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Adaptation to climate change – related ocean acidification: an adaptive governance approach.

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Key words: ocean acidification; adaptive governance; climate change adaptation; aquaculture

Abstract

Climate change-driven ocean acidification (OA) is causing rapid change to global ecosystems and poses a significant threat to marine life. However, predicting ecosystem effects remains highly uncertain and governance responses to OA are not yet forthcoming. Adaptive governance can provide a means to deal with this uncertainty and we consider its application to the polycentric governance of adaptation responses to OA in Scotland, focussing on the aquaculture industry as a vulnerable sector. A workshop was used to develop potential adaptation responses to OA and to gain information about present and potential capacity for adaptive governance at national and regional levels. Scottish legislation, policy and planning documents were subsequently analysed to enable description of how governance arrangements constrain or enable adaptation responses. Legislative and policy analysis indicates convergence across emerging mechanisms in support of adaptive governance. Recent advances in climate change adaptation in Scotland promotes integration of adaptation into wider Scottish Government policy development and functions, based on iterative and collaborative processes across scales. Alongside this, institutional change in coastal and marine governance, including a partnership-led regional marine planning process and devolution of management through Crown Estate Scotland, seek to advance new models of locally-led and learning-based planning and management which can support adaptation. Better integration across policy and planning mechanisms is needed to enhance adaptive capacity, including between climate change adaptation, marine planning and aquaculture planning and management. This could be enabled through co-ordination of monitoring and review processes to promote learning across scale and establishing links between existing and proposed collaborative groups to enhance development of adaptation responses. However, expansion of the aquaculture industry faces significant social and ecological constraints which mean accommodating adaptation through spatial measures is difficult, and is further challenged by the uncertainty in predicting specific OA effects. The low adaptive capacity of the prevailing aquaculture licensing regime is identified as a potential constraint to adaptive governance and recommendations to enhance flexibility and enable adaptation are made.

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1. Introduction

1.1 Ocean acidification

Ocean acidification (OA) refers to the increasing acidity of seawater due to anthropogenic emissions of CO_2, with far-reaching effects on ecosystems and marine users (Fabry et al., 2008; Frommel et al., 2011; Kroeker et al., 2013). In 2019, reporting on OA as Target 14.3 of Sustainable Development Goal (SDG) 14 of the United Nations 2030 Development Agenda indicates increasing concern of "serious consequences to marine life" (United Nations Economic and Social Council, 2019). But ecosystem impacts across scales are difficult to predict, difficult to distinguish from effects due to other causes and the scale and complexity, from global to local, make OA a 'wicked' problem for institutions to address (Galaz et al., 2012; Billé et al., 2013).

In the coastal zone, the OA problem is further complicated by high local variability, driven by a combination of climate change-related and local factors. Local perturbations, caused by precipitation, changing land-use patterns, deforestation and nutrient pollution increase the vulnerability of coastal systems to OA (Kelly and Caldwell, 2013). Global, climate change-driven OA and coastal processes interact dynamically presenting a complex management challenge for coastal nations. Policy and management responses to OA are limited and, besides monitoring and modelling of OA, remain scant (Dannevig et al., 2019; Tiller et al., 2019).

Rising acidity and the associated decrease in carbonate ions in seawater negatively affects growth rates in calcifying marine organisms including shellfish (Gazeau et al., 2013). Impacts on fish and wider ecosystems are anticipated although difficult to predict (Frommel et al., 2011). Marine aquaculture[4], the farming of marine fish and shellfish for human consumption, is particularly vulnerable to the impacts of OA. Aquaculture is the fastest growing food production industry globally, with 28.7 million tonnes (USD 67.4 billion) of production from marine and coastal aquaculture in 2016 (FAO, 2018). The sector plays an increasingly important role in global food security, supporting growing human consumption of protein while production from wild capture fisheries has remained stable with signs of decline (FAO, 2018). Enabling sustainable expansion of the aquaculture industry and mitigating the negative impacts of OA is of global importance.

Impacts on aquaculture are already being felt on the west coast of the U.S. where episodic upwelling supports a productive industry but a state of low carbonate saturation creates particular susceptibility to OA (Feely et al., 2010). In Puget Sound, commercial production of Pacific oysters has suffered including major losses due to negative effects of OA on seed production in 2007 to 2009 (Barton et al., 2015). Through collaborative effort, research and strategies to support adaptation of the regional shellfish industry in Puget Sound are on-going (Craig, 2019). Adaptation responses to date include water quality monitoring and chemical buffering of oyster hatcheries which reduces losses during periods of higher acidity (Clements and Chopin, 2017). Elsewhere, research effort mainly focusses on modelling of ecosystem effects such as further south in the California Current System (Gruber et al., 2012) and in Tasmania where warming seawater is modelled to support salmon aquaculture management (Spillman and Hobday, 2014). Development of adaptation responses are at an early stage globally and little is known about how governance can facilitate adaptation to OA.

[4] Marine aquaculture is also referred to as 'mariculture'. We use 'aquaculture' in this paper to refer generally to production undertaken in coastal and marine areas.

Climate change is occurring, regardless of mitigation measures, and so responding to OA requires *adaptation* i.e. the "anticipation of the adverse effects of climate change and action to prevent or minimise the damage they can cause"[5]; enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change[6]. To support this, in their 2018 report on the state of world fisheries and aquaculture sectors, the Food and Agriculture Organisation of the United Nations (FAO) set out guidance for the adaptation of aquaculture to climate change, recommending that this is addressed within National Adaptation Plans, required by all countries who are parties to the UNFCCC[7]. These plans provide a means for integrating adaptation across the existing policies, programmes and activities of national governments and a basis for developing iterative, country-specific programmes for adaptation. The FAO also describe possible *adaptation interventions* for the aquaculture (and fishing) sectors in adapting to the broad range of climate change risks, including OA, with action required across public and private actors to develop adaptation across scales[8]. Three categories of adaptation interventions are presented: institutions and management, livelihood adaptation and resilience and risk reduction, and are summarised in Table 1.

Table 1.1 Categories of adaptation interventions for the aquaculture sector in responding to climate change effects[9]

Category of Adaptation Interventions	
Institutions and management	Interventions, mainly on the part of public bodies, addressing governance mechanisms, legal, regulatory, policy and management frameworks and public investments and incentives, including the planning, development and management of aquaculture.
Livelihood adaptation	Interventions, mostly in the private sector, including a mix of public and private activities, within or among sectors, most commonly through diversification strategies within or outside the sector to reduce vulnerability.
Resilience and risk reduction	Interventions including a mix of public and private activities to promote early warning and information systems, improve risk reduction (prevention and preparedness) strategies and enhance response to shocks.

But while adaptation policy is advancing, in general, adaptation action outlined by countries has "limited specificity and ambition", due principally to the difficulties in understanding impacts of climate change at spatial and temporal scales relevant for decision-making[10]. Action by the public and private sectors across different levels and scales of governance is needed to develop specific adaptive responses, in the face of uncertainty, to adapt to climate change.

1.2 The need for adaptive governance

[5] https://sdg.iisd.org/issues/climate-change/adaptation/ (accessed 25 October 2019)
[6] United Nations Framework Convention on Climate Change (UNFCCC). 2015. The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement (accessed 2 October 2019)
[7] United Nations Framework Convention on Climate Change
[8] FAO, 2018, p.134
[9] FAO, 2018, p.135
[10] FAO, 2018, p.130

Enabling the expansion of marine aquaculture while adapting to key challenges including OA requires an adaptive governance approach (Craig, 2019). Adaptive governance provides a framework for understanding the characteristics of governance which has the ability (capacity and flexibility) to adapt to changing conditions, in order to maintain and enhance the resilience of socio-ecological systems (Dietz et al., 2003; Chaffin, 2014). Literature aligns around key characteristics of institutionalised adaptive governance (Chaffin & Gunderson, 2016) with four major themes outlined here. Firstly, adaptive governance scholarship promotes polycentricity: distributed decision-making, informed by local context and supported by vertical and horizontal co-ordination across organisational levels (Folke et al., 2005; Ostrom, 2010). Secondly, collaboration and participation of a wide range of stakeholders across state, private sector and civil society enables learning and knowledge co-production in resource management (Plummer et al., 2013). Such collective action also supports legitimacy and adaptation to change and surprise (Cosens et al., 2014). Third, adaptive governance requires incremental improvements supported by on-going assessment and reflection on the processes and practical experience of governance (Brunner, 2010), with flexibility to experiment and respond to feedback (Armitage et al., 2009). Fourth, self-organisation, which underpins adaptive governance, is supported by leadership, visioning, consensus-building and networks committed to change (Leach et al., 2010).

Understanding the emergence of adaptive governance within highly regulated systems of governing is a contemporary challenge facing its scholars. In particular, the role of law in preventing, triggering, and facilitating dimensions of adaptive governance is receiving increasing attention (Craig et al., 2017; Gunderson et al., 2018; Cosens et al., 2018). Legal procedures define how management decisions are taken including the scale of decision-making, who has the capacity (legal authority and resources) to participate and how to adjust and respond to change (Craig, 2019). Attention is drawn to the relevance of legal adaptive capacity, the substantive and procedural legal mechanisms which support adaptive governance and thus allow governance to respond to changing circumstances and emerging knowledge (Garmestani and Benson, 2013; Camacho and Glicksman, 2016). Tension is observed between ensuring flexibility to adapt while preserving necessary stability in governance and a balance is needed (Soininen and Platjouw, 2018).

Taking this perspective, Craig (2019) recently highlighted marine spatial planning[11] as an "inherently flexible" process which provides potential for "procedural innovation" to support adaptive governance of aquaculture in adapting to OA in the U.S. (Craig, 2019: 7). Marine spatial planning can support the spatial allocation of aquaculture activities in relation to other demands, promoting colocation with other industries and enabling the management of ecological impacts to support ecosystem resilience. As a forum for public participation it is suggested to contribute to "creative collaboration and promote experimentation with accountability" and should be considered as an iterative process providing a basis for on-going re-negotiation of priorities and adapting over time (Craig, 2019: 1).

In this paper, we seek to advance understanding of how to facilitate adaptive governance in response to the complex management challenge of OA. This addresses increasing concern regarding the threat it poses to food security of human populations and the limited progress in advancing adaptation of the aquaculture sector. Building on recent work by Craig (2019) and others, we apply an adaptive

[11] *Marine spatial planning* is referred to as such in the U.S. whereas *marine planning* is used in the case study of analysis and this latter term is used in this paper, noting that it refers to the same concept.

governance perspective to the adaptation of aquaculture in Scotland, where there is increasing evidence of the potential detrimental effects of OA combined with a dynamic policy context. This includes recent and rapid progress in climate change adaptation policy, concurrent implementation of marine planning and other legislative developments affecting coastal and marine governance. We consider the feasibility of adaptation of aquaculture to OA i.e. what are potential adaptation responses in Scotland, and, to what extent do policy, planning and management arrangements constrain or enable adaptation responses to OA?

1.3 Background to the Scottish Case

Aquaculture is a critically important sector in Scotland and contributes over £1.8 billion annually to the Scottish economy along with socio-economic benefits, particularly for remote rural and coastal communities[12]. The industry is dominated by the farming of Atlantic salmon, with significant rainbow trout and mussel production, along with oysters, scallops and growing interest in seaweed cultivation. Shellfish cultivation primarily focusses on mussel farming, and over 80% of Scotland's farmed mussels produced in the Shetland Islands in 2017[13]. Scottish Government's policy is to support the aquaculture industry's vision of expanding the sector and to double its economic contribution by 2030[14] and ensuring the sector's sustainability, resilience and adaptability is of national importance.

In 2017, the Marine Climate Change Impacts Partnership (MCCIP)[15] reported that global ocean pH continues to decrease with increasing risk of deleterious effects on ecosystems, particularly shellfish growth, within 50 years, and that OA is happening at a faster rate in the United Kingdom (UK) than the wider North Atlantic[16]. As required by the UK's Climate Change Act 2008[17], the UK Climate Change Risk Assessment (2017) identified priorities for adaptation across devolved administrations of the UK based on emerging science and details OA as of particular risk to marine species and habitats in Scotland[18]. In response, Scotland's second Climate Change Adaptation Programme 2019-2024 (CCAP) was laid before the Scottish Parliament in September 2019[19], fulfilling a requirement of the Climate Change (Scotland) Act 2009 (S.53). The CCAP is the Scottish Government's statutory five year programme for adapting to climate change and presents a cross-cutting strategy to promote

[12] Marine Scotland, 2014. An Assessment of the Benefits to Scotland of Aquaculture, https://www2.gov.scot/Resource/0045/00450799.pdf (accessed 12th October 2019)
[13] NAFC Marine Centre, University of the Highlands and Islands (NAFC), 2019. Shetland Islands Draft Regional Marine Plan, p.108 https://www.nafc.uhi.ac.uk/research/marine-spatial-planning/shetland-islands-regional-marine-planning-partnership/sirmp-2019/ (accessed 11 November 2019)
[14] Scottish Government, 2019. Aquaculture. https://www2.gov.scot/Topics/marine/Fish-Shellfish (accessed 17 June 2019)
[15] In the UK, the MCCIP co-ordinates the development of scientific evidence on marine climate change impacts along with guidance on adaptation to policy advisors and decision makers, see http://www.mccip.org.uk/
[16] MCCIP, 2017. Marine Climate Change Impacts: 10 year report card. http://www.mccip.org.uk/impacts-report-cards/full-report-cards/2017-10-year-report-card/climate-of-the-marine-environment/ocean-acidification/ (accessed 2 June 2019)
[17] The UK's Climate Change Act 2008 was the world's first long-term, legally binding framework law to address climate change.
[18] Department for Environment, Food & Rural Affairs (DEFRA), 2017. UK Climate Change Risk Assessment 2017 Evidence Report, https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/ (accessed 25th August 2019)
[19] This updates Scotland's First Climate Change Adaptation Programme 2014-2019.

integration of adaptation into wider Scottish Government policy development and functions[20]. It details provisions in relation to OA alongside wider climate change risks such as rising sea levels and increased extreme weather events, and identifies policies and activities which support adaptation of vulnerable sectors, including aquaculture. In addressing implementation of the SDGs, Scottish Government identifies OA as a future concern regarding suppressed shell growth and potential to cause reproductive disorders in some species of fish[21]. National adaptation activity in Scotland and the UK has so far focussed on monitoring (of seawater chemistry) and research, including contributing to, and engaging with, relevant national and international groups[22] as has been reported annually since Scotland's first statutory CCAP[23]. The CCAP adopted in 2019 places increased emphasis on the potential effects of OA and the need for action beyond monitoring, but more work is needed to identify specific responses to OA and how these can be facilitated.

Delivering Scottish Government's policy to expand the aquaculture sector faces significant challenges, including sea lice, disease, public objection and conflict for space with other activities[24]. Various national initiatives therefore seek to promote the growth of the aquaculture sector while addressing the constraints, including spatial guidance for finfish development based on environmental sensitivity to nutrient enrichment and benthic impacts[25], designation of protected areas for shellfish growing[26], guidance on addressing visual impacts[27], among others. Development of larger sites further offshore is encouraged to avoid sensitive inshore locations and there is a presumption against further marine finfish farms on the north and east coasts due to potential for interaction with wild salmon[28]. As owner and manager of a range of rural, coastal and marine assets including the seabed and most of the foreshore, Crown Estate Scotland's[29] objectives are to enhance the value of their assets and revenue

[20] Scottish Government, 2019a. Climate Ready Scotland: Second Scottish Climate Change Adaptation Programme 2019-2024, September 2019. https://www.gov.scot/publications/climate-ready-scotland-second-scottish-climate-change-adaptation-programme-2019-2024/ (accessed 12 October 2019).

[21] Scottish Government, 2019b. Scotland and the SDGs: A national review to drive action, draft report, p.252. (Unpublished)

[22] For example, the United Kingdom Ocean Acidification (UKOA) Research Programme, the Ocean Acidification International Reference User Group (OA-iRUG) under IUCN, and OSPAR.

[23] Scottish Government, 2017. Scottish Climate Change Adaptation Programme: Third Progress Report 2017. https://www.gov.scot/publications/climate-ready-scotland-scottish-climate-change-adaptation-programme-third-annual/ (accessed 15 June 2019)

[24] O'Hagan, A.M, et al., 2017. Regional review of Policy and Management Issues in Marine and Freshwater Aquaculture. Report produced as part of the EU Horizon 2020 AquaSpace project. http://www.aquaspace-h2020.eu/wp-content/uploads/2017/10/Regional-Review-of-Policy-Management-Issues-in-Marine-and-Freshwater-Aquaculture.pdf (accessed 19 September 2019)

[25] Marine Scotland Science, 2019. Locational Guidelines: Marine Fish Farms in Scottish Waters. https://www2.gov.scot/Topics/marine/Publications/publicationslatest/farmedfish/locationalfishfarms (accessed 12th October 2019)

[26] Areas designated under the Water Environment (Shellfish Water Protected Areas: Designation) (Scotland) Order 2013

[27] Scottish Natural Heritage (SNH), 2008. Guidance on Landscape / Seascape Capacity for Aquaculture, which addresses impacts on coastal character and scenic qualities. https://www.nature.scot/guidance-landscapeseascape-capacity-aquaculture (accessed 15 November 2019)

[28] Scottish Government, 2015. Scotland's National Marine Plan, p.50, https://www.gov.scot/publications/scotlands-national-marine-plan/ (accessed 15 June 2019)

[29] Crown Estate Scotland is a public corporation of the Scottish Government which manages a range of rural, coastal and marine assets on behalf of the Crown. Following the 2014 referendum on independence for Scotland, the Scotland Act 2016 made provision for the devolution for the management and revenues of Crown Estate assets in Scotland.

from activities including the aquaculture sector (finfish, shellfish and seaweed), and they invest in strategic research and development to support the industry.

The regulatory regime addressing aquaculture in Scotland has been described as overly complex, costly and presenting a barrier to the expansion of the sector, and has led to the process being reviewed[30,31]. This issue is faced across the European Union and there is an identified need to simplify administrative procedures and minimise regulatory burden across Member States to enable industry growth[32,33]. In Scotland, multiple agreements are required for developing an aquaculture facility, including: a seabed (or foreshore) lease agreement from Crown Estate Scotland; planning permission from local authorities in accordance with terrestrial Local Development Planning[34], which must be accompanied by Environmental Impact Assessment; and other licenses and consents from regulatory bodies for installation of equipment, discharges and predator control. Crown Estate Scotland plan to review and amend their aquaculture leasing and terms by 2022[35].

Alongside sector-specific planning, marine planning is being implemented in Scotland through a two-tier approach, at national and regional level, and seeks to support the development of the aquaculture industry in line with government policy. Scotland's National Marine Plan was adopted in 2015 and sets out a strategic policy framework for the sustainable development of Scotland's marine resources out to 200 nautical miles and must be considered in all decisions taken by public authorities that affect Scotland's marine area[36]. This overarching plan is to be delivered through regional marine planning, addressing the eleven Scottish Marine Regions of territorial waters[37] through a phased, learning-based and experimental approach intended to enhance "local ownership and decision-making"[38]. Development of regional marine plans is delegated to regional Marine Planning Partnerships, comprising public authorities and stakeholders[39] and there is flexibility in how the process is developed in each region. Marine Planning Partnerships are established and active in two regions (the Clyde and Shetland Islands Marine Regions) and are in the process of preparing their statutory regional

[30] Scottish Government, 2016. Independent review of Scottish aquaculture consenting. https://www.gov.scot/publications/independent-review-scottish-aquaculture-consenting/ (accessed 22 September 2019)

[31] Scottish Aquaculture Research Forum (SARF), 2016. SARF110 - Strategic Considerations for Locational Regulation of Shellfish Aquaculture in Scotland. http://www.sarf.org.uk/cms-assets/documents/245878-18407.sarf110.pdf (accessed 12 November 2019)

[32] European Commission, 2013. COM(2013)229: Strategic Guidelines for the sustainable development of EU aquaculture, p.4, https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/com_2013_229_en.pdf (accessed 6 October 2019)

[33] O'Hagan, A.M, et al., 2017.

[34] Under the Town and Country Planning (Scotland) Act 1997 (planning permission in respect of operation of marine fish farm).

[35] https://www.crownestatescotland.com/what-we-do/marine/asset/aquaculture (accessed 7th December)

[36] Scottish Government, 2015

[37] Defined under the Scottish Marine Regions Order 2015. The 11 Scottish Marine Regions are: Argyll, Clyde, Forth & Tay, Moray Firth, North Coast, North East, Outer Hebrides, Orkney Islands, Shetland Isles, Solway and West Highlands.

[38] https://www2.gov.scot/Topics/marine/seamanagement/regional (accessed 8 June 2019)

[39] https://www2.gov.scot/Topics/marine/seamanagement/regional/partnerships (accessed 8 June 2019)

marine plans[40]. Although regionally-developed, resulting plans must be consistent with national policy and are subject to adoption by Scottish Ministers[41].

Scottish coastal and marine governance is thus polycentric as described by Ostrom (2010) and McGinnis (2011): it is multi-level, multi-sectoral and involves overlapping jurisdictions. In these nested arrangements, the governance system includes: 1) primary (and secondary) legislation; 2) nationally-led policy and planning processes in government and its agencies; 3) regional and local collaboration in marine planning and other mechanisms; and 4) decision-making in the licensing and management of aquaculture facilities. Our attention is on how this governance system is, or might become, adaptive in supporting adaptation of aquaculture to the impacts of climate change. The term *response option* is used herein to represent an action or societal change that supports adaptation to OA, and corresponds to the term *adaptation intervention* used by the FAO.

2. Methods

To identify potential response options, a one day workshop was held in March 2018 at the Scottish Government Regional Office in Edinburgh. Potential response options were developed through facilitated discussion in response to structured questions and a written record of the discussion was made by the chair and two supporting project researchers. Records were compiled, synthesised and a draft workshop report was circulated to participants and confirmed as an agreed record of the event. Next, outputs were analysed and response options described in relation to the themes of adaptation interventions proposed by the FAO[42] (Table 1), as a logical framework and to promote coherence with emerging international guidance for the adaptation of aquaculture (and fisheries). Analysis of relevant Scottish legislation, policy and planning documents was subsequently undertaken to identify provisions which support identified adaptation responses and legal adaptive capacity, i.e. substantive, structural and procedural mechanisms for institutionalizing adaptive governance for responding to OA.

3. Results

3.1 Participation at the workshop

Nine participants attended the event including staff from Scottish Government's Marine Scotland Science, Marine Scotland's Planning and Policy Division, an environmental non-governmental organisation (ENGO) and academic scientists. The aquaculture industry was invited to attend but all invitees declined with response from a major shellfish industry association indicating that OA is an issue of some interest but is not sufficiently tangible to be of immediate concern. The large, mainly international companies that make up most of the Scottish salmon farming industry appear to be focussed on shorter-term issues (e.g. sea lice, escaped fish and changing regulatory demands) which

[40] As at November 2019, Clyde Marine Planning Partnership are developing the plan following consultation on the "Pre-consultation draft of the Clyde Regional Marine Plan" in March 2019, and Shetland are consulting on the "Shetland Islands Draft Regional Marine Plan 2019". Preparations are underway for regional marine planning in the Orkney Islands Marine Region where the next Marine Planning Partnership is anticipated to be established.

[41] Scottish Ministers represent the highest level of Government in Scotland.

[42] FAO, 2018

240 have visible and direct economic consequences[43] and across the sector resources and capacity to
241 participate were a concern. In contrast, public officials of Scottish Government engaged with the
242 workshop including hosting the event, participating and presenting on the activities underway relating
243 to OA and adaptation across policy and scientific departments. Despite the lack of industry
244 representation discussion centred on the impacts on the aquaculture sector and how to mitigate
245 them, given its vulnerability and socioeconomic significance.

246 ## 3.2 Potential adaptation response options in Scotland

247 At the workshop, 15 response options (ROs) were identified as potential approaches for adapting to
248 OA in Scotland. These are presented in Table 2, categorised under the FAO themes of adaptation
249 interventions, and are described in three subsequent sub-sections.

Response Options to OA in Scotland identified at the workshop	
Institutions and management	
RO1	Mitigation of OA at a large scale by addressing emissions reductions and enhance focus on marine interests in national climate policy and legislation.
RO2	Integrate OA into the broader climate change adaptation agenda to support adaptation responses at other scales.
RO3	Consider further the integration of OA into the EU Water Framework Directive and Marine Strategy Framework Directive implementation as a water quality issue.
RO4	Integrate OA concerns into regional marine planning in Scotland supported by refined objectives in Scotland's National Marine Plan.
RO5	Undertake scenario analysis based on modelling to inform regional management responses.
RO6	Integration of terrestrial and coastal issues to understand and manage co-stressors at regional scale.
Livelihood adaptation	
RO7	Account for adaptation to local changes and consider whether aquaculture may need to re-locate to other locations in future.
RO8	Aquaculture site-level responses could include moving installations vertically in response to changing acidity, combined with early warning systems.
RO9	Diversification of species farmed including more resilient species or cultivation of seaweed.
RO10	Collaborative working and facilitating cross-sector relationships to explore feasibility of operational response options.
Resilience and risk reduction	
RO11	General measures to strengthen ecosystem resilience including identifying particularly vulnerable areas and protecting these by identifying co-stressors and compensating negative impacts.

[43] Highlands and Islands Enterprise (HIE), 2017, Value of Scottish Aquaculture 2017, http://www.hie.co.uk/regional-information/economic-reports-and-research/archive/value-of-aquaculture-2017.html (accessed 14 June 2019)

RO12	Identify how current monitoring programmes can be informative about OA, for example jellyfish and Harmful Algal Blooms (HABs), phosphorus levels recorded under the WFD, and others, in order to measure ecosystem responses.
RO13	Frame monitoring and data collection on a regional scale to best inform understanding of ecosystem changes.
RO14	Awareness raising to improve stakeholder and public understanding of OA and the need to adapt.

Table 3.1 Response options (RO) identified at the stakeholder workshop

3.1.1 Institutions and management

Most responses identified at the workshop fall within the FAO's category of institutions and management and address the development of rules that guide interventions including creation or enhancement of public policy, legislation, institutional design and planning or management frameworks[44]. Responses at this level were noted as essential to underpin and support subsequent planning, management, adaptation and resilience building responses, particularly in the short-term (1-5 years). National government and other public bodies or regulatory authorities were identified as lead actors in these responses, working with regional management bodies and wider stakeholders.

Although addressing adaptation, mitigation was emphasized as a crucial aspect of reducing impacts of OA over the longer term. The overarching response of mitigation of OA (RO1) thus relates to policy and measures already being taken to mitigate climate change and participants considered that policy development in Scotland is robust in this area, suggesting only that increasing understanding and awareness of the socio-economic and ecological consequences of OA may 'add weight' to national policy on emissions reductions[45].

As impacts are predicted regardless of mitigation, climate change adaptation was indicated as the main policy agenda for supporting responses to OA. RO2 identifies increasing emphasis on OA in the broader climate change adaptation agenda in relation to more familiar risks such as flooding and coastal resilience as a fundamental step. Further, RO3 promotes use of existing water quality management frameworks to support understanding and managing local factors which contribute to OA in the coastal zone, including commitments under the EU Water Framework Directive (WFD) (Directive 2000/60/EC) and Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC). Both the MSFD and WFD include targets and objectives for 'acceptable' conditions ('Good Environmental Status' or 'Good Ecological Status', respectively) and a framework for monitoring and understanding ecosystem changes, including those related to pH. The WFD is implemented through River Basin Management Plans[46] (RBMP) which applies to inland and coastal waters out to 3 nautical miles and provides a framework for integrated management of co-stressors including pollution from agriculture. The Scottish Environmental Protection Agency (SEPA), who is responsible for

[44] FAO, 2018, p.134

[45] The Climate Change (Emissions Reduction Targets) (Scotland) Act received Royal Assent on 31 October 2019 and represents further ambitious national climate change legislation and policy.

[46] There are two River Basin Management Plans in Scotland, one covering the Scotland River Basin District; and the other cross border for the Solway Tweed River Basin District.

implementing the WFD in Scotland, are preparing the third iterations of RBMPs for publication in 2020[47] and could support addressing OA and developing resilience in the coastal zone.

Workshop participants also considered the developing regional marine planning process an important mechanism for supporting adaptation of aquaculture in coastal areas (RO4). Although at an early stage, marine planning provides a framework for considering specific measures at a regional scale including spatial options for flexible siting of aquaculture operations in relation to OA changes, according to the characteristics and constraints of individual marine regions. It also provides a mechanism for strengthening ecosystem resilience including identifying vulnerable areas and reducing coastal pollution which contributes to pH fluctuations as well as other stressors (RO6). This should relate to, and be informed by, the RBMPs to target the reduction of cumulative stressors and other inland influences on acidity in coastal waters. Other resilience-building measures identified which could be supported by marine planning included compensatory action (RO11), such as protecting or restoring other vulnerable areas such as fish nurseries in order to counteract potential negative effects of OA on fish recruitment. Further, regional marine planning was considered as providing an appropriate scale for the design of monitoring programmes to understand trends at a smaller scale (RO13). Lastly, the regional and partnership-based model of marine planning being implemented in Scotland was considered to potentially enable greater participation and collaboration between public and private actors in the development of OA responses.

3.2.2 Livelihood adaptation

This category includes specific responses at the operational level of human activities to adapt and reduce vulnerability to OA, supported by institutional and management responses. Responses raised included re-locating aquaculture installations to areas of more favourable pH as conditions change (RO7). However, spatial relocation was perceived to be challenging due to the inflexibility of the current planning process for aquaculture in enabling relocation and the limited space suitable for aquaculture development given the constraints due to pollution, sea lice problems and conflict with other users. Considering optional re-siting areas in areas which have been licensed but not developed was suggested, an issue which is limiting space for aquaculture in Scotland[48]. Uncertainty in predicting change at an appropriate spatial scale was noted as compromising spatial adaptation in the coastal zone.

At individual farms, there may be scope for adaptation responses by aquaculture facility developers, such as adjusting their operations to respond to changing pH of surface waters, for example the height of shellfish cultivation in the water column (RO8). These 'fine-scale' and real-time responses require carbonate chemistry monitoring systems which it was noted may already be in place at aquaculture sites for optimising water treatment (Barton et al., 2015). Participants identified other responses by industry which could include diversification of fish or shellfish species to those more tolerant to higher acidity or to consider cultivation of macroalgae (e.g. Kelp) (RO9) given that acidification of coastal waters increases favourable conditions for algae growth and which may also assist in mitigation (Chung et al., 2013). Collaboration between public bodies, industry at a collective (association) and individual (company) level, along with scientists was noted as necessary to determine economically and technically feasible adaptation responses, and enables sharing of accountability (and cost) of

[47] https://www.sepa.org.uk/environment/water/river-basin-management-planning/
[48] Scottish Government, 2016, p.9

developing response options (RO10). Given the difficulties in engaging industry on the issue raising awareness of OA and its implications was considered an important next step.

3.2.3 Resilience and risk reduction

All options discussed require more scientific evidence to improve preparedness and inform adaptive strategies, in particular the prediction of ecosystem effects and determining thresholds which may cause regime shift. There was strong emphasis throughout on the role of science, including monitoring, to assess how the ecosystem is changing in relation to OA in order to inform refined prediction of effects and response options. Government activity in relation to OA was presented as currently focused in this area through the activities of Marine Scotland Science[49], and participants noted that knowledge in relation to chemistry is well developed but gaps remain in understanding biological ecosystem effects, from primary production upwards. Undertaking a comprehensive monitoring strategy for changing pH of seawater was noted as difficult due to background variability, and the influence of run-off in influencing OA in coastal waters. As predictive models are improved, tools such as scenario analysis (RO5) were proposed as useful to explore changing conditions and appropriate response options, or combination of response options, across a range of possible outcomes.

In addition to the on-going support of Scottish Government's contribution to UK-scale monitoring of OA changes, identified actions to develop capacity for understanding trends at a smaller scale included reviewing existing monitoring programs to ascertain which data collected can be informative about OA, even if indirectly (RO12). For example, occurrences of jellyfish and harmful algal blooms and phosphorus levels which are monitored under the WFD may relate to OA and be used as indicators for ecosystem responses to acidification, particularly where long-term data sets are available. A regional approach was suggested as a relevant scale to frame monitoring and data collection in relation to OA in the coastal area and could be facilitated by integrated planning frameworks such as regional marine planning.

Communicating and raising awareness of OA emerged as necessary although challenging, particularly given the relationship between OA and climate change and the uncertainty in predicting local impacts of OA in Scotland. Industry interest in OA adaptation was noted as low since direct effects are uncertain and companies are focussed on more immediate issues. For the wider public, awareness of OA may be influenced by well-publicised impacts on coral reef, rather than issues facing Scotland. Greater outreach was thought to be needed (RO14) and the role of non-state actors was highlighted as relevant, for example ENGOs in supporting public communication and participation (Brooker et al., 2019).

3.3 Document analysis

Legislation and policy addressing climate change adaptation, the marine planning process and aquaculture planning and management present a range of substantive, structural and procedural mechanisms relevant to the adaptation of aquaculture. Specific goals addressing the adaptation of aquaculture to OA are evident in the CCAP and in a regional marine assessment, with no specific reference in national or regional marine plans. However, in these, other goals and policies address adaptation to OA or adaptation in general and can support responses at the operational level.

[49] Marine Scotland Science is a Directorate of Scottish Government.

Structural and procedural capacity is evident in provisions and promoted changes, and which indicate adaptive capacity in relation to the dimensions of adaptive governance introduced in 1.2., i.e. distributed decision-making, participation and collaboration, learning-based and adaptive approaches, with supporting activities including leadership. Some adaptive capacity is evident across the levels of governance but is more prevalent in new policy and legislation (particularly the CCAP and the Scottish Crown Estate Act 2019). A summary of this analysis is presented in table 3 and the outputs included in the discussion which addresses the extent to which policy, planning and management arrangements in Scotland constrain or enable adaptation responses to OA.

ADAPTIVE CAPACITY IN POLICY AND PLANNING FOR ADAPTATION OF AQUACULTURE IN SCOTLAND	
Specific provisions for adapting to OA	Structural and procedural adaptive capacity
Climate Change Adaptation (Key documents: Second Scottish Climate Change Adaptation Programme 2019-2024[50]; Climate Change (Emissions Reduction Targets) (Scotland) Act 2019; Climate Change (Scotland) Act 2009; UK Climate Change Act 2008).	
• OA identified as a risk to "nature-based industries" and as a risk to ecosystems which supports protection, resilience and enhancement. • Potential for diversification of aquaculture to other species or seaweed indicated. • Spatial planning and RBMP highlighted in relation to management of water quality. • Collaboration supported by a new Climate Change and Ocean Acidification subgroup. • National Forum proposed to support local adaptation efforts.	• "Place-based", locally-led adaptation efforts emphasized. • Promotes systemic behavior change and includes raising awareness through climate literacy. • On-going research, monitoring and evidence gathering, and iterative production of the CCAP based on annual progress monitoring. • Vertical integration between local and national adaptation responses.
Marine Planning (Key documents: Scotland's National Marine Plan[51], Clyde Regional Marine Plan – Pre-consultation Draft[52] and Clyde Marine Region Assessment[53], Shetland Marine Spatial Plan – Consultation Draft[54], Marine (Scotland) Act 2010).	
• National policy addressing growth of aquaculture sector, climate change adaptation and ecosystem protection and enhancement. • OA identified as a threat to shellfish fisheries, as an additional risk to release from carbon sinks, and as a factor to be considered in the designation of future Marine Protected Areas in the Clyde Marine Region.	• Two-tier process includes a devolved, partnership-led approach to marine planning. • Regional marine planning developing through a phased, learning-based approach with flexibility at the regional level.

[50] Scottish Government, 2019a
[51] Scottish Government, 2015
[52] Clyde Marine Planning Partnership (CMPP), 2019. Clyde Marine Plan –Pre-consultation draft, 2019. https://www.clydemarineplan.scot/wp-content/uploads/2019/06/Pre-consultation-draft-Clyde-Regional-Marine-Plan-18-March-2019.pdf (accessed 11 September 2019)
[53] CMPP, 2017. Clyde Marine Region Assessment. https://www.clydemarineplan.scot/wp-content/uploads/2018/02/Clyde-Marine-Region-Assessment-2017.pdf (accessed 11 September 2019)
[54] NAFC, 2019

• Regional policies support diversification; siting of aquaculture further offshore to mitigate inshore risks; and co-existence of marine uses. • Shetland Marine Plan also encourages area-wide Aquaculture Development Management Plans to support an holistic approach to developing aquaculture in the region.	• Marine planning is an iterative process, with reporting and review of national and regional marine planning required. • Collaboration and co-operation supported at regional level, between operators and between sectors.
Aquaculture Planning (Key documents: Crown Estate Scotland draft 2020-23 Corporate Plan[55]; Scottish Crown Estate Act 2019).	
• Crown Estate Scotland strategic objectives support growth of the aquaculture industry, through research and innovation. • Provisions for further devolution of certain Crown Estate Scotland assets to be managed by local authorities, island councils, public bodies and community organisations, including through a Local Asset Management Pilot Scheme. • Crown Estate Scotland plan to review aquaculture leasing and terms by 2022. • Government-led process of on-going improvement of spatial guidance for aquaculture development. • Designations of shellfish growing areas are reviewed every 6 years.	• Promotes changing ownership models and new, locally-led and collaborative arrangements. • Approaches to the leasing of aquaculture could adapt following future reviews. • Crown Estate Scotland capacity to act in a leadership role, with resources and ability to integrate between levels. • Science-led efforts to reduce uncertainty and improve siting options.
Aquaculture Licensing (Key documents: Town and Country Planning (Scotland) Act 1997 (planning permission in respect of operation of marine fish farm) (and amendments); Aquaculture and Fisheries (Scotland) Act 1997 (and amendments)).	
• Changes in use, location and type of equipment at an existing site accommodated through Permitted Development Rights up to a certain scale, or requiring further development application under the terrestrial planning system. • Management Areas promoted for coordinating management in relation to key issues, primarily fish health but could be expanded.	• Some flexibility for adaptation accommodated within existing regulatory process. • Strategic co-operation in management areas promotes collaboration and adaptive capacity over a wider spatial scale.

Table 3.2: Summary of adaptive capacity in policy and planning to support adaptation of aquaculture to OA in Scotland.

4. Discussion

4.1 Adaptive governance for ocean acidification in Scotland

[55] Crown Estate Scotland, 2019

As a complex issue with highly uncertain effects in coastal areas adaptive governance is needed to respond to OA with responses across multiple levels (Craig, 2019). A range of response options are identified here including national policy action by government, regional integrated planning and management by respective authorities and adapting activities at the operational level. Analysis of the polycentric governance system in Scotland indicates adaptive capacity supported by rapid legislative and policy development steering action on climate change adaptation, the implementation of regional marine planning, and through sector-specific planning and licensing frameworks. Substantive, structural and procedural provisions across these promote collective action and power-sharing at local scales, nested within a national framework, and a basis for iterative, learning-based approaches to adaptation. This system is described here to understand the feasibility of adaptation of aquaculture to OA and constraints in advancing adaptation responses for aquaculture in Scotland.

4.2 Climate change adaptation as an enabling policy framework

Participants emphasized the importance of the national climate change adaptation policy agenda and Scotland's second CCAP indicates a strengthening statutory basis for progressing response options and adaptation of aquaculture to OA. The CCAP now specifies OA as a threat to Scotland's aquaculture industry under Outcome 3, which aims to ensure a sustainable and adaptable economy by addressing the risks posed to "nature-based industries" from climate change (Sub-outcome 3.1[56]). Opportunity for farming of other species and seaweed in changing conditions is also identified and requires further research. OA is also considered from an ecosystem perspective in Outcome 6 which aims to ensure the protection, enhancement and resilience of the marine and coastal environment[57] and supports adaptation responses addressing ecosystem resilience. Under these outcomes, the CCAP lists specific policies, proposals and research activities to enable their delivery. These include the Climate Change and Ocean Acidification subgroup established in May 2018 under Scotland's 10 Year Farmed Fish Health Framework[58] and which presents an opportunity for collaborative, polycentric development of strategies to support adaptation of the aquaculture industry, identified as contributing to adaptation Puget Sound (Craig, 2019). Comprised of industry, government, scientists and regulatory agencies the subgroup aims to support fish aquaculture business to adapt by monitoring, reviewing and assessing the impact of climate change and ocean acidification on Scottish waters[59]. Collaborative effort can also be enabled through existing groups supporting public and private co-operation in Scotland[60]. Other important commitments in the CCAP include on-going contribution of Scottish Government to the evidence-gathering activities of the MCCIP to enhance preparedness and a further action could consider which other monitoring activities could provide information on OA trends at a smaller scale. In terms of the WFD, the CCAP refers to RBMPs as relevant to adaptation through management of water quality including land-based sources of pollution, and could support addressing OA in the coastal zone, as identified by participants.

[56] Sub-Outcome 3.1: "Scotland's businesses based on natural resources are informed and adaptable to climate change"(Scottish Government 2019a, p.92)
[57] Outcome 6: "Our coastal and marine environment is valued, enjoyed, protected and enhanced and has increased resilience to climate change" (Scottish Government 2019a, p.178)
[58] https://www.gov.scot/publications/scotlands-10-year-farmed-fish-health-framework/
[59] https://www2.gov.scot/Topics/marine/Fish-Shellfish/Strategic-Framework/Subgroup4 (accessed 14 October 2019)
[60] For example Scotland's Aquaculture Innovation Centre (SAIC), https://www.scottishaquaculture.com/ and the Scottish Aquaculture Research Forum (SARF), http://www.sarf.org.uk/

Beyond provisions specific to OA, procedural and structural mechanisms supporting adaptive governance are seen throughout the CCAP. Firstly, the CCAP is fundamentally learning-based and adaptive based on a monitoring framework to support continuing progress. This includes annual progress reporting and updating of the CCAP every 5 years (required under the Climate Change (Scotland) Act 2009) and allows for new understanding to inform future adaptation. The CCAP, under the Climate Change (Scotland) Act 2009, therefore indicates substantive adaptive capacity based on goals of adaptation as well as procedural adaptive capacity by enabling adjustment to new information (Carmanco and Glicksman, 2016).

Secondly, the CCAP emphasises the importance of locally-led efforts in adapting to climate change with action and decisions taken at a scale which reflects local geographies and demographics. A "place-based" approach is a key theme of the CCAP, aligned with the 'Place Principle'[61] being adopted across Scottish Government in response to new legislation requiring increased community engagement and local governance in Scotland[62]. This reflects potential for distributed decision-making and could promote the development of self-organisation in adaptation efforts at smaller scales (Cosens et al., 2018). Further, the development of a National Forum proposed in the CCAP[63] to support local adaptation initiatives could support vertical interplay across national, regional and local levels in developing responses.

Adaptive capacity is also enhanced by initiatives proposed under the CCAP to improve 'climate literacy' to aid public awareness and through promotion of systemic behaviour change[64]. This directly supports awareness-raising identified as a barrier in Scotland and sustained effort in learning and capacity building to enable co-production of knowledge to respond to OA (Dannevig et al., 2019). More broadly, an explicit adaptation agenda as set out in the CCAP supports developing a "culture of tolerance for change and uncertainty" which is essential for developing adaptive approaches (De Caro et al., 2017: 5). As a new programme further analysis will be needed to ascertain the extent to which adaptive governance is supported by the CCAP but overall it represents an advanced framework which supports adaptive governance and a basis for developing adaptation responses across scales.

4.3 Marine planning and the potential for adaptive governance

The marine planning process in Scotland could support adaptive governance in responding to OA through a combination of substantive, structural and procedural characteristics. At the national level, Scotland's National Marine Plan includes policy objectives for the sustainable growth of the aquaculture industry along with a range of climate change adaptation policies, including the need for spatial planning, an ecosystem approach and adaptive management[65]. The current iteration of the National Marine Plan does not specifically consider OA and adaptation is instead framed in relation to flooding, sea level rise and the resilience of coastal infrastructure. However, it is supportive of measures to strengthen resilience through policies to protect and enhance the marine environment

[61] "The Place Principle calls on all those responsible for providing services and looking after assets in a place to work and plan together, and with local communities, to improve the lives of people, support inclusive and sustainable growth and create more successful places that will be capable of adapting to climate change" (Scottish Government, 2019a, p.71)
[62] Including the Community Empowerment (Scotland) Act 2015 and the recent Planning (Scotland) Act 2019.
[63] Scottish Government, 2019a, p.27
[64] *Ibid,* p.25
[65] Scottish Government, 2015, p.182

as well as promoting appropriate siting of aquaculture facilities in relation to ecological constraints and colocation or diversification of activities where appropriate[66]. Policy related to OA is likely to be included in future iterations of the National Marine Plan and would enhance focus on adaptation responses[67].

Regionally, the Marine Planning Partnerships must address national policy objectives and develop regional policies in their marine plans which apply to activities developed within their regions[68]. In their assessment of the region required to inform marine planning, the Clyde Marine Planning Partnership identified OA as a threat to shellfish fisheries, as an additional risk to release from carbon sinks and as a factor to be considered in the designation of future Marine Protected Areas in the Clyde Marine Region[69]. While not specific to OA, policies in the current versions of the Clyde and Shetland can support adaptation of aquaculture in line with the identified responses. These include diversification to other species or seaweed cultivation, promoting siting of aquaculture facilities in areas further offshore to mitigate inshore risks and policies which promote co-existence of aquaculture with other marine uses which may increase siting options[70]. Combined with policies to address ecosystem resilience these promote the viability of the sector considering a range of constraints and factors which supports adaptation to OA (Craig, 2019). Spatial constraints on relocation noted by stakeholders are evident in emerging marine plans, particularly in Shetland where aquaculture activity is extensive and limited new space exists without technological innovation to develop activities further offshore[71].

Structurally, the partially decentralised approach to regional marine planning in Scotland indicates polycentricity which could support adaptive governance. In this nested arrangement, national government provide legal legitimacy, economic incentives and policy oversight while the partnerships support learning and collaboration at the regional level, based on strong leadership and participation (Greenhill et al., 2020). Involvement in partnership-based plan-making has improved decision-making legitimacy in Shetland in relation to aquaculture siting and supported siting of aquaculture proposals in relation to fishing interests (Greenhill et al., 2020). It also provides a foundation for addressing 'social licence' and issues related to public acceptance of the expansion of aquaculture, another constraint facing the industry (Billing, 2018).

However, the extent to which marine planning can influence adaptive outcomes, including adaptation measures, may be constrained by the overlapping planning and management processes which it seeks to guide (Greenhill et al., 2020). Marine planning in Scotland is not equivalent to "a legally sanctioned process for allocating marine space" (Craig 2019: 3) and the siting of aquaculture facilities is primarily steered by sector-specific policy and planning by national government and local authorities. Further, marine planning is not equivalent to *management* and the extent to which Marine Planning Partnerships can facilitate adaptive responses depends on their influence on regulatory and permitting decisions for aquaculture taken by local authorities and national regulatory bodies in

[66] E.g. "AQUACULTURE 13: Proposals that contribute to the diversification of farmed species will be supported, subject to other objectives and policies being satisfied." (Scottish Government, 2015, p.51)
[67] The National Marine Plan is reviewed every 3 years with the next review due in 2021.
[68] The Marine (Scotland) Act 2010 also requires that any regional marine plan must set out "objectives relating to the mitigation of, and adaptation to, climate change" (Art. 5(4)(a)).
[69] CMPP, 2017
[70] NAFC, 2019
[71] Ibid.

accordance with legislative requirements. This has two major implications: firstly, the "experimentation with accountability" promoted by Craig (2019: 1) for adaptive governance is limited to the marine planning arena since *management* authority does not change and secondly, implementation of adaptation responses consequently depends on the accommodation of adaptation through flexibility in the wider aquaculture planning and management framework (discussed in 4.4).

The role of regional marine planning in supporting adaptation measures is also dependent on when, how and if marine planning proceeds in Scotland. Progress in implementation is slower than anticipated; there is uncertainty regarding available resources for marine planning in other regions and the process itself is currently under review[72]. Further, in an 'experimental' and flexible marine planning system, regional differences affect the ability of partnerships to develop influential regional policy, spatial or non-spatial, and include the complexity of the region, the degree of cohesion between stakeholders and available resources (Greenhill et al., 2020). In Scotland, socio-cultural and governance arrangements in certain island contexts are indicated as better enhancing legitimacy and accountability through marine planning, building on existing (and increasing) devolution of management powers to the same scale (Greenhill et al., 2020).

As an iterative process requiring review of regional assessments and marine plans, marine planning is able to respond to changing circumstances and new knowledge including the impacts of OA on aquaculture. Marine planning provides a valuable repository of data and information and provide the basis for refining adaptation action over time in response to regional trends and predicted effects. OA could receive greater emphasis in later iterations of regional marine plans and, as an on-going forum for public participation and collaboration, adaptation responses could be considered alongside changing priorities and ecological changes (Craig, 2019). This could incorporate scenario analysis suggested by participants to consider adaptation options across a range of predicted outcomes to inform adaptation planning. In Shetland, a constraints-based approach which steers industry to areas preferable for development based on gradational understanding of risk can be more adaptive than a spatial allocation ('hard zoning') approach, as it is flexible and can be more easily updated to respond to new information (Kelly et al., 2014).

4.4 Flexibility in aquaculture planning and management

Given their role in leasing the seabed for aquaculture development, Crown Estate Scotland could play an important role in aquaculture adaptation, underpinned by the new Scottish Crown Estate Act 2019 which provides for the long-term management of Crown Estate assets devolved to Scotland. Although they do not have a role in regulatory compliance, as manager of the seabed they have a strategic interest in supporting the industry to ensure growth and enhanced revenue generation. For example, Crown Estate Scotland's propose a review of aquaculture leasing and terms to "safeguard aquaculture businesses"[73], which could include the need to accommodate adaptation measures in leasing arrangements. The Scottish Crown Estate Act 2019 also includes provisions for further devolution of certain assets to be managed by local authorities, island councils, public bodies and community organisations within a national governance framework. Increased decision-making and ownership at

[72] The Scottish Parliament's Environment, Climate Change and Land Reform Committee is currently undertaking a review of progress in developing regional marine planning partnerships. https://www.parliament.scot/parliamentarybusiness/CurrentCommittees/111991.aspx (accessed 12 November 2019)

[73] Crown Estate Scotland, 2019, p.13

513 the local level is being promoted including through a Local Asset Management Pilot Scheme[74] which
514 may support adaptive governance based on shared management rights (Greenhill et al., 2020) and
515 could provide another mechanism for collaborative development of locally-relevant adaptation
516 responses. In Shetland, the Sullom Voe Masterplan[75] is being progressed under this scheme and
517 focusses on re-opening areas for aquaculture development previously closed for navigational
518 purposes.

519 Other potential mechanisms to support adaptation of the industry to OA include Aquaculture
520 Management Areas (AMAs) promoted by the FAO as fundamental in implementing an ecosystem
521 approach to aquaculture[76]. AMAs enable collective farm management at a more appropriate scale for
522 managing the risks to and from aquaculture and builds on the likelihood that facility operators self-
523 organise around areas which are suitable for development[77]. Monitoring of environmental change can
524 be collaboratively and strategically undertaken to understand vulnerability and address threats such
525 as eutrophication (and OA). Governments play a key role and the AMA provides an entity which can
526 support community engagement[78]. Management areas exist in Scotland have been developed
527 specifically to address the need to strategically address challenges of disease in fish farms (Disease
528 Management Areas[79]) and management agreements between multiple operators in a farm
529 management area are supported by the Aquaculture and Fisheries (Scotland) Act 2013 (S.1 (2)).
530 Strategic co-operation in management areas supports collaboration and provides adaptive capacity
531 over a wider spatial scale and could be expanded to consider climate change adaptation needs. It is
532 more difficult to establish new AMAs where industry is already well established (as in Scotland) but
533 there is potential for gradual strategic co-ordination and management based on collective action by
534 industry[80]. Regional marine planning in Shetland encourages area-wide Aquaculture Development
535 Management Plans to support an holistic approach to developing aquaculture proposals in the
536 region[81] and could facilitate the benefits of an AMA approach.

537 Ultimately, decisions concerning specific aquaculture projects are taken through national and local
538 licensing processes which focus on site selection, environmental impact assessment and local social
539 acceptance[82]. Livelihood adaptation responses therefore require flexibility, not just in planning and
540 leasing arrangements, but in the regulatory processes it seeks to guide. Depending on the scale of the
541 response some changes in use (for example to other species or activity), location and type of
542 equipment may require repeating some of the permitting process, including public consultation,
543 particularly if beyond the existing planning boundary of a site[83]. This includes addressing the spatial
544 specificity essential for aspects such as navigational safety of fish farm moorings and equipment.

[74] https://www.crownestatescotland.com/what-we-do/local-pilot-scheme
[75] https://www.nafc.uhi.ac.uk/research/marine-spatial-planning/sullom-voe-master-plan-project/
[76] FAO, 2017. Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture: A handbook, p.37, http://www.fao.org/3/a-i6834e.pdf (accessed 5 December 2019)
[77] Ibid.
[78] FAO, 2017, p.38
[79] https://www2.gov.scot/Topics/marine/Fish-Shellfish/FHI/managementagreement
[80] FAO, 2017, p.17
[81] NAFC, 2019
[82] O'Hagan et al., 2017, p.8
[83] Regulated by the Town and Country Planning Marine Fish Farming (Scotland) Order 2007 which applies to the placement of equipment in the sea, on the seabed or on the foreshore out to 12 nautical miles.

Some change can be accommodated within permitted development rights of existing consents[84], however, given the cost of planning application fees for aquaculture industry is incentivised to apply for the smallest initial development area restricting flexibility for future changes[85]. Addressing the payment mechanism and considering how flexibility can fairly be built into consent applications may support adaptation. Future review of aquaculture regulation and licensing should consider the need for flexibility and appropriate mechanisms to enable not just spatial relocation, but to enable experiments and trials of adaptation measures at aquaculture site level.

5. Conclusion

There is consensus that OA will alter ecosystems, affect human activities and governance needs to respond (Billé et al., 2013). Adaptation of the aquaculture industry is essential to protect an important economic sector and provide food security for an expanding global population. Climate change adaptation requires adaptive governance to enable robust decision-making in the context of uncertainty, and is enabled through a governance system consisting of polycentric arrangements and a versatile choice of policy instruments to foster adaptive and innovative responses (Arnold and Gunderson, 2013).

Scotland provides a pertinent case given the increasing importance of the aquaculture sector with national policy to double its economic contribution by 2030, combined with increasingly ambitious climate change policy, and supports understanding of implementing adaptive governance in response to OA. Findings indicate a range of response options across the themes of institutions and management, livelihood adaptation and resilience and risk reduction, supporting the need for nested arrangements and providing a basis for framing adaptation in relation to new FAO guidance. Uncertainty in predicting specific effects in coastal areas presents a significant challenge in developing operational responses and emphasis in the short-term is on public bodies to lead scientific effort and providing an enabling policy framework with flexibility for adaptation at smaller scales. Alongside, collaboration with industry is essential to raise awareness and understand the feasibility of adaptation responses at sector and project level.

Legal and institutional arrangements are critical in defining the capacity for adaptive governance in existing regulatory systems (Cosens et al., 2018). In this analysis findings indicate convergence in developing legislation and policy in Scotland on institutional change towards adaptive governance, with substantive, structural and procedural adaptive capacity enhanced through emerging instruments. New climate change adaptation policy provides a cross-policy, iterative basis for advancing adaptation responses and an explicit, substantive impetus for adaptive approaches. Alongside this, institutional change in coastal and marine governance including a new, two-tier marine planning process and the adoption of the Scottish Crown Estate Act 2019 seek to advance new models of devolved and learning-based planning and management. These mechanisms intersect in the coastal zone and present opportunity for adaptive governance in the adaptation of aquaculture to OA.

[84] Regulated by the Town and Country Planning (General Permitted Development) (Fish Farming) (Scotland) Amendment Order 2012

[85] Scottish Aquaculture Research Forum (SARF), 2016. SARF110 - Strategic Considerations for Locational Regulation of Shellfish Aquaculture in Scotland. http://www.sarf.org.uk/cms-assets/documents/245878-18407.sarf110.pdf (accessed 12 November 2019)

Collaborative and polycentric activity is fundamental to adaptive governance and is supported by emerging structural capacity across the governance system. This includes government led public – private initiatives, the regional Marine Planning Partnerships, organisations and groups proposing to take on local management of Crown Estate Scotland assets and co-operation supported through Aquaculture Management Areas. In this supportive institutional context, actors operating at different levels can support awareness raising, advance collective action and enhance adaptive capacity.

Marine planning can encourage and facilitate consideration of potential adaptation options alongside other priorities, but the process is still developing and challenges are evident in its implementation and in understanding its influence on the management of marine activities (Greenhill et al., 2020). Greater connectivity between marine planning, national policy development and regulatory decision-making regarding aquaculture would increase capacity to develop and implement adaptation responses for the sector. Strengthening the legal procedures connecting marine planning and aquaculture sector planning and management by government, Crown Estate Scotland's leasing process and local authority licensing in Scotland could enhance the role of marine planning in adaptation, including increasing its capacity to facilitate legitimate debate on adaptation options (Craig, 2019).

While opportunities exist for advancing adaptation responses at different scales there is a need for effective integration, including horizontal and vertical institutional linkages, to support adaptive governance (Folke et al. 2005; Berkes, 2010). Coherence in governance is required to enhance adaptive capacity, especially in geographical contexts where several regulatory and / or governance arrangements overlap (Soininen and Platjouw, 2018). Procedural adaptive capacity could be supported by co-ordination between cycles of monitoring and evaluation of marine planning, policy implementation and effectiveness of adaptation responses, in addition to monitoring of ecosystem change. Making the information from review processes easily accessible would increase accountability and transparency in adaptive governance (Craig and Ruhl, 2014). Additionally, since the institutional changes identified here are at early stages of implementation, further investigating the complementarity and potential for integration in enabling adaptation would be an important next step.

Communication regarding OA remains a challenge given the interlinkages with climate change processes, local variability and uncertain effects, compounding the difficulties in engaging stakeholders to determine pre-emptive response options. While low saliency of OA remains a broad challenge (Tiller et al., 2019) progress can be supported through measures to enhance climate literacy and increasing facilitation of multi-stakeholder groups at multiple levels. Attention to the issue of OA is increasing and Extinction Rebellion, a popular response to the climate emergency, has expressed interest in what is known about OA and its impacts in the coastal waters of Western Scotland (P. Tett, pers. comm.).

Despite increasing adaptive capacity in policy and planning, the adaptive capacity of existing regulation of aquaculture may still constrain adaptation responses. The licensing process remains the main arena for considering the specific details of proposed aquaculture operations and their social and ecological implications and requires specificity to enable fixed agreements and permissions. It also includes processes for public objections and appeal against applications and decisions which influence what is possible for aquaculture development (Billing, 2018). In addition to promoting more streamlined licensing procedures to support sector growth, future reviews of aquaculture

management needs to consider the need for flexibility to accommodate adaptation responses. Future research could also consider how legal provisions supporting strategic and collaborative approaches could be more widely implemented, including how Aquaculture Management Areas (with community involvement) could be utilised to support adaptation responses at the operational level.

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