A framework for agenda-setting ocean acidification through boundary work

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Abstract

Ocean acidification (OA) is already impacting marine organisms and may fundamentally alter marine ecosystems in the coming decades, with major implications for ocean services, such as food provision. Though OA is an emerging concern in coastal zone management, current actions are limited to monitoring and knowledge production. This article presents a framework for addressing coastal zone OA in local-level policy agendas through workshops, and lessons learned and outcome from the implementation of this framework in two cases in southern and northern Norway. The framework includes four components: 1) facilitating knowledge exchange and identify challenges and opportunities relating to OA; 2) ensuring legitimacy of new knowledges; 3) building capacity through learning and skill development; and 4) raise awareness about OA among local decisionmakers. The case studies include local and regional coastal zone management stakeholders and, using OA measurements and modelling, illustrate co-production of new knowledge of coastal ocean acidification and its potential local impacts. Through two rounds of workshops, we demonstrate that the level of OA awareness markedly increases among stakeholders. This awareness manifests in vocal interest for looming projected impacts and their necessary mitigative measures. This concern is compounded by stakeholders who recognize that OA should be treated as a component of water-quality, implying that OA is gaining salience as a local policy issue. However, it is evident that local management faces challenges in addressing such an issue, combined with expectations that higher levels of government take responsibility for mitigative and adaptive actions in response to OA.

Key words

Ocean acidification
Coastal zone management
Co-production of knowledge
Boundary arrangements
Environmental governance
Participatory methods

1. Introduction

Ocean acidification (OA) may significantly alter marine ecosystems and related ecosystem services (IPCC, 2014), to an extent that it will impact communities and industries (AMAP, 2018). Calcifying organism will suffer, commercially important species such as cod (*gadhus morhua)* may be negatively affected, while macroalgae such as kelp and other species will benefit (ibid.) Despite these consequences it is still not included or addressed in coastal zone management. As with climate change and other global environmental change issues, scientific knowledge about the impacts of OA does not necessarily translate into policy action (Meyer et al., 2015). Coastal zone management, the venue in which coastal OA needs to be addressed, already faces challenges due to multiple interests from many stakeholders and the involvement of strong sectoral management institutions. Examples of such management institutions in Norway are the Directorate of Fisheries that manages fisheries licenses and the Food Safety Authority that monitors the water quality around aquaculture facilities.

While it is clear that more knowledge about the effects OA is required to ensure full inclusion of the issue in policy development, this does not happen simply by providing decision-makers with increasingly accurate and detailed scientific knowledge, contrary to what many researchers and policymakers seem to believe (McNie et al., 2016). Here we outline a framework for agenda-setting and awareness raising of OA in coastal zone management. Workshops and outreach about OA consequences, combined with results from measurements of coastal OA in case study localities are the key components of the framework.

Current knowledge about OA impacts on a scale that is relevant for coastal zone management is largely unknown and riddled with uncertainty. Consequently policymakers and coastal zone managers do not necessarily consider OA to be a management issue to contend with (Kelly et al., 2014). We therefore have limited knowledge about the tools available to coastal zone management in responding to an issue with such a high level of uncertainty. Add climate change and the uncertainty increases even further.

We are proposing that our in-depth knowledge about how adaptation to climate change is implemented in local level governance agendas may serve as a proxy for understanding OA in local contexts and is instructive for introducing OA to policy and coastal zone management. The agenda-setting and subsequent governance of climate change adaptation at the local level has been found to be contingent on *co-production* of knowledge (Dannevig et al., 2013; Kirchhoff et al., 2015). The concept of co-production of knowledge can be defined in multiple ways. Here we understand it as the deliberate process of producing knowledge through collaboration between users and experts in order to ensure relevance and legitimacy (Clark et al., 2016). Adaptation requires both application of abstract scientific knowledge (e.g. climate scenarios and models) and interdisciplinary approaches. In addition, there are major uncertainties about climate impacts and consequences, and their interaction across social-ecological systems. Despite this ambiguity, national legislations and guidelines are being developed while regional governments and municipalities are, to some extent, addressing climate change adaptation in spatial planning efforts, often as a result of involvement in research projects or municipal networks (Dannevig et al. 2013). Yet, studies show that there are discrepancies between broad national guidelines on adaptation and the need for information and support relevant to the local level (Westskog et al. 2017). In Norway and most European countries, there are several organizations acting as *boundary organizations* in the field of adaptation to climate change. A boundary organization is defined as an organization that is able to straddle the two domains of science and policy due to its dual duty to both (e.g. Gieryn 1983). Relevant examples of boundary organizations are the national food safety committees that establish threshold levels for how much toxic substances can be allowed in food, or flood protection agencies that identify flood hazard zones. However, none of the boundary organizations working on adaptation to climate change are addressing OA. Some progress has been made in California, where OA has been added to the policy agenda thanks boundary organizations that have ensured stable interactions between science and policy over time (Meyer et al., 2015). With the exception of the study by Meyer et al. (2015), research on OA policy has not addressed how to add OA to policy agenda, or the specific challenges that arise when designing measures towards issues that are riddled with major uncertainties. Similar to climate change, OA has the characteristics of a "wicked

problem" (Funtowicz and Ravetz, 1994), because it is complex, difficult to define and lacks a clear "one size fits all" solution (e.g. Westskog et al. 2017).

To address this conundrum, we develop a framework for placing OA on the local and regional governance agendas. Our objectives are: 1) facilitating knowledge exchange and identify challenges and opportunities relating to OA; 2) ensure legitimacy of new knowledges; 3) capacity building through learning and skill development and 4) raise awareness of OA among local decisionmakers. The framework also details the participatory methods used to ensure inclusion of stakeholders from multiple management institutions and industries in the agenda-setting conversation.

Before outlining our framework, we briefly present a review of research on OA impacts and current adaptation, and an overview of Norway's current coastal zone management system.

1.1 Impacts and adaptation to ocean acidification

Both climate change and its lesser known cousin, OA, are causing major changes to our oceans and marine ecosystems (Caldeira and Wickett, 2003). OA is the progressive change in carbonate chemistry and reduction in pH of the ocean, which results from the absorption of carbon dioxide from the atmosphere. OA, particularly in coastal areas, may also result from long term changes in ocean circulation and fluvial and cryospheric inputs. OA has been shown to influence the performance metrics of a wide range of marine organisms, biogeochemical cycling and pollutant toxicity (AMAP, 2018). Lack of knowledge and uncertainty about the impacts of OA on ocean ecosystems is even more prevalent than that of the impacts of climate change on humans and nature. Developing policy responses and implementing measures under this level of uncertainty pose a challenge to scientists and policymakers, alike.

While knowledge about OA impacts on marine species and ecosystems is increasing (AMAP, 2018; Skjelvan et al., 2014; Stiasny et al., 2016), less is known about the impacts on socioeconomic systems, let alone the necessary adaptive measures to address negative OA impacts. Some case studies from the US have included social, legal and economic aspects of OA, and these highlight a number of significant knowledge gaps in the physical science basis and in how society can adapt to OA. The Pacific Northwest, in particular, has experienced several acute OA events with severe impacts on the shellfish industry (Ekstrom et al., 2015). Several states have, therefore, begun drafting

legislation to mitigate OA impacts. Economic impacts are currently not felt in Europe, but recent findings show that OA can cause major disruptions in commercially-important fish stocks, such as North Atlantic Cod (*Gadus Morhua*) (Stiasny et al 2016). In Norway, as in the rest of Europe, OA is presently not on the policy agenda.

1.2 Governance in the coastal Zone

In Norway, the municipality is the leading authority in coastal zone planning, with the responsibility of designating coastal water zones in the municipal spatial plans, and sometimes in designated marine spatial plans (276 or 2/3 of all Norwegian municipalities are coastal). County councils, the elected regional-level governments, are tasked with regional coordination of municipal coastal zone planning, and different strategies for coastal zone management apply [1]. Municipal coastal zone planning autonomy is restricted through several national acts devolving powers to national agencies with respect to fisheries, navigation, environmental management, and aquaculture. These complex managerial relationships submit coastal management to an inherently multi-level governance structure (Hovik and Stokke 2007).

Underpinning this complexity, Norway has adopted the core principles of integrated coastal zone management (ICZM), which involve the use of knowledge from multiple disciplines and participation of stakeholders in management (Bremer and Glavovic, 2013; Hovik and Stokke, 2007; Sandersen and Kvalvik, 2014). Integration of different forms of knowledges and participatory approaches are found to be critical for successful coastal zone management (Bremer and Glavovic, 2013; Knol, 2010). In all planning processes, the Norwegian Planning and Building Act's requirements about public participation have to be followed. However, several studies show that there are clear discrepancies between the overall goal of participation and the actual requirements related to participation in the Act (Knudtzon, 2015).

Since 2007 the coastal areas are subject to management under the Water Framework Directive (WFD), which requires assessment, monitoring and observation of coastal locations[2]. OA is currently not included in the water quality assessments and monitoring carried out under the WFD. OA monitoring of Norwegian shelf and fjord regions has only been performed since 2010 and the incremental changes are too small

[1] See Supplementary Online Material for details about the Norwegian coastal zone management.
[2] See Supplementary Online Material for details about the Water Framework Directive

to detect in the highly variable and seasonal carbonate system (Skjelvan et al., 2014). Knowledge of OA is therefore reliant both on models that operate on larger time-scales and on our understanding of the changes occurring in the water bodies that supply coastal Norway. The nascent stage of coastal modeling and management requires holistic consideration of actors and institutions that both decide and rely on the future of these coastal regions. Their cooperation is contingent on organized and effective modes of communication and decision-making

2. Participatory research methods for co-production of knowledge: A way forward

We argue that *boundary arrangements* for the co-production and application of knowledge of OA is a prerequisite for achieving sustainable management of the coastal zone. A boundary arrangement is similar to a boundary organization in that it ensures communication, legitimation and mediation of knowledge between the domains of science and policy (e.g Cash et al., 2003). Hence, it is a framework for carrying out boundary work and co-production of knowledge. Both boundary organizations and boundary arrangements ensure the involvement of different voices and mediate conflicts that arise when highly uncertain issues are added to the governance agenda (Cash et al., 2003; Kirchhoff et al., 2013). Except where boundary organizations are formal, lasting institutions, boundary arrangements (see also Hoppe 2005) are , temporal and/or ad hoc phenomena designed to address specific issues.

Scholarship with a deliberate focus on co-production of knowledge in the context of ICZM has not been overly concerned with how new issues, such as climate change adaptation and OA, can be added to the agenda. There are also particular challenges in co-producing knowledge for wicked problems, which is exacerbated in the case of OA due to lack of recognition and awareness (Meyer et al., 2015). Much of the literature on co-production does not sufficiently address how stakeholders (or other users of knowledge) are involved, contribute to and learn from knowledge production. Learning, in particular, is a necessary component of co-production, and a significant body of literature on this component resides under the umbrella of social learning in organizations (Reed et al., 2010) and its importance for adaptation (Adger, 2009; Pelling et al., 2008). However, the research literature on social learning tends to confuse social

learning as a process with social learning as an outcome (Reed et al. 2010). It is thus necessary to pay attention to the specifics of how stakeholder participation is organized and how it unfolds.

Literature on participatory methods distinguishes between different levels of engagement; Arnsteins "ladder" remains a frequently used heuristic (Arnstein, 1969; Collins and Ison, 2009), with little involvement and participant control on the lower rungs, and transformative involvement at the top. Methods used for stakeholder participation aimed at fostering social learning and co-production of knowledge need to be tailored to the level of engagement sought at different stages of the production and learning process (Reed, 2008). If the goal is to achieve both capacity-building and co-production of knowledge, it is necessary to do more than occasionally communicate and consult with stakeholders.

Rather, stakeholders must partake in formulating the research questions in addition to improving their own knowledge and understanding of the issue at hand. Stakeholders need to be given real and equal influence in decisions and perceive the process to be fair and valid (Tippet et al., 2007). Thus, participation requires "a level playing field," wherein inequalities between participants are made negligible by the ubiquity of education about the problem. Furthermore, participants must build mutual trust , which will facilitate a willingness to learn and share knowledge. Workshops have been shown to be an effective method for facilitating and achieving deliberate coproduction (Nilsson et al., 2017).

Through repeated meetings and cooperation, stakeholder groups could eventually evolve a relationship of confidence and trust, forming a *hybrid management space* (Dannevig and Aall 2015), where exchange of knowledge and learning are promoted (Dannevig and Aall, 2015; Pelling et al., 2008).

In order to agenda-set and manage a new issue derived from science, *boundary objects* that can aid the translation from science to policy is required (Dannevig and Aall, 2015; Guston, 2001). Threshold levels in environmental governance are classic examples, such as for toxins in food or return periods of floods. In the case of OA-management, no threshold levels or other boundary objects have been identified or defined.

The following section explains our approach for gaining stakeholder trust and engagement (Smit et al., 2010).

3. Methods for co-producing OA knowledge for coastal zone management

The framework includes the following organizational steps: 1) Input workshops with stakeholders that guide the production of OA knowledge; 2) OA measurements and modelling with participation from users in water sampling; 3) production of guidance material on OA for stakeholders, and press releases in the media; 4) Scenario feedback and response options workshops. The project framework is illustrated in Figure 1 below. New policy solutions for adaptation to OA as the final outcome of the project will be presented in a subsequent article.

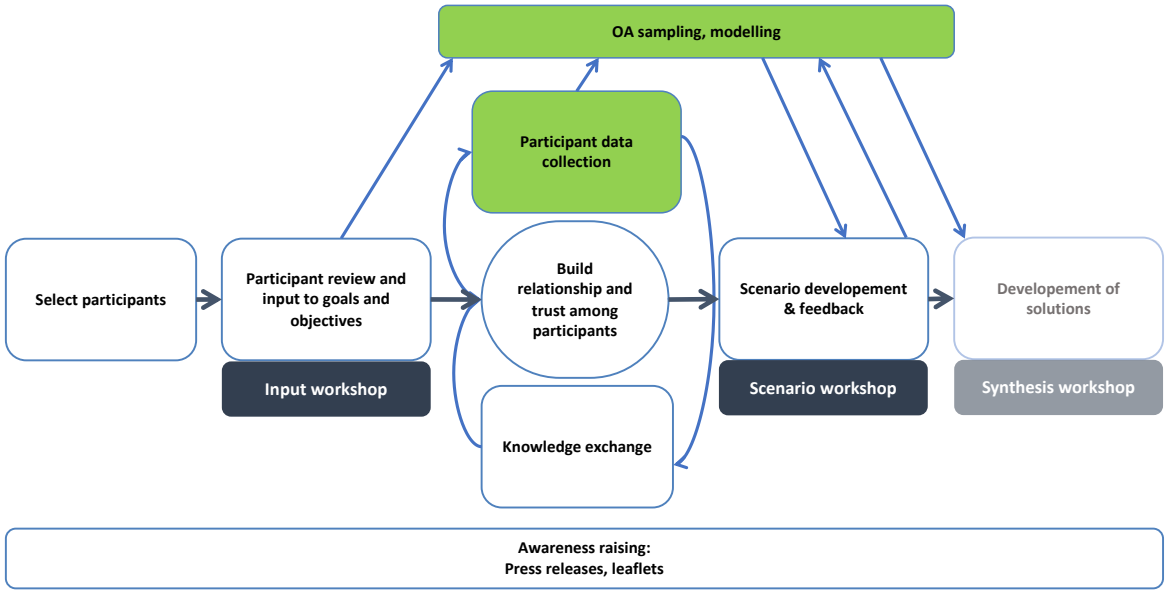

Figure 1. The model for stakeholder participation for co-production of OA-knowledge. Green boxes are the marine science project tasks, the white ones are tasks targeted at stakeholder involvement and the blue are the workshops.

3.1 Workshop methods

Five workshops and two meetings with stakeholders, as well as two town hall-meetings with the general public, were conducted from autumn 2016 to autumn 2017. The key coordinating actors for coastal zone management, the planning departments at the county councils in Nordland and Hordaland counties, were invited into the project at the research proposal stage and had the opportunity to influence the study's focus. Review

of academic literature on Norwegian coastal zone management, as well as grey literature on coastal zone plans, municipal plans and the plans of the water regions was conducted.

In the northern case, local partners were trained in seawater sampling techniques in order to conduct monthly water samples for the characterization of carbonate system and nutrient variables.

Below, we outline how the cases and stakeholders were selected and describe the cases physiographic characteristics before presenting our approach to creating conditions for the co-production of knowledge.

3.2 Case and Stakeholder selection

Cases were selected using the following criteria: fjords with multiple uses (fisheries, aquaculture, tourism, protected areas); municipalities that prioritized coastal zone planning (through allocation of administrative resources) and were willing to join the project; availability of oceanographic time series data (pH, temperature, salinity); a representative geographic distribution, i.e. one case in Southern Norway and one in Northern Norway (see Figure 2). Following the criteria above – the northern case selected was the Buksnesfjord in Vestvågøy municipality in the Lofoten Islands in Nordland county , and the southern case was the Kvinnheradsfjord, Kvinnherad municipality, in the Sunnhordland region of Hordaland county. We recruited stakeholder partners from all the governmental organizations involved in coastal zone management at the regional and local level (see table 1 below for details). This include departments in the county councils, the municipalities and the county governor. The latter is the national government's regional office. We also invited officials from the Norwegian Environmental Agency, who are responsible for coordinating the WFD on the national level as well as monitoring OA. Further, we recruited stakeholders from industry and other users of the coastal zone. A stakeholder is here defined as an actor with user interests in the issue at hand, in this case coastal zone management. A stakeholder might thus have several representatives. For each case the selected stakeholders constituted a regional user group.

Table 1. Stakeholders

County	Stakeholder	Responsibility/role
Nordland and Hordaland	County governor, dept. of environment	- Checks municipal spatial plans - Issues discharge permits from industries and municipalities (incl. aquaculture)
Nordland and Hordaland	County councils, dept. of climate and environment, and dept. of industry	- Coordinates water quality assessments. - Coordinate coastal zone planning - Approves new aquaculture licenses (Hordaland only)
Nordland	County council, dept. of industry	- Approves new aquaculture licenses
Hordaland	Directorate of Fisheries	- Approves new aquaculture licenses - Sets quotas for coastal fisheries - Checks municipal spatial plans on behalf of fisheries
Nordland and Hordaland	Kvinnherad and Vestvågøy municipalities, planning department and industry departments	- Produce marine spatial plans - Approve marine zoning plans -
-	Norwegian Environmental Agency	- Monitors OA in Norwegian sea areas - Steers the environmental dept. at the county governor.
Hordaland and Nordland	Water area managers for Lofoten and Sunnhordland	- Coordinates activities related to the WFD in the municipalities
Hordaland and Nordland	Aquaculture companies	- Need access to coastal areas for fish farms, submit marine zoning plans for these to the municipality
	Fishing companies/fishermen	- Have rights to certain types of fisheries in the coastal zone
Hordaland	Aquaculture industry organisations	- Promote industry interests
Nordland and Hordaland	Fisheries industry organisations	- Promote industry interests

Figur 2: Map of Norway with case study regions in red, the northern case of Lofoten and the southern case of Sunnhordland.

3.2.1 The southern case

Kvinnheradsfjorden, the outer part of Norway's second largest fjord system, Hardangerfjorden, constitutes the core of the Sunnhordland case region (Figure 2). The fjord stretches 21 km northeast to the island Varaldsøy. Traditional use of the fjord includes inshore fisheries, dominated by catches of saithe (*Pollachius virens*), cod (*Gadus morhua*), herring (*Clupea harengus*) and prawns (*Pandalus borealis*). In recent decades, Sunnhordland has become one of the most important aquaculture areas in Norway; Kvinnheradsfjord alone includes more than thirty aquaculture locations with licenses for salmon farming. The water quality of the Kvinnherad fjord basin is considered 'moderate' due to its contact with the highly contaminated Sørfjorden waters, the

innermost part of the fjord system polluted by heavy industry since 1908 (Ruus, et al. 2013). Other significant stakeholder groups are the tourism industry, outdoor recreation interests and leisure salmon fishing. One notable user-interest conflict in the coastal zone pits coastal fisheries on one side and fish farming, contamination from industry, wastewater and waste disposal on the other. Since 2000, prawn catches in Sunnhordland have been scarce, and in addition trawling in the fjord waters is hampered by aquaculture facilities. A coastal zone management plan prepared by the county administration has caused fierce resistance from the aquaculture industry, which asserts that the administration is restrictive and represents 'anti fish farming attitudes.'

3.2.2 The northern case

Buksnesfjorden, part of the Vestfjord fjord system, constitutes the core of the Lofoten case area (Figure 2). The 7 km long fjord is mostly surrounded by low-lying agricultural land and has the highest population density in Lofoten. Vestågøy municipality has approximately 11,300 inhabitants (in 2017). Three larger villages, several smaller hamlets and farms form a contiguous string of settlements along the fjord. Leknes harbor in the innermost part of the Buksnesfjord is one of Northern Norway's largest cruise ship harbors and an important fishing port, especially for the herring fleet. Other significant stakeholder groups are the tourism industry, which includes diving and surfing, outdoor recreation interests and leisure fishing. There are several fish farming sites at the outlet of the fjord, such as Lofoten Seafood, which has produced Atlantic salmon (*Salmo salar*), dried fish and salt fish in Buksnesfjord since 1980. A crucial water quality challenge faces Buksnesfjord due to nutrient discharge from sewage and fish farming industrial activity. Due to this contamination, the water quality of both the inner and outer fjord basin of Buksnesfjorden is considered 'moderate.' The municipality is upgrading their drainage system and plans to move the sewage further out in the fjord. At present, there are no coastal zone strategies for the Vestvågøy municipality or the Lofoten region.

4. Learning, capacity building and agenda-setting through workshops

4.1 Workshop implementation

The project included two sets of workshops, with the overall aim to facilitate coproduction of OA knowledge relevant for coastal zone management. *Input workshops* held during the initial phase of the project served to establish case-wise regional user groups of the stakeholders and to introduce these to the topic of OA. *Scenario feedback workshops* conducted midway through the project comprised group discussions on possible consequences and management strategies, based on OA scenarios that were presented to the stakeholders. In the following we will show the main components of the input and scenario feedback workshops[3].

The input workshops started with introductory lectures on the significance of OA, given that the issue is a novel challenge with impacts that are difficult to directly discern and observe from a stakeholder perspective. Leaflets with key messages about the severity of OA were also provided to the stakeholder groups. Press releases to local and regional media precipitated four newspaper articles and one radio interview. Media coverage was partly motivated by raising the awareness of the OA issue among stakeholders and others in the local communities in the case study region. Furthermore, the input workshops were used to discuss possible consequences of OA based on local knowledge, and to identify vulnerability themes and geographical areas of particular interest in the case areas.

The scenario feedback workshops started with a series of presentations on possible outcomes of OA in the fjord ecosystems, and discussions between user groups, which highlighted perceptions of both OA and its impacts. Sampling-based OA projections from the two fjord systems, as well as impact scenarios for key species in the regions (see box 1 and fig. 3) were presented to the workshop participants. The projections showed OA-levels in 20-year intervals until 2060, instead of the usual 2100 projections, to make it more relevant for the stakeholders with a shorter planning horizon. The OA projections showed marked differences between sampling stations, illustrating the local variations in coastal OA, which make it difficult to establish baseline

[3] See Supplementary Online Material for details about the workshop implementation.

OA levels for larger areas. The OA scenarios demonstrated the potential and likely effects on ecosystems and key species projected to arise in a few years for the southern and within a few decades for the northern case. Following the scenario presentation the participants were divided into two group exercises. The first addressed participants' perceptions of OA consequences for different sectors, the second OA management and governance [4].

In both case areas the participants of the input workshop and scenario feedback workshop were largely the same (N= 13-14 participants; 8-9 not belonging to the research group). A majority of the user groups comprised officials from public administration at both the municipal and regional government level. These participants represented a large diversity of professional backgrounds and responsibilities, including spatial planning, water planning, environmental management, and business development. Representatives from aquaculture companies and their industry organizations also participated in all workshops, while fishery representatives made last-minute cancellations in both cases.

Box 1: Local OA-projections

Model: SINMOD. This is a 3D ocean biogeochemical model that simulates the interactions of ocean circulation, seawater physico-chemical properties, and a simplified planktonic food web (Slagstad et al., 2015).

IPCC scenario: SRESA1B. This is one of the scenarios produced by the IPCC's Special Report on Emissions Scenarios (IPCC SRES, 2000). that assumes rapid economic growth, a convergent, globalised economy, and a "balanced" emphasis on all energy sources.

Approach: Baseline measurements from the monitoring campaign were corrected for future change using SINMOD projections (at the closest grid point to Buksnesfjord) to produce scenarios of ocean acidification from 2017 to 2067. Interpolated measurements and associated projections for surface pH in the Buksnesfjord are shown below in figure 3 (50-year decrease is ~0.2 pH units).

[4] See Supplementary Online Material for details about the excercises.

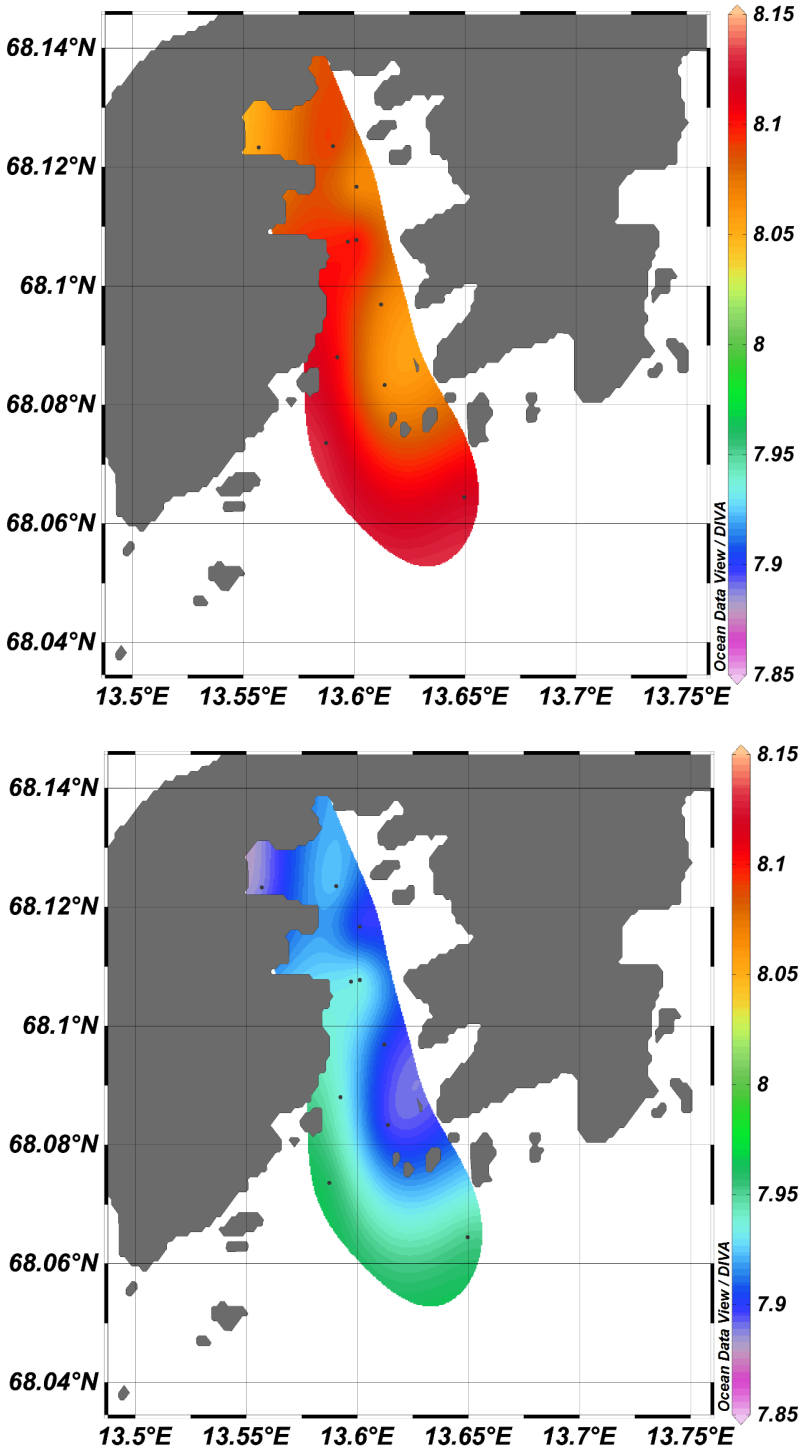

Figure 3. These plots illustrate the measured present-day values (May 2017, upper figure(top)) and projected values for May 2067 (lower figure) for surface seawater pH_T (T = total scale).

4.2 Workshop outcome

Major workshop outcomes were: (1) genuine interest in OA due to concern about its impact on fjord ecosystems; (2) identification of exacerbated conflicts of interests in coastal zones due to land use planning processes (both cases); (3) perceptions of OA as an opportunity to launch an overdue coastal zone management plan (northern case); (4) identification of the WFD as a feasible framework for dealing with OA matters (both cases); (5) discussion of suitable water sampling station sites; (6) perceptions of OA as an indirect challenge for fish farming, potentially providing opportunities for kelp farming. Overall, there was agreement that the level of knowledge about OA is low and that there is need for popularized dissemination of information on OA. The input workshop provided valuable insights in the local cases but revealed to researchers the challenge of mobilizing relevant user groups. The major shortcoming was the absence of group members due to short notice cancellations.

Across scenario workshops in the case areas, there were several and identifiable requisites (see table 2): increased knowledge on OA consequences in all relevant sectors, relevance of OA information for decision-makers and, lastly, communication of this information to the public. Moreover, workshop participants raised concerns about local adaptive capacity, restructuring of both fisheries and aquaculture, and the need to take precautionary measures against OA. Groups also expressed differing perceptions about the municipalities' ability to extend land-use planning into the ocean in consideration of OA. Several participants underlined the need to incorporate OA management into the work of the WFD and stressed that this initiative must come from the national or even international level.

In the northern case, scenario workshops prompted concern over a darkening of the azure-blue waters often observed in the region. This potential change is attributed to a decline in seasonally-dominant calcifying phytoplankton and an increased weathering rate of shell fragments (AMAP, 2018), of which the white sandy beaches in Lofoten are composed. Alarm for this shift is predicated on its potentially negative consequences for tourism and recreational activities, such as diving, surfing and kayaking in the region. More fundamentally, a change in coastal appearance threatens Lofoten's sense of place and identity. Compounding this cosmetic concern are the negative effects of increasing jellyfish populations, an issue that was brought up in both the discussions and in plenary meeting due to the organism's historically negative impact on fish farming. In both

discussion groups, near-future OA consequences on fisheries and fish farming were questioned, and the need for local adaptation to OA, as well as increasing ocean temperatures , were underlined.

In the discussion that followed the group work exercise in the southern case, an aquaculture company acknowledged the importance of taking local OA levels into account when localizing fish farming facilities. In the northern case, there was agreement that the municipalities should use their power as marine spatial planning authorities to limit industrial and commercial activity in particularly vulnerable areas, and that OA parameters should be included in the assessment and monitoring program mandated by the regional water plan (part of the WFD-work).

Table 2 Categorization of input from stakeholders during the workshops and attribution of salience and legitimacy to these.

	Input scenario northern case	**Input scenario southern case**	**Scenario workshop northern case**	**Scenario workshop southern case**
Issues and sectors potentially impacted by OA, as defined by stakeholders	-Lofoten cod fisheries could be affected -Marine biodiversity compromised	-Fisheries reduced. -Potential stress on wild salmon will impact aquaculture industry	-Fisheries reduced, fish stocks move further north - Fish farming activities impacted - Darkening of beaches and seawater	- Opportunities for kelp farming
Indicators of salience of OA-issue	-County councils as formal project partners -Request for more knowledge	-County councils as formal project partners -Request for more knowledge	-Calls for inclusion of OA-parameters in water quality measurements and monitoring	
Indicators of legitimacy of knowledge	(not relevant)	(not relevant)	-Consider relocation of planned sewage treatment plant -Municipality should use marine spatial plan to protect vulnerable areas -Include OA parameters in water quality assessments and monitoring programs.	-Aquaculture representatives recognize need to take OA into account in future location criteria for fish farms.

The two bottom rows categorize the input from the workshops according to Cash and colleagues criteria for usable knowledge: salience and legitimacy (2003). Cash and colleagues' third criteria, credibility, pertaining to the rigor and trustworthiness of the science involved was not assessed in our workshops.

4.3 Workshop evaluation

For the study's workshops, we brought multiple stakeholder groups together, provided them with information on OA, and invited them to reflect on potential and actual vulnerabilities and consequences derived from OA. This workshop method and structure proved an effective way to facilitate knowledge co-production on the topic of OA, especially because, until recently, the issue has been largely unaddressed amongst these actors. Stakeholders managed to gain an awareness of OA consequences beyond their immediate interest groups and visualize impacts from other stakeholders' perspectives. The project facilitated multiple meetings between the stakeholders, ensuring that there was space and time for learning between groups. This was most evident in the development of stakeholder positions on OA salience and the perceived need for adaptation measures, as summarized in table 3.

Despite their positive outcomes, the workshops suffered from certain shortcomings, the most prominent was underestimating the challenge of mobilizing busy professionals. This resulted in the absence of fishermen from all workshops, though representatives from fishery research and management did participate. Appointments with more than one representative for each stakeholder group would have made the workshops less vulnerable to last minute cancellations.

5. Lessons learned

Two lessons learned from organizing the workshops and outreach are most prominent: 1) the raised awareness of OA among the participating stakeholders. This overlaps with the overall result of the framework implementation, but it shows the importance of facilitating mutual learning and co-production of knowledge between researchers and stakeholders, and the benefits from doing outreach activities in the case study areas. The latter included both a town hall meeting in relation to one of the workshops, user involvement in data collection, and press releases that resulted in local news media coverage; and 2) the challenge of getting the stakeholders attending the workshops.

Recruitment of relevant stakeholders to research projects is a recurring challenge, but even more challenging is to ensure that they show up at the workshops. Even when stakeholders agree to participate and the workshops are scheduled based on their availability, more pressing tasks have a tendency to get in the way. One way to overcome this challenge in the future is to organize the same workshop several times in the same case study region. In the southern case we did both workshops twice, on two different locations, to get as many stakeholders to attend as possible. Limited time and financial resources put the brakes on organizing multiple workshops.

The outcome and results from the workshop implementation are summarized in line with the framework objectives: a) facilitating knowledge exchange and identifying challenges and opportunities relating to OA; b) ensuring legitimacy of new knowledges; d) building capacity through learning and skill development; e) raise awareness OA in the case study communities and f) finally we also sum up research and monitoring needs as defined by the stakeholders.

a. *Facilitating knowledge exchange and identify challenges and opportunities related to OA.*

Many of the participants that had been involved in the project from the beginning showed increased knowledge of OA during the scenario workshops (see also table 3). This was conveyed through an outspoken interest in looming OA impacts, and through discussions of measures to mitigate future consequences. While the stakeholders were skeptical to whether OA were as threatening as the scenarios suggested, they also agreed that OA would have to be dealt with in the future.
The workshops clearly generated sincere interest in OA impacts on fjord systems and increasing the participants knowledge about the subject.

b. *Ensuring legitimacy of new knowledges*

Evidence that OA is increasingly becoming salient is illustrated in as the stakeholders acknowledgement that acidification should be treated as a water quality issue and that OA parameters should be included in monitoring and assessment programs as part of the implementation of regional water plans (under WFD). Representatives from sectors contributing to nutrient discharge, e.g. sewage plants and aquaculture, acknowledge that

it OA should be considered in future planning of new locations for their respective industrial development. This response indicates that the legitimacy of OA, is positioned as a persistent problem that warrants action (Cash et al., 2003). Currently detailed knowledge of both local OA projections and impacts is lacking stalling the mediation between researchers and stakeholders. We surmise that if OA were made central to marine activity regulation and/or coastal zone planning, boundary work mediation would become essential and create space for the use of co-produced knowledge as a foundation for action.

c. Capacity building through learning and skill development.

To "level the playing field" (e.g Reed, 2008) is critical for further co-production of knowledge and enabling meaningful engagement of stakeholders. The verbalization of concerns and solutions illustrated above indicates that capacity building has taken place. The final workshops contained extensive and productive discussions between stakeholders from different sectors; the aquaculture representative in the northern case noted that it was especially useful to meet and discuss with municipal representatives because it gave him the opportunity to exchange information relevant for moving sewage further out into the fjord. This indicates that our efforts to create temporal hybrid management spaces, where social learning, capacity building and co-production of knowledge takes place, are successful (Dannevig and Aall, 2015).

d. Awareness raising

There are clear indications of increased awareness among our stakeholders and case study communities, exemplified by how they discussed the new areas of potential impacts of OA and solutions for mitigating. This dovetails with objective a. seeking indicators for increased awareness. Additionally there are indications that local- and regional newspaper articles about the project and its findings raise the awareness in the case study communities.

f. Research and monitoring needs

The workshop discussions also raised the need for more monitoring and research on OA, for enabling local and regional management. The values of different OA-parameters (such as pH and aragonite saturation) in coastal waters show significant variation in

comparison with the high seas. This is due to highly variable local conditions, indicating that the establishment of local or regional OA-thresholds for management requires a substantial research effort.

6. Conclusion

To what extent did we succeed in adding OA to the coastal zone management agenda? In our experience, OA is an even more challenging issue to engage with than climate change. Both qualify as "wicked problems", but OA is still a novel issue, with even fewer "real world events" that raises awareness and that can serve as "windows of opportunities" for agenda-setting (Birkland, 1998; Dannevig et al., 2013). Thus, the effort required to co-produce OA knowledge for coastal zone management is daunting. For OA to be seen as a salient and legitimate management issue, substantial resources must be dedicated to awareness raising, learning and capacity building to enable co-production of knowledge. In this study, we do this through OA lectures and interaction in the workshops, popular science dissemination in town hall meetings and through local news media articles.

During the workshops, solutions for management of OA was discussed, such as implementing pH-threshold levels in the "traffic light" system of the WFD or including OA parameters in measuring water quality. In doing so, boundary objects, such as pH data and coastal community health become actionable items where scientific knowledge is turned into policy decisions (Clark et al., 2011). Workshop discussions, along with reviews of coastal zone plans , confirm findings in the ICZM-literature (e.g Hovik and Stokke, 2007; Sandersen et al., 2013), which underline the obstacles in tackling issues that cross sectorial boundaries, issues that often rely on local voluntary efforts and are not initiated at the national level.

We have yet to document the extent to which these workshops have initiated further OA discussions in formal venues of local and regional coastal zone planning. This is a subject for further research.

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Appendix: Supplementary online material for the article "A framework for agenda-setting ocean acidification through boundary work"

Governance in the Coastal Zone and the Water Framework Directive

Some Norwegian counties, such as Hordaland, Sør-Trøndelag and Troms, chose to develop independent regional coastal zone plans (Hovik and Stokke, 2007), while others, in addition to negotiating between public and private sectors, have collaboratively developed inter-municipal coastal zone plans with neighboring municipalities, as encourage by the national government. While the principles of Integrated Coastal Zone Management (see article for outline) has been adopted for the management of the coastal waters, the high seas is managed according the principles for ecosystem-based management (EBM), which have been explicitly included in the larger scale management plans for the Barents Sea, North Sea and Norwegian Sea. EBM relies heavily on regular monitoring and observation input from marine science, and these requirements are not met for the management of the coastal sea areas (Sandersen et al. 2013).

Complicating the already complex coastal zone management in Norway is the implementation of the water framework directive (WFD) The WFD is a EU-directive that was adopted in Norway in 2007. Rather than following existing administrative and political borders the WFD uses an ecosystem-based approach and draw on hydrological units so called River Basin Districts for management. Each River Basin should thus follow the water as it passes from mountains to fjord regardless of the existing national and international borders within the area. The WFD sets out to protect fresh water, surface water, water ways, ground water, brackish water, transitional water, and coastal water out to one nautical mile off land.

There is an ongoing controversy regarding the extent the WFD shoul include aquaculture. At the moment, the impacts from salmon lice and escaped salmon is not monitored or managed under WFD. It has been argued that aquaculture contributes to diminished wild salmon stocks caused by the permanent presence of salmon lice in the fjords, and escaped farmed fish (Svåsand, Grefsrud et al. 2017). These accounts are

partly opposed by the fish farmers' interest groups, who accuse Norwegian aquaculture policy of being based on scientifically unreliable marine research (SjømatNorge 2016).

Workshop implementation

The input workshops took place in spring 2016, in the initial part of the project. The northern case input workshop was held in Leknes (Vestvågøy municipality), while the southern case included two subsequent meetings, in Rosendal (Kvinnherad municpality) and the city of Bergen.

In the autumn of 2017, *scenario feedback workshops* were conducted in Rosendal and Leknes. A third scenario workshop was conducted in Bergen later in the fall, further covering the southern case. These workshops were primarily composed of participants from regional level organizations and national government. Table 1 shows the number of participants and the distribution between stakeholder groups for input workshops and scenario feedback workshops alike.

Table 1 Stakeholders that participated in input workshops and scenario feedback workshops (figures for the southern case include workshops that took place in both Rosendal and Bergen).

	The input workshops		The scenario feedback workshops	
	Northern case	Southern case	Northern case	Southern case
Fish farming	-	2	1	2
Municipality	2	2	4	3
Inter-municipality	1	1	2	-
County	1	1	1	1
County Governor	2	1	-	1
Governmental		2	-	1
NGO	2	1	-	-
Consultancy	1	-	-	-
Research group	4	5	5	5
Total	13	14	13	13

Scenario workshop participants were invited to ask questions and comment throughout the workshop. Subsequently, they were divided into random groups of four participants for two group discussions. The first discussion pertained to the participants' perceptions

of the consequences of OA for three sectors: 1) fisheries, 2) fish farming and 3) tourism in the two case areas. The groups focused on one sector at a time and were asked to identify their concerns about OA effects. These concerns were noted on posters assigned to each sector. When the groups moved their discussion to the next sector, they also swapped posters, allowing each new deliberation to build on the previous group's discussions. Beginning with a short presentation of the governance of coastal zones in Norway, the second discussion addressed management and governance measures for responding to the consequences of OA. Participants were asked to reflect on measures taken at various governance levels. During the group discussions, the study's researchers followed the trajectory of conversation, answered specific questions and recorded specific details, all of which provided a detailed dataset to accompany what the workshop groups noted on the posters.

After completing their discussions, the workshop groups presented their identified issues and concerns for each sector, followed by an open discussion between both participants and researchers. Researchers created short summaries of the issues raised during the scenario workshops and plenum sessions. The researchers' presentations (e.g. the OA-projections) were made available through hyperlinks in these summaries, which were then sent out to all participants to ensure that all topics were covered and accessible. In Lofoten's case, some of the participants responded with additional issues.

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