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

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8

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

## 10 Abstract

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

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## 36 1. Introduction

### 37 1.1 Ocean acidification

38 Ocean acidification (OA) refers to the increasing acidity of seawater due to anthropogenic emissions  
39 of CO<sub>2</sub>, with far-reaching effects on ecosystems and marine users (Fabry et al., 2008; Frommel et al.,  
40 2011; Kroeker et al., 2013). In 2019, reporting on OA as Target 14.3 of Sustainable Development Goal  
41 (SDG) 14 of the United Nations 2030 Development Agenda indicates increasing concern of “serious  
42 consequences to marine life” (United Nations Economic and Social Council, 2019). But ecosystem  
43 impacts across scales are difficult to predict, difficult to distinguish from effects due to other causes  
44 and the scale and complexity, from global to local, make OA a ‘wicked’ problem for institutions to  
45 address (Galaz et al., 2012; Billé et al., 2013).

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

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

63 Impacts on aquaculture are already being felt on the west coast of the U.S. where episodic upwelling  
64 supports a productive industry but a state of low carbonate saturation creates particular susceptibility  
65 to OA (Feely et al., 2010). In Puget Sound, commercial production of Pacific oysters has suffered  
66 including major losses due to negative effects of OA on seed production in 2007 to 2009 (Barton et  
67 al., 2015). Through collaborative effort, research and strategies to support adaptation of the regional  
68 shellfish industry in Puget Sound are on-going (Craig, 2019). Adaptation responses to date include  
69 water quality monitoring and chemical buffering of oyster hatcheries which reduces losses during  
70 periods of higher acidity (Clements and Chopin, 2017). Elsewhere, research effort mainly focusses on  
71 modelling of ecosystem effects such as further south in the California Current System (Gruber et al.,  
72 2012) and in Tasmania where warming seawater is modelled to support salmon aquaculture  
73 management (Spillman and Hobday, 2014). Development of adaptation responses are at an early  
74 stage globally and little is known about how governance can facilitate adaptation to OA.

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<sup>4</sup> 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.

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

89 *Table 1.1 Categories of adaptation interventions for the aquaculture sector in responding to climate change effects<sup>9</sup>*

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.

90 But while adaptation policy is advancing, in general, adaptation action outlined by countries has  
 91 “limited specificity and ambition”, due principally to the difficulties in understanding impacts of  
 92 climate change at spatial and temporal scales relevant for decision-making<sup>10</sup>. Action by the public and  
 93 private sectors across different levels and scales of governance is needed to develop specific adaptive  
 94 responses, in the face of uncertainty, to adapt to climate change.

95 [1.2 The need for adaptive governance](#)

<sup>5</sup> <https://sdg.iisd.org/issues/climate-change/adaptation/> (accessed 25 October 2019)

<sup>6</sup> 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)

<sup>7</sup> United Nations Framework Convention on Climate Change

<sup>8</sup> FAO, 2018, p.134

<sup>9</sup> FAO, 2018, p.135

<sup>10</sup> FAO, 2018, p.130

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

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

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

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

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<sup>11</sup> *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.

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

### 143 1.3 Background to the Scottish Case

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

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

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<sup>12</sup> Marine Scotland, 2014. An Assessment of the Benefits to Scotland of Aquaculture, <https://www2.gov.scot/Resource/0045/00450799.pdf> (accessed 12<sup>th</sup> October 2019)

<sup>13</sup> 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)

<sup>14</sup> Scottish Government, 2019. Aquaculture. <https://www2.gov.scot/Topics/marine/Fish-Shellfish> (accessed 17 June 2019)

<sup>15</sup> 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/>

<sup>16</sup> 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)

<sup>17</sup> The UK's Climate Change Act 2008 was the world's first long-term, legally binding framework law to address climate change.

<sup>18</sup> 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 25<sup>th</sup> August 2019)

<sup>19</sup> This updates Scotland's First Climate Change Adaptation Programme 2014-2019.

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

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

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<sup>20</sup> 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).

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

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

<sup>23</sup> 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)

<sup>24</sup> 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)

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

<sup>26</sup> Areas designated under the Water Environment (Shellfish Water Protected Areas: Designation) (Scotland) Order 2013

<sup>27</sup> 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-landscapes-seascape-capacity-aquaculture> (accessed 15 November 2019)

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

<sup>29</sup> 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.

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

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

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

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

<sup>31</sup> 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](http://www.sarf.org.uk/cms-assets/documents/245878-18407.sarf110.pdf) (accessed 12 November 2019)

<sup>32</sup> 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](https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/com_2013_229_en.pdf)  
(accessed 6 October 2019)

<sup>33</sup> O'Hagan, A.M, et al., 2017.

<sup>34</sup> Under the Town and Country Planning (Scotland) Act 1997 (planning permission in respect of operation of  
marine fish farm).

<sup>35</sup> <https://www.crownstatescotland.com/what-we-do/marine/asset/aquaculture> (accessed 7<sup>th</sup> December)

<sup>36</sup> Scottish Government, 2015

<sup>37</sup> 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.

<sup>38</sup> <https://www2.gov.scot/Topics/marine/seamanagement/regional> (accessed 8 June 2019)

<sup>39</sup> <https://www2.gov.scot/Topics/marine/seamanagement/regional/partnerships> (accessed 8 June 2019)



207 marine plans<sup>40</sup>. Although regionally-developed, resulting plans must be consistent with national policy  
208 and are subject to adoption by Scottish Ministers<sup>41</sup>.

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

## 218 2. Methods

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

## 231 3. Results

### 232 3.1 Participation at the workshop

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

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<sup>40</sup> 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.

<sup>41</sup> Scottish Ministers represent the highest level of Government in Scotland.

<sup>42</sup> FAO, 2018

240 have visible and direct economic consequences<sup>43</sup> 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.

<sup>43</sup> 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.

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

251 **3.1.1 Institutions and management**

252 Most responses identified at the workshop fall within the FAO’s category of institutions and  
 253 management and address the development of rules that guide interventions including creation or  
 254 enhancement of public policy, legislation, institutional design and planning or management  
 255 frameworks<sup>44</sup>. Responses at this level were noted as essential to underpin and support subsequent  
 256 planning, management, adaptation and resilience building responses, particularly in the short-term  
 257 (1-5 years). National government and other public bodies or regulatory authorities were identified as  
 258 lead actors in these responses, working with regional management bodies and wider stakeholders.

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

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

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<sup>44</sup> FAO, 2018, p.134

<sup>45</sup> 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.

<sup>46</sup> 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.

278 implementing the WFD in Scotland, are preparing the third iterations of RBMPs for publication in  
279 2020<sup>47</sup> and could support addressing OA and developing resilience in the coastal zone.

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

### 296 3.2.2 Livelihood adaptation

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

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

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<sup>47</sup> <https://www.sepa.org.uk/environment/water/river-basin-management-planning/>

<sup>48</sup> Scottish Government, 2016, p.9

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

### 320 3.2.3 Resilience and risk reduction

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

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

343 Communicating and raising awareness of OA emerged as necessary although challenging, particularly  
344 given the relationship between OA and climate change and the uncertainty in predicting local impacts  
345 of OA in Scotland. Industry interest in OA adaptation was noted as low since direct effects are  
346 uncertain and companies are focussed on more immediate issues. For the wider public, awareness of  
347 OA may be influenced by well-publicised impacts on coral reef, rather than issues facing Scotland.  
348 Greater outreach was thought to be needed (RO14) and the role of non-state actors was highlighted  
349 as relevant, for example ENGOs in supporting public communication and participation (Brooker et al.,  
350 2019).

### 351 3.3 Document analysis

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

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<sup>49</sup> Marine Scotland Science is a Directorate of Scottish Government.

358 Structural and procedural capacity is evident in provisions and promoted changes, and which indicate  
 359 adaptive capacity in relation to the dimensions of adaptive governance introduced in 1.2., i.e.  
 360 distributed decision-making, participation and collaboration, learning-based and adaptive  
 361 approaches, with supporting activities including leadership. Some adaptive capacity is evident across  
 362 the levels of governance but is more prevalent in new policy and legislation (particularly the CCAP and  
 363 the Scottish Crown Estate Act 2019). A summary of this analysis is presented in table 3 and the outputs  
 364 included in the discussion which addresses the extent to which policy, planning and management  
 365 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
<b>Climate Change Adaptation</b> (Key documents: Second Scottish Climate Change Adaptation Programme 2019-2024 <sup>50</sup> ; Climate Change (Emissions Reduction Targets) (Scotland) Act 2019; Climate Change (Scotland) Act 2009; UK Climate Change Act 2008).	
<ul style="list-style-type: none"> <li>• OA identified as a risk to “nature-based industries” and as a risk to ecosystems which supports protection, resilience and enhancement.</li> <li>• Potential for diversification of aquaculture to other species or seaweed indicated.</li> <li>• Spatial planning and RBMP highlighted in relation to management of water quality.</li> <li>• Collaboration supported by a new Climate Change and Ocean Acidification subgroup.</li> <li>• National Forum proposed to support local adaptation efforts.</li> </ul>	<ul style="list-style-type: none"> <li>• “Place-based”, locally-led adaptation efforts emphasized.</li> <li>• Promotes systemic behavior change and includes raising awareness through climate literacy.</li> <li>• On-going research, monitoring and evidence gathering, and iterative production of the CCAP based on annual progress monitoring.</li> <li>• Vertical integration between local and national adaptation responses.</li> </ul>
<b>Marine Planning</b> (Key documents: Scotland’s National Marine Plan <sup>51</sup> , Clyde Regional Marine Plan – Pre-consultation Draft <sup>52</sup> and Clyde Marine Region Assessment <sup>53</sup> , Shetland Marine Spatial Plan – Consultation Draft <sup>54</sup> , Marine (Scotland) Act 2010).	
<ul style="list-style-type: none"> <li>• National policy addressing growth of aquaculture sector, climate change adaptation and ecosystem protection and enhancement.</li> <li>• 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.</li> </ul>	<ul style="list-style-type: none"> <li>• Two-tier process includes a devolved, partnership-led approach to marine planning.</li> <li>• Regional marine planning developing through a phased, learning-based approach with flexibility at the regional level.</li> </ul>

<sup>50</sup> Scottish Government, 2019a

<sup>51</sup> Scottish Government, 2015

<sup>52</sup> 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)

<sup>53</sup> 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)

<sup>54</sup> NAFC, 2019

<ul style="list-style-type: none"> <li>• Regional policies support diversification; siting of aquaculture further offshore to mitigate inshore risks; and co-existence of marine uses.</li> <li>• Shetland Marine Plan also encourages area-wide Aquaculture Development Management Plans to support an holistic approach to developing aquaculture in the region.</li> </ul>	<ul style="list-style-type: none"> <li>• Marine planning is an iterative process, with reporting and review of national and regional marine planning required.</li> <li>• Collaboration and co-operation supported at regional level, between operators and between sectors.</li> </ul>
<p><b>Aquaculture Planning</b> (Key documents: Crown Estate Scotland draft 2020-23 Corporate Plan<sup>55</sup>; Scottish Crown Estate Act 2019).</p>	
<ul style="list-style-type: none"> <li>• Crown Estate Scotland strategic objectives support growth of the aquaculture industry, through research and innovation.</li> <li>• 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.</li> <li>• Crown Estate Scotland plan to review aquaculture leasing and terms by 2022.</li> <li>• Government-led process of on-going improvement of spatial guidance for aquaculture development.</li> <li>• Designations of shellfish growing areas are reviewed every 6 years.</li> </ul>	<ul style="list-style-type: none"> <li>• Promotes changing ownership models and new, locally-led and collaborative arrangements.</li> <li>• Approaches to the leasing of aquaculture could adapt following future reviews.</li> <li>• Crown Estate Scotland capacity to act in a leadership role, with resources and ability to integrate between levels.</li> <li>• Science-led efforts to reduce uncertainty and improve siting options.</li> </ul>
<p><b>Aquaculture Licensing</b> (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)).</p>	
<ul style="list-style-type: none"> <li>• 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.</li> <li>• Management Areas promoted for coordinating management in relation to key issues, primarily fish health but could be expanded.</li> </ul>	<ul style="list-style-type: none"> <li>• Some flexibility for adaptation accommodated within existing regulatory process.</li> <li>• Strategic co-operation in management areas promotes collaboration and adaptive capacity over a wider spatial scale.</li> </ul>

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

367 **4. Discussion**

368 **4.1 Adaptive governance for ocean acidification in Scotland**

<sup>55</sup> Crown Estate Scotland, 2019

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

#### 380 4.2 Climate change adaptation as an enabling policy framework

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

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<sup>56</sup> Sub-Outcome 3.1: "Scotland's businesses based on natural resources are informed and adaptable to climate change" (Scottish Government 2019a, p.92)

<sup>57</sup> 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)

<sup>58</sup> <https://www.gov.scot/publications/scotlands-10-year-farmed-fish-health-framework/>

<sup>59</sup> <https://www2.gov.scot/Topics/marine/Fish-Shellfish/Strategic-Framework/Subgroup4> (accessed 14 October 2019)

<sup>60</sup> For example Scotland's Aquaculture Innovation Centre (SAIC), <https://www.scottishaquaculture.com/> and the Scottish Aquaculture Research Forum (SARF), <http://www.sarf.org.uk/>



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

412 Secondly, the CCAP emphasises the importance of locally-led efforts in adapting to climate change  
413 with action and decisions taken at a scale which reflects local geographies and demographics. A “place-  
414 based” approach is a key theme of the CCAP, aligned with the ‘Place Principle’<sup>61</sup> being adopted across  
415 Scottish Government in response to new legislation requiring increased community engagement and  
416 local governance in Scotland<sup>62</sup>. This reflects potential for distributed decision-making and could  
417 promote the development of self-organisation in adaptation efforts at smaller scales (Cosens et al.,  
418 2018). Further, the development of a National Forum proposed in the CCAP<sup>63</sup> to support local  
419 adaptation initiatives could support vertical interplay across national, regional and local levels in  
420 developing responses.

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

#### 430 4.3 Marine planning and the potential for adaptive governance

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

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<sup>61</sup> “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)

<sup>62</sup> Including the Community Empowerment (Scotland) Act 2015 and the recent Planning (Scotland) Act 2019.

<sup>63</sup> Scottish Government, 2019a, p.27

<sup>64</sup> *Ibid*, p.25

<sup>65</sup> Scottish Government, 2015, p.182

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

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

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

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

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<sup>66</sup> 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)

<sup>67</sup> The National Marine Plan is reviewed every 3 years with the next review due in 2021.

<sup>68</sup> 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)).

<sup>69</sup> CMPP, 2017

<sup>70</sup> NAFC, 2019

<sup>71</sup> Ibid.

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

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

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

#### 502 4.4 Flexibility in aquaculture planning and management

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

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<sup>72</sup> 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)

<sup>73</sup> Crown Estate Scotland, 2019, p.13

513 the local level is being promoted including through a Local Asset Management Pilot Scheme<sup>74</sup> 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<sup>75</sup> 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<sup>76</sup>. 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<sup>77</sup>. 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<sup>78</sup>. 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<sup>79</sup>) 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<sup>80</sup>. 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<sup>81</sup> 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<sup>82</sup>. 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<sup>83</sup>. This includes addressing the spatial  
544 specificity essential for aspects such as navigational safety of fish farm moorings and equipment.

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<sup>74</sup> <https://www.crownstatescotland.com/what-we-do/local-pilot-scheme>

<sup>75</sup> <https://www.nafc.uhi.ac.uk/research/marine-spatial-planning/sullom-voe-master-plan-project/>

<sup>76</sup> 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)

<sup>77</sup> Ibid.

<sup>78</sup> FAO, 2017, p.38

<sup>79</sup> <https://www2.gov.scot/Topics/marine/Fish-Shellfish/FHI/managementagreement>

<sup>80</sup> FAO, 2017, p.17

<sup>81</sup> NAFC, 2019

<sup>82</sup> O'Hagan et al., 2017, p.8

<sup>83</sup> 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.

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

## 552 5. Conclusion

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

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

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

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<sup>84</sup> Regulated by the Town and Country Planning (General Permitted Development) (Fish Farming) (Scotland) Amendment Order 2012

<sup>85</sup> 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)

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

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

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

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

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

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

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