a system (i.e., how it changes overtime) and how it might respond to

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perturbations (Sterman 2000). While there are techniques that can enable feedback pathways in BBNs, these can quickly lead to cumbersome models with a large amount nodes, even for very simple feedbacks (Kjrulff and Madsen 2008). If the purpose of a model is to explore the role of feedback pathways in governing temporal dynamics, then other modeling methodologies such as systems dynamics (Sterman 2000) would be more appropriate to use than Bayesian statistical modeling. However, in our modeling, we are interested in using a methodology that allows straightforward integration of multidisciplinary (environmental, social, and economic) variables, accommodates expert opinion as a data source, and allows models to be developed even when data are relatively scarce. Furthermore, in our work we are focused on scenario analysis (i.e., what if?) where changes in conditions (new evidence) may be used to update our prior understanding of an event (e.g., the priority issue in our model) to posterior understandings. These ideals are well matched by the attributes of BBNs.

The other main component of the BBN is the set of conditional probability tables (CPTs) that quantitatively define the conditional dependence between linked nodes. In the workshop setting outlined in this paper, the perceptions of the stakeholders are used to populate these CPTs with probabilities, quantifying their beliefs about the relative importance of different variables within the network. The underlying probabilistic framework (i.e., Bayes theory) provides a mechanism of directly integrating social, economic, and environmental variables within a single model (Kjærulff and Madsen 2008).

During the workshops used in this study and elsewhere (Richards et al. 2013; Tiller et al. 2013), development of the structure of the BBNs is a group-level exercise. That is, it represents the group-level belief about which variables are included and how arcs connect them. Therefore, this process typically requires negotiation between the stakeholders. Conversely, each stakeholder populates the CPTs with their probabilities, providing individual-level parameterisation. The individually parameterised BBNs can then be combined into a single model because they share the same structure but have different CPTs. This is achieved here by using an auxiliary variable (Kjærulff and Madsen 2008), which weights each of the individual stakeholder CPTs so that the beliefs of one stakeholder can be given more weighting in the model than others. For this study the stakeholders were weighted evenly. Finally, the BBN-development process facilitates the capture of further information through the discussions that accompanied the development of these networks, that narrative providing important context to the importance of different variables during the workshops.

In terms of the time series of cod versus jellyfish, we used the aggregated data from the National statistics for Trøndelag area (including Sør- and Nord-Trøndelag) to illustrate the changes in fisheries resources over the last decade. To capture the changes in cod and jellyfish from this time series and their associated effects on fishermen and their livelihood, a structured questionnaire survey was conducted among the small-scale commercial fishermen in the inner Trondheimsfjord for cod fishing. The questionnaire were divided into several sections, including basic fishing information (e.g., fishing area, gear, and season), economic components (catch and catch composition), price and cost, views on *P. periphylla* effects, and socio-demographic characteristics of fishermen. The respondents were also given the opportunity to provide commentary to questions. The questionnaire was provided by mail to all the fishermen in the inner Trondheimsfjord, and 50% replied, most with relatively complete answers.

JELLYFISH

The fishermen in the Trondheimsfjord have reported increased jellyfish blooms affecting their fisheries. These blooms, however, are not only a local problem in the Trondheimsfjord. They have also become an increasing global problem in the last few decades (Purcell 2007; Brotz et al. 2012). A number of stressors that include natural ecological fluctuations, anthropogenic activity (e.g., eutrophication; Arai 2001; Richardson et al. 2009), overfishing, habitat modification, chemical pollution, and introduction of exotic species in the marine environment (Hay 2006; Purcell 2007; Richardson et al. 2009) are suggested causes of these blooms. Climatic changes that alter temperatures, and nutrient fluxes also favor jellyfish; they therefore often strike in ecosystems that are out of balance (Lynam et al. 2005; Hay 2006; Purcell 2007; Halpern et al. 2008). The most important direct negative consequences of jellyfish blooms are economic losses, which include reduced tourism in affected areas due to stinging danger. It can also reduce fish catches of artisanal and commercial fishers due to damage to net gear, stinging danger and the resultant longer working hours required to clean and fix fishing nets (Quiñones et al. 2013), fish mortality due to stinging, oxygen deprivation in the aquaculture industry, and blocking of water inlets of power plants (Hay et al. 1990; Båmstedt et al. 1998; Hay 2006; Purcell 2007). These negative consequences can lead to large economic losses through reduced profits and increasing costs, especially for fisheries (Graham et al. 2003; Quiñones et al. 2013), as well as to the whole fishing industry at a sector level (Kim et al. 2012; Nastav et al. 2013).

The reason for their immense impact on the fishing industry is that they are gelatinous zooplankton, including both medusa of the phylum Cnidaria and planktonic members of the phylum Ctenophora (Brotz et al. 2012). They are therefore more resilient than fish in a changing world owing to a suite of attributes they possess that enable them to survive and thrive in disturbed marine environment (Richardson et al. 2009). They are furthermore nonvisual predators, seeking prey without using eyesight. This gives them a great advantage over other predators, like fishes, in waters with reduced light penetration such as during increased spring-flood river run-off or general

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pollution. *P. periphylla* is naturally distributed in all world oceans in waters with a wide range of temperatures, and like other scyphozoans, it can tolerate low oxygen concentrations better than most fishes. Thus, the annual cycles in light, temperature, salinity and oxygen saturation that are typical of Norwegian fjords may occasionally favor jellyfish over the fishes. Especially in periods of reduced abundance of fish, whether due to natural stock fluctuations or overexploitation, scyphozoans like *P. periphylla* can utilize their superior reproduction capacity (spawning throughout the year), longevity (>30 years) and recruitment.

Different jellyfish species will be affected differently by changes in the marine environment, though. Temperate species that come under stress from higher temperatures will increase in abundance, be able to overwinter and have longer reproductive seasons, which combined will result in larger populations. Tropical species, however, will be stressed under higher temperatures and therefore shift their distribution towards cooler waters and have shorter active seasons (Purcell 2005). Many species of jellyfish bloom more frequently than others (Purcell 2007) with some areas of the world experiencing more devastating consequences of jellyfish blooms than other areas. There is one famous example of a jellyfish causing the collapse of a whole ecosystem as well as the entire fishing industry in the area, namely the introduction of *Mnemiopsis leidyi* to the Black Sea in the 1980s. *Mnemiopsis* sp. was introduced to an already unstable ecosystem (mainly due to pollution and overfishing), and with its extreme ingestion and reproductive rate along with the lack of predators, it was not long until it had outcompeted all other species in the ecosystem. Since the 1980s, *Mnemiposis* sp. has been a nuisance in the Mediterranean and plagued large areas of Western Europe (Gershwin 2013:55–75). In Japan and China, blooms of giant jellyfish *Nemopilema nomurai* (which can reach a diameter of 2 m and a weight of 200 kilos) have caused devastating consequences for the fishing industry. *N. nomurai* blooms in spring in the East China Sea and is then transported with the currents into the Sea of Japan where it dies off in winter. Blooms of the *N. nomurai* jellyfish are extensive. In just one day, >3 million jellyfish can pass the Tsushima Strait. Fishing gear in these areas are torn apart and ruined, their poisonous tentacles sting the fishermen, the fish catch is minimal and working hours are longer (Uye 2011). In Qingdao, China, several deaths have also been reported from contact with this jellyfish (Purcell 2007). A third example of jellyfish blooms comes in the shape of the toxic *Pelagia noctiluca*, which has been a nuisance for tourists in the Mediterranean Sea and the Adriatic Sea, where the tourism industry suffer great economic losses due to stinging danger (Purcell 2005).

In India, furthermore, invasions of jellyfish have been a nuisance for the fishing industry as well as popular beaches in Palolem in Canacona, Utorda in Salcete, Miramar in Tiswadi and some other North Goa beaches (Fernandes 2012). Pollution and permanent parking of vessels in the Mandovi river of Panaji is also giving rise to toxic jellyfish blooms, causing problems for the fishing industry (Nagvenkar 2012). The moon jelly *Aurelia aurita* has also caused problems for fisheries, as well as power plants and aquaculture around the world (Mills 2001). In China, increased number of marine construction where polyps settle and decreased currents (retention) in bays has lead to a higher than usual abundance of moon jellies (Dong et al. 2012). Generally speaking, with increasing size of the predatory jellyfish the predation rate increases (Purcell and Arai 2001), so one can imagine that 200-kg jellyfish appearing in millions in a given area can cause severe impacts on the ecosystem and fishing industry.

TRONDHEIMSFJORD: COD VERSUS JELLYFISH

In Norway the financial losses related to jellyfish have been primarily the aquaculture and fishing industries. Aquaculture has had heavy losses due to jellyfish such as *Apolemia uvaria* and lion's mane *Cyanea capillata* clogging the fish cages and stinging the gills of the fish, causing suffocation and mortality (Båmstedt et al. 1998). The traditional fisheries experience, however, has centered around high densities of jellyfish, specifically the helmet jellyfish *Periphylla periphylla*, which has been clogging their nets, stinging fishers, and preyed on both the larval stages of cod and Atlantic Herring *Clupea harengus* as well as the food of these fish, the redfeed, thereby reducing the catches for the artisanal fishers in the area dramatically over the years.

Helmet jellyfish have established and thrived in many Norwegian fjords in recent years. It has gradually become a predominant species in the inner Trondheimsfjord ecosystem for the last decade (Solheim 2012). These jellyfish have caused a series of problems to the ecosystem and marine resources that coastal fishermen in the areas depend on for their livelihood. Trondheimsfjord is the third longest and seventh deepest fjord in Norway. The innermost part of the fjord (our study area) is divided into three main basins, namely Beitstadfjord, Verrasund, and Verrabotn (Figure 1). It used to be a relatively self-sustained and functional ecosystem containing a number of marine species and resources. Currently, the most important marine resources for the coastal fishermen are cod and Saithe *Pollachius virens*. Emerging species like European Pollack *Pollachius pollachius* and crab have also gradually become important to fishermen as an income supplement in light of declining stocks of the former.

Trondheimsfjord supports a local, self-recruiting cod stock, which traditionally has been the keystone species in the ecosystem and has sustained local fishermen for their livelihood for centuries (Dahl 1899; Mork, Reuterwall et al. 1982; Mork et al. 1985). Outside the spawning season cod are dispersed throughout the fjord, but aggregate on the spawning grounds in the innermost parts of the fjord in spring (March–May), when the annual spawning fishery takes place (Dahl 1899). Local artisanal fishermen use 30–35 ft (9.14–10.67 m) coastal fishing

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FIGURE 1. Location of the three fishing areas in the innermost basin of the Trondheimsfjord, in central Norway, where the impacts of jellyfish on stakeholders were examined.

vessels with conventional and low-tech gears such as gill nets to harvest cod. Data from the National Statistics for Trøndelag area (including Sør- and Nord-Trøndelag) illustrate the changes in fisheries resources over the last decade (Figures 2, 3), showing that cod and Saithe are the predominant species in terms of catch and value, although overall they have shown a gradual declining trend in the last few of years. European Hake *Merluccius merluccius* is the most valuable fish species in terms of monetary value, while Saithe gets the market's lowest price. The opposite is true when it comes to quantities caught, as expected. The price gap between cod and Saithe, however, has become smaller, owing to a declining price in cod and increasing price in Saithe (Figure 4). However, cod is still the fishermen's favorite species to catch, according to the responses to the questionnaires in the current study.

The Trondhjem Biological Station (TBS) has collected samples and data from the study area for cod and *P. periphylla* in spring and autumn for the past two decades. The results (Figure 5) clearly reveal that the catch per unit effort (CPUE) of cod has drastically fallen down (solid line) while the CPUE of *P. periphylla* has sharply increased (dotted line) in the same period. This contrasting development suggests that *P. periphylla* possibly may have had negative impacts on cod, and certainly on the fishing patterns of the local fishermen. The visible drop in the spring sample of 2013 is based on a documented mass death of *Periphylla*. The standing crop of *Periphylla* in the fishing areas Verrasundet and Verrabotn has been quite variable as measured by CPUE. Those locations are mainly "fed" with *Periphylla* drifting from the main population in the Beitstadfjord and can probably not themselves sustain large *Periphylla* populations over time. Those two locations are too shallow for the dial vertical migration requirements of *Periphylla* and too small and meagre with respect to prey for the jellyfish.

Documentation exists on more or less periodic mass deaths of the jellyfish at those two locations. The results of mass deaths have been detected after the winter, possibly pointing to starvation in the cold part of the year when the abundance of prey organisms are reduced in the fjord (Solheim 2012). As measured by CPUE, the mass death in Verrasundet/Verrabotn during winter 2010–2011 wiped out more than 90% of the autumn standing crop there. The mass death was also confirmed on bottom video using a remotely operated vehicle (the ROV "Minerva" of

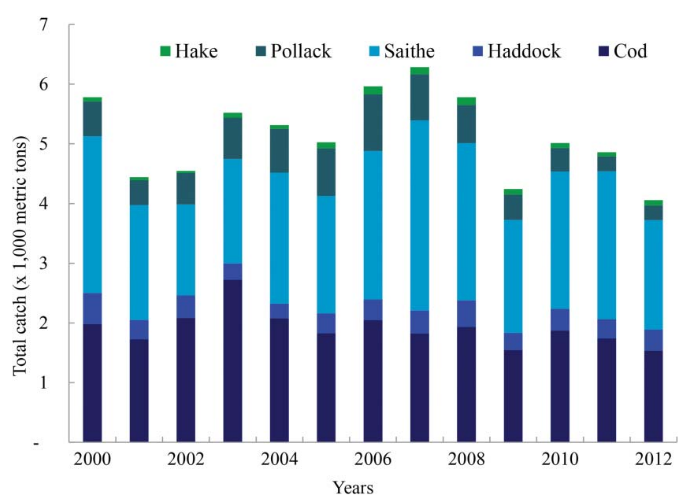

FIGURE 2. The catches of the major commercial fish species in Trøndelag, Norway.

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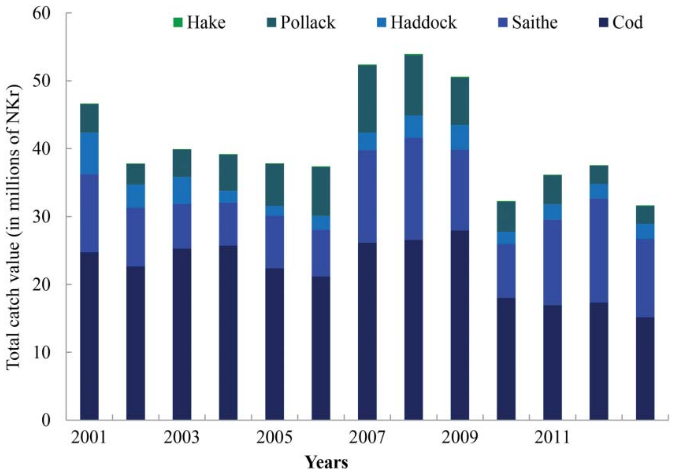

FIGURE 3. The nominal values of major fish species in Trøndelag, Norway.

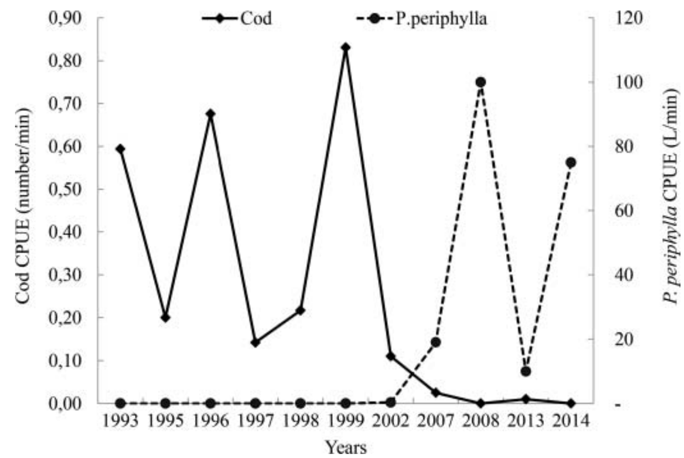

FIGURE 5. The catch per unit effort (CPUE) of cod versus the jellyfish *Periphylla periphylla* in the Trondheimsfjord, Norway.

NTNU). Also in recent years, a marked drop in CPUE of Periphylla in Verrabotn and Verrasundet after the winters has been observed, although not as severe as in the winter 2010–2011.

RESULTS

The mass deaths aside, the results of the questionnaires sent out to these fishermen were that they had observed *P. periphylla* blooms dating back as far as to the 1998–1999 fishing season. The catch composition in fishermen's catches has changed substantially since then (Figure 6), the catch of cod decreasing from over 60% of the total catch in 2000 to about 30% in 2012 while Saithe increased from 20% to 50%. European Hake and European Pollack have also shown increasing trend since they receive better price in the market due to increasing demand.

In line with the observations of the fishermen, bottom trawl data suggests that *P. periphylla* established itself in the inner Trondheimsfjord around 1999, probably first in Beitstadfjord, where *P. periphylla* blooms were observed earlier than in other parts of the inner fjord. Some of the fishermen who traditionally used Beitstadfjord as an important fishing ground, reported that they responded to the jelly problem by partly shifting their fishing efforts away from the Beitstadfjord to the more coastward neighbouring location near the Ytterøya Island, where the jelly density was much lower and, hence, less problematic. In general, however, the fishermen indicated that the overall effect of *P. periphylla* on their fishing activities was relatively significant. The questionnaires distributed indicated that the total income from cod fishing had been reduced over the last decade, although *P. periphylla* was not attributed as the primary factor. The main reason was the market price for cod and their increasing cost of fishing in general. However, the their increased fishing cost was partially due to *P. periphylla*, which caused fishermen to go farther out in their fishing zones and spend longer hours in sea and required more time cleaning and repairing nets. The fishermen also pointed out that they would leave the jellyfish-affected fishing areas to go somewhere else to fish, if management would provide alternatives for them, and otherwise would likely have to find alternative income to compensate for the loss (e.g., blue mussel farming). This indicates that fishermen in the area have gradually accepted that they will have to adapt to the situation if management cannot mitigate the jellyfish problem.

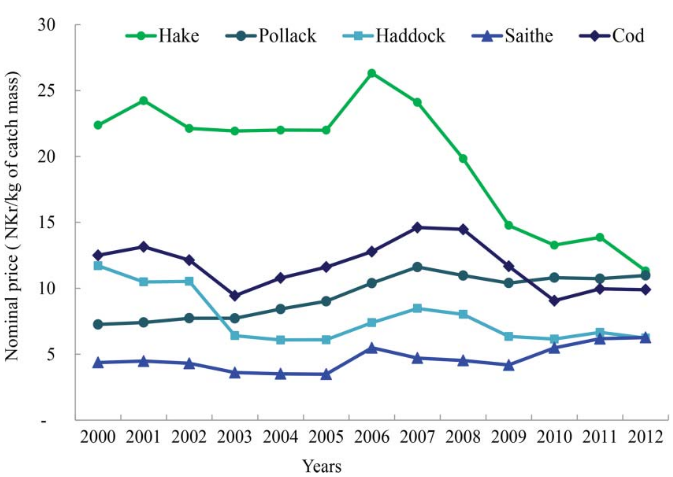

FIGURE 4. The nominal prices of major commercial fish species in Trøndelag, Norway.

Overall, the fishermen did not indicate being worse off because of the income loss from cod fishing, since it had been compensated by the income from other activities like increasing opportunities for emerging species, like crab and pollack or mussel farming. For instance, some fishermen indicated that only half of their current income came from fishing. They further mentioned that they have considered selling their fishing vessels and permits if *P. periphylla* continues to be a problem and alternative options for income become less available, albeit is fishing is their part of their preferred lifestyle, which

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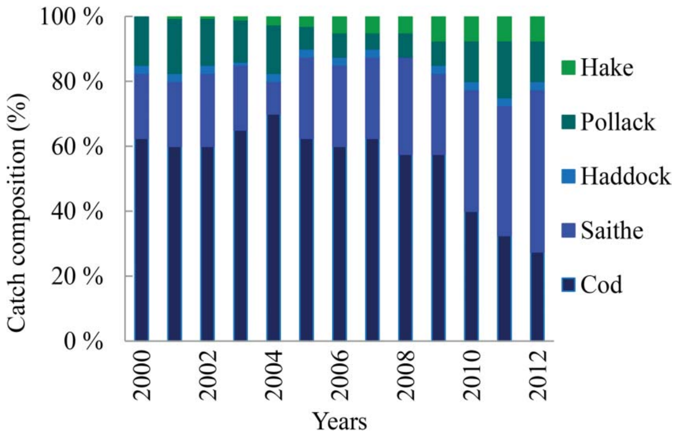

FIGURE 6. Fish species catch composition in the Trondheimsfjord, Norway, from 2001–2012.

they want to continue as long as they can sustain their livelihood. This is in line with ethnographic fieldwork elsewhere in Norway as well, where similar views are expressed (Broch 2013). However, the fishermen generally perceived the future fishing in the Trondheimsfjord as not very promising. They believe that policy and management can help improve their fishing situation, but they did not support new fishing regulations would potentially restrict their fishing activities even further. These different attitudes indicate that the fishermen do not believe policy and management can change the jellyfish situation, but they do need financial support for maintaining their fishing activities, despite the fact that there are fewer fish each passing year. They stressed that if *P. periphylla* can be explored and used for commercial values, however, they would be willing to adapt to this venture, and harvest these instead, if the opportunity arises. This is also in line with the observation of Broch (2013), who quotes a fisher stating, "If some fish stocks disappear there will always be something else to fish."

The questionnaires largely mirrored the group interviews done with the same group of fishermen, where systems thinking and BBN were the tools of investigation. They echoed the issue of *P. periphylla* taking up room in the fishing nets that would otherwise go to commercially desired species like cod. This had caused them to have to travel further to reach enough fish to harvest, increasing fishing cost as well as possible opportunity cost due to the loss of fishing grounds. They also discussed the challenge of having to spend hours cleaning the nets after use, which was both straining and time consuming, as well as hazardous to the fishermen cleaning them. During the last years, one of them had two 3-week medical leaves after getting jelly slime in his eyes. Another effect was that the quality of the fish caught in the net was also reduced due to scarring from jellyfish burns and jelly pigments, which in turn made them less valuable at landing sites. The increased weight of nets filled with jellyfish furthermore heightened the chance of the boat rolling over, which could have dramatic consequences for the fishermen involved. They furthermore feared that dead and decaying *P. periphylla* that sunk to the bottom would absorb available dissolved oxygen. Overall, the ecological, economic, and social ramifications associated with *P. periphylla* becoming established in the fjord lead the fishermen to believe they might have to find other work, or end up unemployed, which was similar to what they expressed in the later questionnaires.

These causal pathways were reflected in the system conceptualization (Figure 7), and it all centred around jellyfish and the financial ramification of this new player in the local ecosystem.

The BBN modeling process was not only to aid the stakeholders in discussing their adaptive capacity to *P. periphylla*, but also to provide for mitigation options, including political mitigation options (or as presented to the stakeholders, "where something could actually be done"; i.e., the bottom nine variables in Figure 8). This is also the area of the program where the policy maker can make changes and see how these actions play out in projections of other outcomes further up in the network. The starting point for the BBN modeling was the selection of a priority issue from the systems thinking processes (Figure 7), and it was expected that the stakeholders would centre their perceptions around the issue area of the negative implications jellyfish had and would continue to have on their system and how to alleviate this problem. The stakeholders first framed their priority issue of income in their experiences with *P. periphylla* and (under the guidance of the researchers) discretised (the process of categorising the node into discrete states) this priority issue by allocating a desirable and undesirable state to it, which in this case became "liveable" (desirable) and "nonliveable" (undesirable).

Following this, the stakeholders selected a set of primary-level variables that they felt directly influenced their ability of attaining an income that was liveable. They framed their selections around three themes: (1) if the fish biomass was high (fish biomass), (2) if the landing sites were local (fisheries landing sites) and (3) if the commercial harvest of *P. periphylla* was profitable (*harvest Periphylla commercially*) and respectively discretized these with states of high versus low, local versus not local, and profitable versus not profitable. The stakeholders then assigned the secondary-level variables that they believed had direct influence on the primary-level variables using the context of where "something could be done" and assigned two states to each of these; the resulting BBN is presented in Figure 8. We then ran a sensitivity analysis following the results of the conditional probability table, as applied to the BBN model, to formally tests the sensitivity of the BBN (using the priority node as the reference point) to changes in the variable settings.

The priority node (income) was most sensitive to fish biomass, as expected from data on availability of fish stocks declining along with the increase in jellyfish in the area. The importance of fish biomass appears to be a result of these

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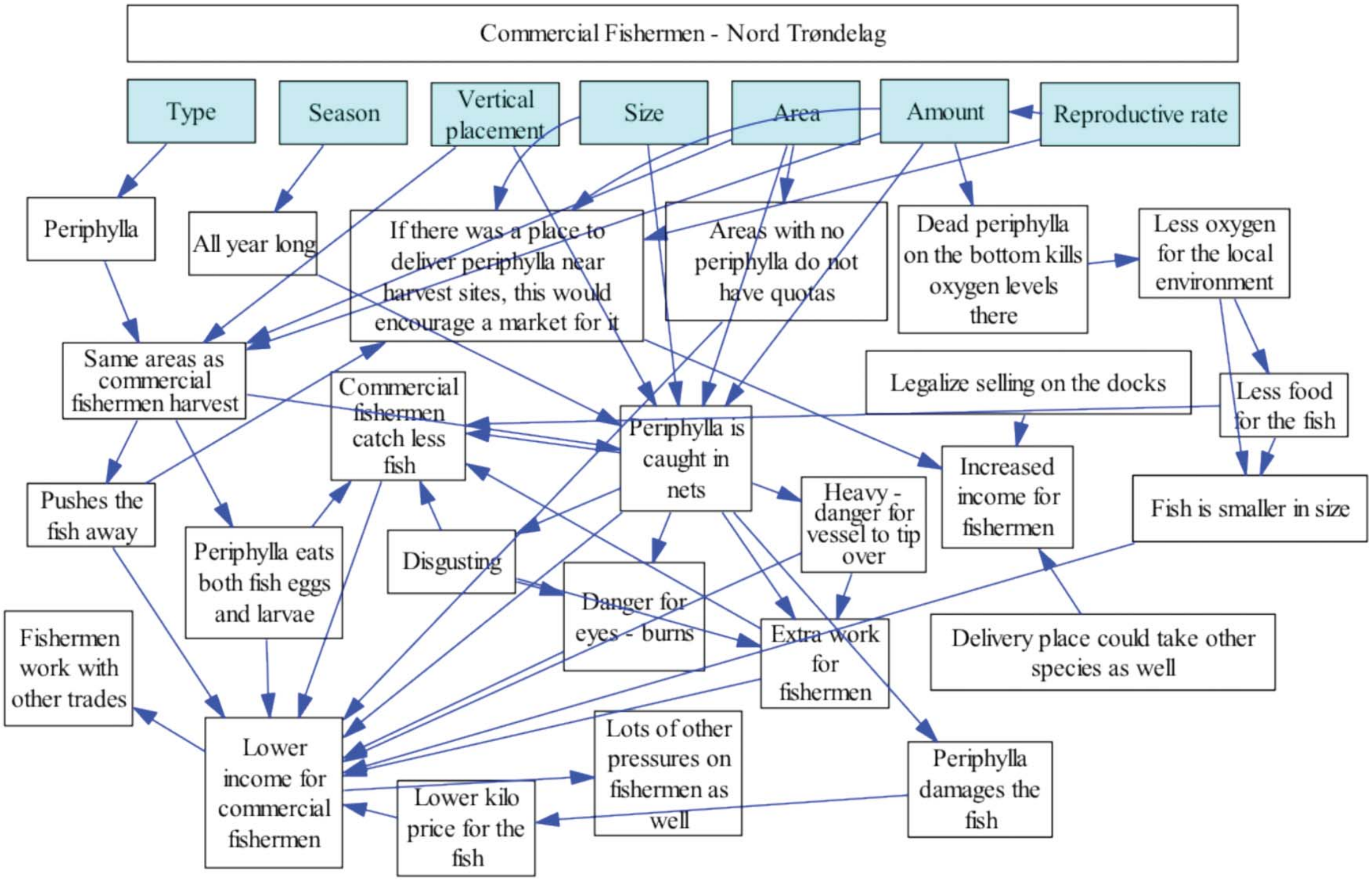

FIGURE 7. Causal pathways of the systems conceptualization process, as applied to commercial fishermen of Nord Trøndelag.

fishermen stating that they were having difficulty in fulfilling their fish quotas because of *P. periphylla*. However, it was also because of the presence of purse seiners harvesting the food of the cod. In parallel to this narrative, the influence of purse seining for Atlantic Herring and Sprat *Sprattus sprattus* emerged from the sensitivity analysis as the main determinant of whether fish biomass was high or low (these variables shown in red in Figure 8), which was a serendipitous discovery. The group showed clear frustration of what they figuratively perceived to be a "vacuuming" of the waters of the main staple in the cod diet (Atlantic Herring and Sprat), as well as cod, which follow shoals of herring and are therefore caught as bycatch. This vacuuming, they claimed, was by large company purse seiners from other parts of Norway that were allowed to come in to their fjord to harvest Sprat quotas, mirroring an ongoing tension between the coastal and the ocean going fishing fleets. Such statements are based perceptions of threat or fear, and not based on biological or economic data, yet as drivers of stakeholder actions, are important to acknowledge.

The stakeholders then proceeded to rank fish biomass (and hence income) to be much less sensitive to the two other secondary nodes (i.e., *P. periphylla* harvesting scenario and environmental protection of the fjord), something that was unexpected, since the focus of the workshop had consistently been on how damaging jellyfish are for the fishery. The concept of environmental protection also received much attention during discussion with the stakeholders during the workshop. However, much of this talk too was framed as a contamination issue associated with the purse seiners and the necessity of protecting them (the artisanal fishermen) from these commercial purse seiners. Their frustration with purse seining was very clear and that, while *P. periphylla* had been experienced and was exacerbating the current problem, there appeared greater issue with the purse seiners.

This was also reflected in the questionnaires, where commenting was common in the margins. One of these comments referred to a question as to the yearly catch in 2011–2012; this fishermen answered in this case that "…the fjord was emptied out of sprat by purse seiners [that year]…" On a question on agreement or disagreement to more environmental regulations in the fjord, the response strongly opposed more regulations, including closing off areas in the Trondheimsfjord, e.g., "…there has to be put an end to the sprat and herring fishing in the fjord," again referring to the purse seiners from other areas of Norway.

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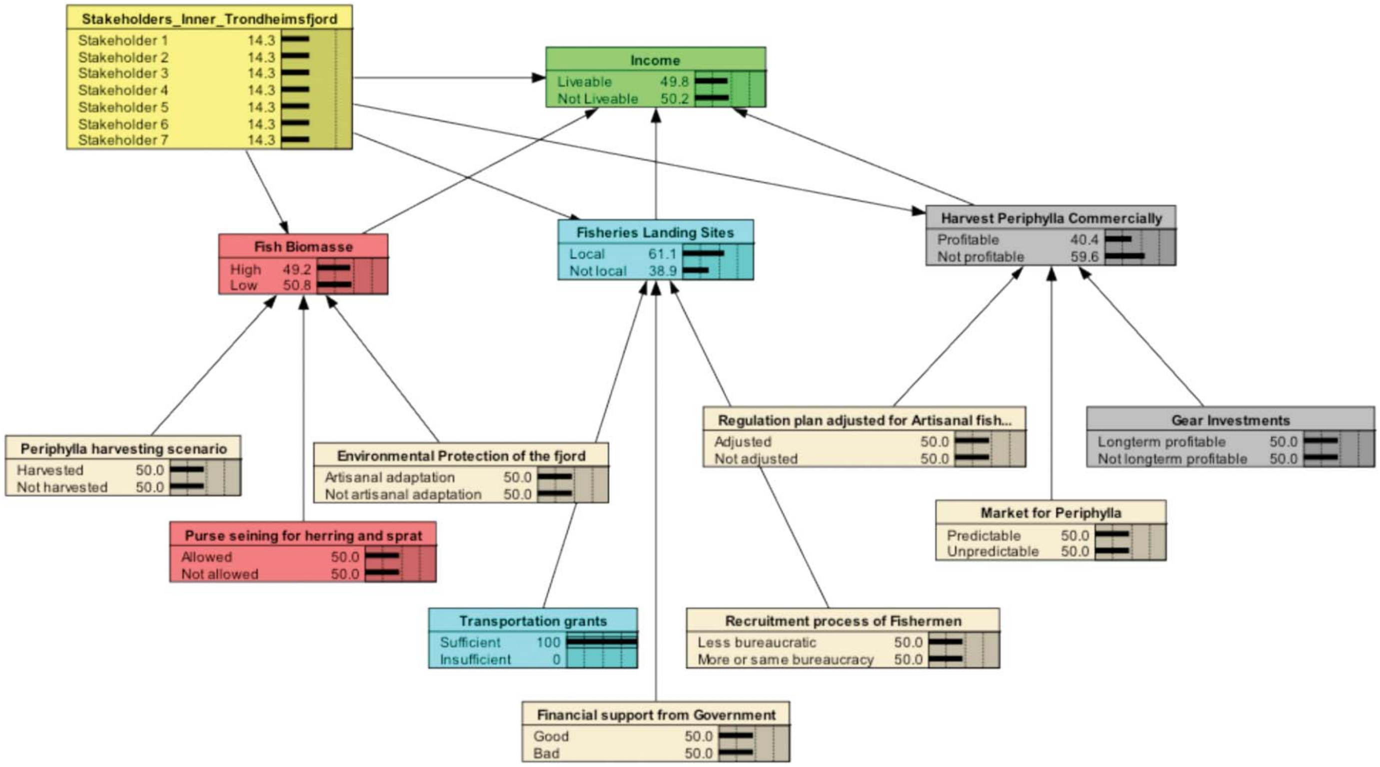

FIGURE 8. Bayesian belief network for artisanal fishermen, showing purse seining for Atlantic Herring and Sprat as having the biggest influence on their priority issue, rather than the jellyfish *Periphylla periphylla*.

DISCUSSION

Since the last decade the ecological structure and the fish abundance of the Trondheimsfjord has changed, not only because of jellyfish, but probably also due to intense exploitation of fisheries, climate change, and market forces. These have combined to generate unwanted effects on fishing behavior and patterns on the local fishers. The fulltime artisanal fishermen depend on harvesting ocean resources for their livelihood. They have rich knowledge about the fjord and resources therein, and have witnessed the changes in the marine resources and fishing conditions over time. Their fishing grounds are in general located in the areas close to their homes in the coastal areas as effected by vessel size and the location of landing sites. In this paper, we have found that these artisanal fishermen are facing increasing complexities within their fishery through the combination of ecological impacts from jellyfish and competition from commercial purse seiners that harvest cod prey as well as the cod as bycatch, elucidating thereby the idiom “Scylla and Charybdis,” or being caught between a rock and a hard place. In this case, both the jellyfish and the purse seiners are targeting commercial species fish of utmost interest to the local artisanal fishers. What emerged in this study was that though jellyfish populations were rampant, and there was a distinct correlation between jellyfish increase and cod decrease, yet the focus of the fishers was still on a human dimension. They consistently referred to competing stakeholder groups—the long-distance purse seiners—as a contributing problem of great scale in their fishing areas, almost equal to that of the jellyfish. The former is an ad hoc political issue, where the Norwegian coastal fishermen often feel discriminated against in national politics and prioritization between the local and long-distance fishing fleet. The fisher’s union affiliation of these stakeholders split in the 1990s, demonstrating the underlying feeling of discrimination. In 1987, the Association of Coastal Fishers (“Kystfiskernes Forening”), now called the Association of Norwegian Coastal Fishers (“Norges Kystfiskarlag”), was established. The group of coastal fishermen present at the proposal stage of the association commented upon the increased influence of the Norwegian Fishing Vessel Owners Association (“Fiskebåt”), which has a membership base of around 90% of all Norwegian ocean-going vessels larger than 27.5 m in the Norwegian Fishermans Association (“Norges Fiskarlag”). The Norwegian Fishermans Association is the largest fisheries organization in Norway, with some 5,700 members. It consists of seven local chapters spread along county lines, with the main administration in Trondheim, Norway. Members are both coastal fishermen with small vessels, as well as the crew of ocean-going trawlers, thereby ensuring a broad and encompassing membership base with both employers and employees represented (Norwegian Fishermans Association 2014). Though size

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clearly is paramount, especially within an interest group setting where size and membership numbers matter, there are still voices that may be lost even when the organization is as topic-specific as the Norwegian Fishermans Association. Thus, coastal fishers wanted to create a counterweight to the Norwegian Fishing Vessel Owners Association *within* the association to ensure the coastal fisherman a louder voice when decisions were made. However, when the Association of Coastal Fishers applied for group membership in the Norwegian Fishermans Association, similar to Norwegian Fishing Vessel Owners Association in 1990, the application was declined, and the group has since stood in opposition to the Norwegian Fishermans Association as a distinct and nonassociated organization. The organization is different from the Norwegian Fishermans Association in that its membership base consists entirely of coastal fishermen; these fishermen believe the rights to and fights for increased amounts of quotas and a livelihood base has, since the 1960s, been consistently taken from them and distributed to trawlers. In 2014 the organization had around 1,000 members and about 600 vessels from the coastal fleet associated with it (Association of Norwegian Coastal Fishers 2014).

The fishers affected by jellyfish in the Trondheimsfjord, believe they were unfairly impacted by top–down decisions allowing for rest quotas being distributed liberally to purse seiners and allowing them to enter the fjord where artisanal fisheries had their livelihoods. This allowance was voiced to be a bigger hindrance of adaptive capacity for the fishermen than the jellyfish, with expressions such as "vacuuming the fjord of fish." We also discovered that, though there is a jellyfish infestation in this area that could be coupled with a the decrease in cod populations, the stakeholders had complementary views on how to achieve sustainable development while still preserving both the cod and the artisanal fisherman in the inner Trondheimsfjord within the framework of their biggest perceived threat, namely the purse seiners. They suggested developing marine protected areas that would ensure that purse seiners were not allowed in to the area at all, while still allowing for artisanal fishermen to harvest the surplus of the fjord area. This protectionist vantage point expressed by the fishermen in the Trondheimsfjord could be a reflection of the discovery of an economic morality in regards to the harvest of a marine surplus (Gezelius 2004). In this study, which looked at compliance to fisheries regulation and the morality of not adhering to said regulations, it was discovered that morality was divided into green and yellow spheres of economic activities at each extreme, and a continuum along which all fishing activities were perceived to land within this area. Large offshore fishing fleets were considered to be more yellow than small inshore fisheries, which were only considered moderately yellow. The fishers in the Canadian case furthermore blamed the groundfish collapse, among others, on excessive demands driven by offshore trawlers (Gezelius 2004).

These are examples of when the bottom–up stakeholder involvement can be formalized. However, purse seining in the Trondheimsfjord is not as common as perceived by the fishers in this area, and the views of the fishers were in this case more a reflection of frustration of resource limitation. There was a limited purse seine fishery on Sprat in 2009–2010, and no fishing in 2011–2012 in the Trondheimsfjord (Bakketeig et al. 2013). In 2009, the local newspaper did report fantastic Sprat catches by purse seiners from these areas, as well as bycatches of cod (Roel 2009a) though, which could be another reason that fuelled the frustration of the fishers. At the same time, however, the Ytterøya cod production facility experienced two big escape events in December 2009 and September 2010, with 25,000 and 43,000 cod specimens, respectively (Roel 2009b). Those escapes took place in the actual purse seining area those years. Thus, the purse seine bycatch of cod those years might not have affected native Trondheimsfjord cod stock as severely as the artisanal fishers perceived it to have. Thus, even though the input of local ecological knowledge from stakeholders is critical for legitimacy of policy and compliance of stakeholders to management decisions, their perceptions need to be considered within the trinity of biological and economic data as well. In involving not only highly trained experts, including biologists, modellers, economists, and political scientists in determining the adaptive capacity of a given community, the stakeholders can highlight the areas of most critical emphasis to them and their perceptions of threat to their focus area. Ultimately, sustainable development is critical to achieve, and the participation of stakeholders is necessary to uncover possible avenues of management that are dormant in expert opinion. This would bring legitimacy to the process, thereby ensuring a higher likelihood of compliance to regulations by the government and, in turn, effective resource management. In the case of the cod fishers in the inner Trondheimsfjord, the serendipitous discovery was that the threat they perceived to be more imminent than jellyfish infestation in their fishing grounds was a commercially driven threat of larger ocean-going fleets with higher capacity fishing in the same area. The importance of this finding to management is that strategies should include acknowledging this de facto fear through consultations and inclusion, thereby creating more legitimacy and less frustration with the process.

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