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Stakeholder perspectives on the importance of water quality and other constraints for sustainable mariculture

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ABSTRACT

Aquaculture, including marine aquaculture (mariculture), is the fastest growing food production sector globally and is expected to play a key role in delivering future food security. A potential factor limiting growth of the aquaculture industry, however, is the maintenance of good water quality, on which all forms of aquaculture depend. This is particularly challenging in 'open' coastal and estuarine systems and requires engagement with a wide range of stakeholders that can influence water quality. We applied a semi-quantitative method (Q-method) to capture and evaluate perspectives across diverse stakeholders in order to address the overarching question: "How do stakeholders rank water quality issues and management options versus other issues and actions for ensuring the sustainability of shellfish mariculture in South West England?" Results from this regional case study were used to highlight key issues and knowledge gaps that have national and international relevance. Stakeholders were found to hold distinct perspectives (P1−3), but there was general consensus that good water quality is essential for sustainable aquaculture, and that there is a need for better understanding of spatial and temporal variations in land use throughout catchments to ensure effective water quality management. Stakeholder engagement highlighted the importance of managing anthropogenic and environmental (climatic) pressures on land and water through agri-environment and urban planning policy in order to ensure sustainable food production, including from mariculture.

1. Introduction

Aquaculture is the fastest growing food production sector globally (FAO, 2017) and unlike agriculture and capture fisheries, which are plateauing or declining (Asche and Smith, 2018; FAO, 2017), aquaculture offers huge potential for future sustainable growth (DEFRA, 2015; Westbrook, 2017; Seafish, 2018). Global food fish production from aquaculture (82 million tonnes, US$250 billion per year) now exceeds capture fisheries and growth projections see production rising to 109 million tonnes, by 2030 (FAO, 2017), with a significant contribution coming from marine aquaculture (mariculture), including from bivalve shellfish (Kapetsky et al., 2013; EEA, 2017; FAO, 2017). Asia currently generates 89 % of global aquaculture production, while the European Union (EU) generates only ~2% in volume and 3.7 % in value (FAO, 2017). The aquaculture industry is projected to grow moderately in the EU (Guillen et al., 2019), while production in England is expected to double between 2020 and 2040, with revenues at first point of sale rising to £60 million (Seafish, 2019). More extensive growth in revenues and jobs are likely to be generated by the wider seafood value chain, including food processing, restaurant, hospitality and tourism industries (DEFRA, 2017). In particular, there is scope for substantial growth in bivalve shellfish mariculture along the Channel coast of South and South West England. Here mariculture currently produces ~3500 tonnes, £5 million of shellfish per year (CEFAS, 2015; Hambrey and Evans, 2016)

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and production per km of coastline is 1/20th of that along the North coast of France (EEA, 2017).

A range of environmental and socio-economic factors constrain future mariculture expansion in the UK and elsewhere around the world, including impaired water quality (Campos and Lees, 2014; Evans et al., 2016; Hassard et al., 2017), lack of available space in coastal areas (Kapetsky et al., 2013; Gentry et al., 2017), climate change (Stewart-Sinclair et al., 2020), harmful algal blooms (Brown et al., 2019) and lack of investment. Stakeholder perceptions of mariculture (including its visual impact), global dietary preferences (for finfish and crustaceans), cultural traditions (including capture fishing), burdensome policy and regulation, also limit the growth of mariculture (EC, 2013a; DEFRA, 2015; Alexander et al., 2015; Gentry et al., 2017; Guillen et al., 2019). Understanding stakeholder perspectives on the importance of these various constraining factors and the relative merits of different mitigation options is vital for sustainable mariculture development.

Stakeholder engagement is essential for reaching consensus for effective policy development and implementation, and the process requires sharing and understanding of contrasting stakeholder perspectives, in order to minimise conflict and to ensure equitable and sustainable outcomes (Menzel and Buchecker, 2013; Blackstock et al., 2014; Feliciano et al., 2014). The benefits of multi-disciplinary stakeholder engagement derive from the examination of problems and solutions from different end-user perspectives, gaining access to a diverse pool of knowledge, building trust, making relevant, transparent and effective decisions, fulfilling regulatory and ethical requirements, and enabling the translation of research findings into effective policy and practice (Deverka et al., 2012; Lavery, 2018). These benefits have been demonstrated for land management and conservation (de Vente et al., 2016; Sterling et al., 2017; Schmidt et al., 2020), (marine) environmental planning (Newton, 2012; Newton and Elliott, 2016), including mariculture development planning (Bacher et al., 2014) and climate change mitigation (Steeves and Filgueira, 2019).

Here we focus on the impact and mitigation of water quality impairment on coastal mariculture sites, which are potentially influenced by a wide range of stakeholders throughout catchments. Mariculture represents the nexus of environment–food–health systems, with food productivity and quality depending on clean waters and healthy ecosystems (FAO et al., 2018). For example, wild and farmed shellfish filter large volumes of water (between 1−100 L/individual/hour, depending on species, body size/weight and feeding conditions Riisgård, 2001), and can accumulate water-borne contaminants, which are potentially harmful to human consumers. Contaminants can include a broad spectrum of microbiological pathogens (including norovirus, enterococci and salmonella) and chemicals (metals, agrochemicals, biocides etc.), originating from a wide range of land- and marine- based sources. Microbiological water quality is of particular concern for shellfish farmers, as shellfish consumption has been linked occasionally to outbreaks of infectious intestinal disease (mainly due to norovirus). These outbreaks can impact on the National Health Service and on industry, through loss of sales, product recalls and loss of consumer confidence (Campos and Lees, 2014; Hassard et al., 2017). Short-term elevation of enteric bacterial counts (*in lieu* of pathogen loads) in water and shellfish can often exceed levels considered safe for human consumption. This can lead to protracted downgrading of the classification of UK (and EU) shellfish waters under EU Food Hygiene Regulation (EC) No. 854/2004 (EC, 2004a, 2004b, 2004c).

Chemical contaminants in industrialised estuaries can also reduce scope for shellfish growth (Brooks et al., 2009) and/or suppress immune function, leading to increased susceptibility to disease and mortality (ICES, 2005). The combination of accumulating chemical pollutants and pathogenic microbes in bivalves (Girón-Pérez, 2010) has been shown to result in increased susceptibility of these shellfish to diseases (Bernal-Hernandez et al., 2010; Gagnaire et al., 2007; Luna-Acosta et al., 2012; Moreau et al., 2015a, 2015b). Increasing nutrient and pesticide inputs have also been associated with the occurrence of harmful algal blooms (Harris and Smith, 2015; Stayley et al., 2015), which can have significant impacts on coastal and offshore mariculture (Brown et al., 2019).

The sustainable development of mariculture therefore depends on the maintenance of high quality water in estuarine and coastal environments. This in turn depends on multiple, interconnecting upstream land-based activities, and environmental, economic and societal factors including climate change, flood risk, human population growth and changing environmental policy affecting land use and marine spatial planning and water quality management. Effective policy development consequently necessitates wide stakeholder consultation and engagement throughout whole catchments (Orr et al., 2007; Lovatelli et al., 2013).

Here we present the outcomes of a consultation, which takes a ‘catchment-based approach’ embodying a community partnership approach involving members of the public, Government, Local Authorities, Water Companies and businesses for managing water quality and general environmental quality in river catchments. A wide range of stakeholders who interact with, and affect water quality from headwaters to the coast, in Cornwall, Devon, Dorset and Somerset were engaged, with the aim of highlighting key constraints and knowledge gaps that need to be addressed for ensuring the future sustainability and prosperity of UK mariculture. The outcomes from this study pertain to agricultural catchments with localised urban development in coastal areas, which are typical of SW England, but may be generalised and applied to other similar areas in the UK and the EU.

2. Methods

Here we apply the Q-method (Zabala, 2014) to evaluate “How stakeholders rank water quality issues and management options versus other issues and actions for ensuring the sustainability of shellfish mariculture in South West England?” The Q-method is an empirical, semi-quantitative technique designed to explore subjective views (perspectives) on a contentious topic, in a clear and structured way (Zabala, 2014). The method was initially devised for evaluating the breadth of opinion around sensitive societal and political issues (Brown, 1980; Watts and Stenner, 2005). The Q-method has been applied more broadly recently, including in the context of mariculture development and marine spatial planning (Bacher et al., 2014); eco-labelling (Weitzman and Bailey, 2019); and climate change (Steeves and Filgueira, 2019). The Q-method was implemented in the following six steps (2.1–2.6).

2.1. Concourse (volume of discussion on the research question)

A concourse covering the volume of discussion on the above research question was compiled. This was done by gathering information from a wide range of digital sources, including relevant peer reviewed scientific literature (Shumway et al., 2003; Rose et al., 2014; Jones et al., 2015b; Wartenberg et al., 2017), industry and regulatory reports and policy documents (Laing et al., 2004; UNEP, 2012; Lovatelli et al., 2013; Jeffery et al., 2014; DEFRA, 2015; FitzGerald and Syvret, 2018; FAO, 2018). Multi-disciplinary stakeholder views on the research question were also compiled from recent (2018–2020) mariculture stakeholder meetings, including the SeaFish Aquaculture Common Issues Group (x4), Aquaculture Research Collaborative Hub UK (×3) and recorded interviews with individual stakeholders representing a range of stakeholder groups from the mariculture industry, marine regulation, conservation and academia (×7).

2.2. Q-statement compilation

The concourse was distilled down to 40 Q-statements, which succinctly covered the overall range of perspectives on the research question. This was carried out by three independent researchers who generated a comprehensive list of statements from the concourse, capturing both positive and negative views on the importance and interdependence of each of the following issues: land use; water quality; shellfish quality; marine spatial planning (Table 1). Statements were then refined and distilled collectively by the researchers to give the final set of Q-statements.

2.3. Selection of Q-sort participants

Q-sort participants (n = 29) were selected for the study using purposive sampling, such that they represented a range of perspectives across different organisations (n = 22) and sectors i.e. stakeholder groups (n = 6), which had a vested interest in water quality and/or mariculture (Table 2). Stakeholder group representation was broad rather than exhaustive, and included Academia, Shellfish Industry, Other Industries (water and sewage companies, farming and insurance industries), Regulators - Government or Government Agencies, - Non Departmental Public Bodies, Independent/Charities (Conservation). Participants were invited to a multi-stakeholder workshop on ‘Water quality management underpinning sustainable aquaculture’ (12 June 2019), which explored how water quality and mariculture potential could be optimised through land use, river basin and coastal zone management.

2.4. Q-sort

The Q-sort formed a key component of the invited stakeholder workshop and followed a series of presentations on water quality issues and management options for sustainable mariculture. Participants were asked to independently sort each of the 40 Q-statements into a Q-grid representing a forced ‘normal distribution’ of opinion scores, which ranged from strong disagreement (-4) to ambivalent (0) to strong agreement (+4). There were two grid squares in each tail of the distribution, increasing to 8 grid squares in the centre, providing 40 squares in total (one square for each Q-statement) (Fig. 1).

2.5. Q-sort data analysis

The populated Q-grids (referred to as Q-sorts) were then analysed using the R package ‘qmethod’ (v 1.5.4) (Zabala, 2014) to evaluate disparities and commonalities in stakeholder perspectives on the research question. The ‘qmethod’ data analysis (detailed in Appendix A), involved the grouping of stakeholder participant’s Q-sorts using principal component analysis (PCA), followed by factor analysis to identify a number of ‘ideal factors’ that captured the variance in opinions/perspectives within and between each group. Q-statements contributing most to this variance, and thus characterising each factor, were identified and used to create a narrative describing the perspectives of each stakeholder group.

2.6. Follow-up analysis

In addition to sorting the Q-statements, participants were also asked to explain the rationale behind their Q-sorting, particularly the selection of Q-statements with which they strongly agreed or disagreed. Feedback questionnaires (Appendix B) and follow-up discussions (first in small multi-sectoral groups of 5–6 people and then in a whole workshop plenary, immediately after the Q-sort) provided additional qualitative data to capture any important issues raised by the Q-statements and to further develop the narratives around the perspectives of statistically different groups of participants/stakeholders. This step also facilitated understanding of any differences in reasoning underlying each participant’s Q-sort, since different reasoning can sometimes lead to similar ranking and sorting of Q-statements (Zabala et al., 2018). The participants were also asked if there were any Q-statements they felt were missing from the 40 provided, to ensure that the method, based on established literature and best practice, did not overlook any emerging or previously under-developed theme. We cross-referenced these

Table 1
Q-statements representing perspectives on the importance of water quality (WQ) management options versus other priorities for sustainable shellfish mariculture.

Land management and water quality	
1	Dairy farming is a bigger issue for WQ than arable farming
2	Landscape restoration (woodlands, mires) can reduce rainwater runoff and improve WQ
3	Landscape restoration provides more scope to improve WQ than wastewater treatment
4	Sustainable farming practices are effective for reducing river pollution
5	Upstream land management/WQ interventions are less cost effective than downstream
6	Changes in agricultural policy could have significant positive impacts on WQ
7	Changing consumer food preferences will be more effective than regulating farm practices
8	Agricultural subsidies are effective for sustaining natural capital-based economies
9	Agricultural subsidies would be better spent directing them on environmental improvements
Other options for water and shellfish quality management	
10	Changing land management practices will have little benefit for improving shellfish quality
11	Point source discharges are more significant sources of pollution than diffuse sources
12	Rainfall has a greater effect on WQ than the number of toilets flushed at any one time
13	WQ regulations should be stricter, particularly in designated shellfish waters
14	Flood risk management is key to sustainable aquaculture in the UK
15	The cost of testing of shellfish quality is good value compared to the costs of people falling ill
16	Official control monitoring of shellfish quality is key to sustainable aquaculture in the UK
17	Rainwater runoff from urban areas is not a major threat to WQ
18	Protecting bathing WQ in coastal areas helps protect shellfish quality
Linking water quality to shellfish quality and quantity (and *vice versa*)	
19	Variable WQ is the main risk facing the UK shellfish industry
20	Aquaculture businesses would be more insurable if WQ risks were better quantified
21	Classification of the quality of shellfish waters and shellfish is too stringent
22	Shellfish aquaculture can make a substantial contribution to maintaining/improving WQ
23	Our waters would be cleaner if natural shellfish populations weren’t overexploited
24	Shellfish farming in polluted estuaries should attract payments for improving WQ
25	Chemical pollutants present limited risk to shellfish quality and growth
26	Microbial pathogens (bacteria and viruses) present the greatest risk to shellfish quality
27	Investment for sustainable aquaculture should include controlling WQ problems at source
28	Aquaculture needs to invest in engineering for purging contaminants from live shellfish
29	Approved self-testing of shellfish quality would help overcome uncertainty about variable WQ
Spatial planning	
30	Many shellfish sites suffer poor WQ because of their location in highly populated areas
31	Spatial planning constraints on aquaculture are comparable to WQ constraints
32	There is significant potential to expand aquaculture sustainably in the UK (incl. SW England)
33	There is scope in the marine planning process to facilitate aquaculture expansion
34	Conflicts over space between aquaculture and other marine stakeholders are rarely justified
35	The visual impact of aquaculture is a major barrier to industry growth
36	Aquaculture expansion should be controlled - over expansion may impact existing businesses
37	Disease transmission among shellfish populations is the main risk to aquaculture expansion
38	Expanding aquaculture offshore will negate the need for land-based interventions to improve WQ
39	Changing public perception of shellfish as a desirable healthy food is more important than improving WQ
40	Securing export markets is more important than managing WQ for aquaculture industry expansion in the UK

Table 2
Stakeholders participating in the sorting of Q-statements (Q-sort).

Sector (stakeholder group)	Sector abbreviation	Organisations	No. of organisations	No. of individual participants
Academia	AC	Exeter University, Plymouth University, Plymouth Marine Laboratory, RC-UK	4	7
Regulator - Government or Government Agency	GA	DEFRA, CEFAS, Devon County Council	3	3
Regulator - Non Departmental Public Body	ND	Environment Agency, Marine Management Organisation, Food Standards Agency, SeaFish Industry Authority, Natural England	5	7
Shellfish Industry	SI	Shellfish Industry	5	5
Other Industry	OI	Water company, Aquaculture Insurance	2	4
Independent/Charity (Conservation)	IC	Westcountry Rivers Trust, Dorset Coast Forum, National Lobster Hatchery	3	3
		Totals	22	29

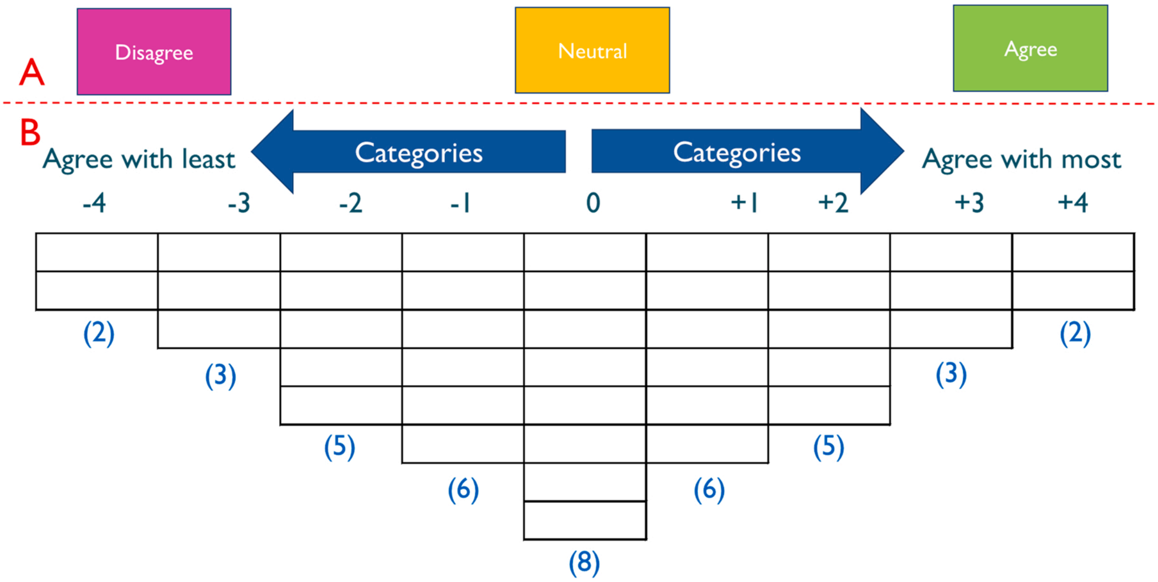

Fig. 1. Q- grid for allocation of 40 Q-statements.
1 Q-statement was allocated to each grid square. All 40 Q statements are listed in Table 1.

stakeholder discussions with published research and reports in order to corroborate existing knowledge versus knowledge gaps and to identify areas in which research is required to build understanding and consensus on measures for ensuring the sustainability of shellfish mariculture, using South West England as a regional case example.

3. Results

Three distinct perspectives were defined using factor analysis of stakeholder prioritisation of Q-statements [statements numbered in square parentheses]. Perspectives were given the following titles: P1 ‘Upstream thinking’ – focusing on the management of combined sewer overflows (CSOs) and control of microbial contamination during flood events; P2 – ‘Broad view’ considering upstream and downstream pressures on microbial and chemical water quality to be equally important; P3 ‘Upstream thinking’ prioritising the control of diffuse and point source pollution from agricultural land. Cumulatively, these perspectives (P1 = 22 %, P2 = 21 %, P3 = 10 %) explained 53 % of the variance between the Q-sorts of the 29 stakeholder participants (Appendix C). All participants associated (loaded) significantly with one of the three perspectives, each of which included more than one sector i.e. perspectives were not found to be sector-specific (Fig. 2). Idealised Q-sorts, indicating where each Q-statement would be sorted if a participant were to fit perfectly with a given perspective, enabled distinguishing Q-statements (p-values < 0.05) and consensus statements to be identified (Table 3). Q-statements with which participants strongly disagreed (ranked −4, −3) or strongly agreed (+3, +4), and justification for these rankings, were used to generate a headline narrative for each perspective.

3.1. Perspective 1 - downstream thinking

The ‘Downstream thinking’ perspective was held by 6 participants: 1 from a Government Agency; 1 from Regulation; 4 (a clear majority of 4 out of 5) from the Shellfish Industry. The perspective centres on the importance of managing municipal wastewater inputs and minimising sewer overflows during flood events, in order to mitigate against variable microbiological water quality and shellfish quality. This perspective strongly agreed (ranks +3 or +4) that many shellfish sites suffer poor water quality because of their location in highly populated areas [30] and that point source discharges are more significant sources of pollution than diffuse sources [11]. These views were reinforced by strong disagreement (rank -4) that landscape restoration provides more scope to improve water quality than wastewater treatment [3] and ambivalence (rank 0) that changes in agricultural policy could have significant positive impacts [6]. Participants with a downstream thinking perspective also disagreed strongly (ranks +3 or +4) that changing public perception of shellfish as a healthy food [39], or securing export markets (e.g. during Brexit) [40] are more important than managing water quality. However, participants in this group felt

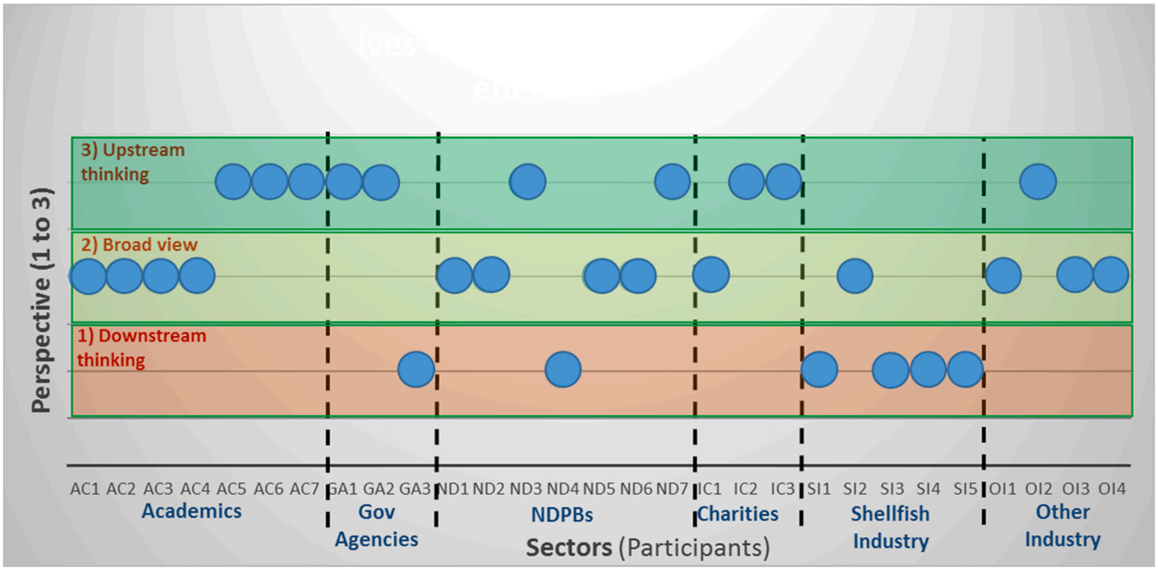

Fig. 2. Distribution of stakeholder participants and sectors among perspectives (P1 to 3) on the importance of water quality management options versus other actions for contributing to the sustainability of shellfish mariculture.

Table 3
Idealised sorting of Q-statements for three overarching perspectives: P1 Downstream thinking; P2 Broad thinking; P3 Upstream thinking. The Q-method analysis uses participants' Q-sorts (a grid in which strength of agreement/disagreement with statements is allocated) to reveal groupings of stakeholders with similar perspectives. Idealised Q-sorts indicate where each Q-statement would be sorted if a participant were to fit perfectly with a given perspective. Both distinguishing and consensus Q-statements are highlighted (*p*-values: * < 0.05; ** <0.01).

Q-statements	Idealised Q-sorts per perspective			
	P3	P2	P1	dist.and.cons
1. Dairy farming is a bigger issue for WQ than arable farming	1*	0**	−2*	Distinguishes all
2. Landscape restoration (woodlands, mires) can reduce rainwater runoff and improve WQ	3	3	1**	Distinguishes P1 only
3. Landscape restoration provides more scope to improve WQ than wastewater treatment	0	0	−4**	Distinguishes P1 only
4. Sustainable farming practices are effective for reducing river pollution	2	2	−2**	Distinguishes P1 only
5. Upstream land management/WQ interventions are less cost effective than downstream	−3*	−3*	−2*	Distinguishes all
6. Changes in agricultural policy could have significant positive impacts on WQ	4	4	0**	Distinguishes P1 only
7. Changing consumer food preferences will be more effective than regulating farm practices	−2*	−1	−1	Distinguishes P3 only
8. Agricultural subsidies are effective for sustaining natural capital-based economies	0	−1	0	Consensus
9. Agricultural subsidies would be better spent directing them on environmental improvements	3*	1	2	Distinguishes P3 only
10. Changing land management practices will have little benefit for improving shellfish quality	−4	−4	0**	Distinguishes P1 only
11. Point source discharges are more significant sources of pollution than diffuse sources	0	−1	4**	Distinguishes P1 only
12. Rainfall has a greater effect on WQ than the number of toilets flushed at any one time	2*	3	3	Distinguishes P3 only
13. WQ regulations should be stricter, particularly in designated shellfish waters	1	−3**	2	Distinguishes P2 only
14. Flood risk management is key to sustainable aquaculture in the UK	−1	1*	−2	Distinguishes P2 only
15. Testing of shellfish quality is good value compared to the costs of people falling ill	1	0	1	Consensus
16. Official control monitoring of shellfish quality is key to sustainable aquaculture in the UK	0	0	1	Consensus
17. Rainwater runoff from urban areas is not a major threat to WQ	−3	−3	−3	Consensus
18. Protecting bathing WQ in coastal areas helps protect shellfish quality	4**	1**	−3**	Distinguishes all
19. Variable WQ is the main risk facing the UK shellfish industry	3*	2*	4*	Distinguishes all
20. Aquaculture businesses would be more insurable if WQ risks were better quantified	1	0	0	Consensus
21. Classification of the quality of shellfish waters and shellfish is too stringent	−1	3**	−1	Distinguishes P2 only
22. Shellfish aquaculture can make a substantial contribution to maintaining/improving WQ	1	2*	0	Distinguishes P2 only
23. Our waters would be cleaner if natural shellfish populations weren't overexploited	−2	0*	−2	Distinguishes P2 only
24. Shellfish farming in polluted estuaries should attract payments for improving WQ	2**	1*	−1*	Distinguishes all
25. Chemical pollutants present limited risk to shellfish quality and growth	−4**	−2*	−1*	Distinguishes all
26. Microbial pathogens (bacteria and viruses) present the greatest risk to shellfish quality	0**	2*	3*	Distinguishes all
27. Investment for sustainable aquaculture should include controlling WQ problems at source	2	3	**2**	Consensus
28. Aquaculture needs to invest in engineering for purging contaminants from live shellfish	−1	−1	0	Consensus
29. Approved self-testing of shellfish quality would help overcome uncertainty about variable WQ	0**	2	2	Distinguishes P3 only
30. Many shellfish sites suffer poor WQ because of their location in highly populated areas	1	0	3**	Distinguishes P1
31. Spatial planning constraints on aquaculture are comparable to WQ constraints	−1	−1	2*	Distinguishes P1 only
32. There is significant potential to expand aquaculture sustainably in the UK (incl. SW England)	2	4**	2	Distinguishes P2 only
33. There is scope in the marine planning process to facilitate aquaculture expansion	0	1*	−1	Distinguishes P2 only
34. Conflicts for space between aquaculture and other marine stakeholders are rarely justified	−2	−2	0	
35. The visual impact of aquaculture is a major barrier to industry growth	−1*	−2*	0*	Distinguishes all
36. Aquaculture expansion should be controlled - over expansion may impact existing businesses	0	−2**	1	Distinguishes P2 only
37. Disease transmission among shellfish populations is the main risk to aquaculture expansion	−1	0	−1	
38. Expanding aquaculture offshore will negate the need for land-based interventions to improve WQ	−3*	−4*	1**	Distinguishes all
39. Changing public perception of shellfish as a desirable healthy food is more important than improving WQ	−2	−1	−3*	Distinguishes P1 only
40. Securing export markets is more important than managing WQ for aquaculture industry expansion in the UK.	−2	−2	−4*	Distinguishes P1 only

moderately strongly (rank +2), that spatial planning constraints on mariculture are comparable to water quality constraints [31].

3.2. Perspective 2 - broad view

The 'Broad view' perspective was held by 12 participants: 4 from Academia; 1 Non-Departmental Public Body; 1 Conservation Charity; 2 Regulators; 1 from the Shellfish Industry; 3 from Other Industries. The perspective focused on water quality as a constraint for mariculture (in common with other perspectives), but was highly supportive (rank 3) of multiple environmental management options, both upstream [2] and downstream [17]), as well as re-examination of regulations regarding water and shellfish quality classification. There was strong agreement (rank 3) that classification of the quality of shellfish waters and shellfish is too stringent [1321] and that the system should be based on risk, rather than hazard. The justification given by participants for this high ranking was based on concerns that transient, anomalously high microbial contaminant levels (*Escherichia coli* (*E. coli)* colony forming units) quantified in shellfish meat can trigger long-term downgrading in the classification of shellfish waters, without the need for further risk assessment. Downgrading of shellfish waters impacts on the public perception of shellfish quality and delays sales, since shellfish subsequently require purging in clean water, in order to protect the health of human consumers. Despite these concerns, participants sharing this perspective also agreed very strongly (rank 4) that there is significant potential to expand mariculture sustainably in the UK (incl. SW England) [32], but were only marginally convinced (rank +1) that there is scope in the current marine spatial planning process to facilitate mariculture expansion [33]. In addition to food provisioning, the potential use of shellfish in the bio-remediation of water quality [22] was also ranked moderately high (rank +2), which added further to the breadth of this perspective.

3.3. Perspective 3 - upstream thinking

The 'Upstream thinking' perspective was held by 9 participants: 3 from Academia; 2 from Government Agencies; 2 from Conservation Charities; 1 Regulator; 1 from Other Industry. Upstream thinking centres on the importance of upstream land management (including farming) practices and targeted interventions, such as the restoration of woodlands and mires to minimise soil erosion, mitigate river flooding and improve water quality [2]. In particular this perspective agreed strongly (rank +3) that agricultural subsidies would be better spent directing them on environmental improvements [9] and that regulating farm practices would be more effective than changing consumer food preferences [7]. In addition, there was strong disagreement (rank -4) that chemical pollutants present limited risk to shellfish quality and growth [25], which was justified by participant concerns around the potential for agricultural chemicals, such as herbicides, pesticides and veterinary pharmaceuticals, to enter watercourses, particularly during flood events. Similar to perspective 2, and in line with upstream 'green' thinking, there was moderate agreement (rank +2) that shellfish farming in polluted estuaries should attract payments for improving water quality [24].

3.4. Consensus statements

Six out of the forty Q-statements from Table 1 were ranked similarly by all participants, i.e. they were non-significant ($p > 0.05$) in terms of differentiating the three perspectives. All participants agreed moderately/strongly (ranks +2 or +3) that investment for sustainable mariculture should include controlling water quality problems at source [27] and that rainwater runoff from urban areas is a major threat to water quality [17]. The remaining four consensus statements were ranked between -1 (mild disagreement), 0 (ambivalent) and +1 (mild agreement). These low ranking statements indicated that participants were generally not convinced (either way) about the effectiveness of agricultural subsidies for sustaining natural capital-based economies [8] and the value of testing of shellfish quality [15, 16] or investing in shellfish cleaning/purging technologies [28] for protecting human health and ensuring the sustainability of UK mariculture. The responses to the latter statements are consistent with the common desire to tackle water quality issues at their source, but also reflect variation and uncertainty in the measurement of water and shellfish quality (see discussion).

3.5. Contentious statements

Seven statements were ranked dissimilarly by all participants ($p > 0.05$). The most contentious statement (ranking between -3 and +4) was around whether protecting bathing water quality (WQ) in coastal areas helps protect shellfish quality [18]. The next most contentious statement, spanning 5 rankings (-4 to +1), was the assertion that expanding aquaculture offshore will negate the need for land-based interventions to improve WQ [38]. This stems from occasional detection of *E. coli* in shellfish sampled several nautical miles offshore in SW England, which greatly exceed detection levels in close proximity to known point sources, for example in estuaries. Other moderately contentious issues, spanning 2 or 3 rankings included the risk of variable water quality [19], including levels of microbial markers/pathogens [26] to shellfish quality, the impact of dairy farming on water quality [1], and the importance of visual impact as an additional barrier to mariculture expansion [35]. The least contentious issue, on which all perspectives disagreed relatively strongly (ranked -3 to -2), was that upstream land management/WQ interventions are less cost effective than downstream [5]. Disagreement over the majority of the above statements stems from the considerable variation and uncertainty in water quality prediction, in both space and time, and different perceptions of the principal sources of contaminants (see discussion).

3.6. Other emerging issues

A key issue emerging from Q-sort feedback questionnaires and from subsequent workshop discussions among stakeholders was the need to understand how pressures on water quality and mariculture may change in the future, in response to climate change, as well as with changes in rural/agricultural and urban land use and development. Stakeholders with a Downstream thinking perspective were particularly concerned about ageing sewerage infrastructure and lack of investment in upgrading this in tandem with rural and urban housing developments.

4. Discussion

Application of the Q method showed that all stakeholder participants aligned with one of three perspectives (Fig. 2). These perspectives (P1, P2 and P3, detailed above) were defined by individual stakeholder perceptions of the importance of different pollution sources throughout catchments in limiting water quality and shellfish quality, rather than being pre-determined by stakeholder group membership. The naming of perspectives (upstream to downstream thinking) was consistent with different recognised approaches for managing water quality and quantity (Gregersen et al., 2007), including in SW England via South West Water's Programmes (SWW, 2020a, 2020b) and the Environment Agency's South West River Basin Management Plan (EA, 2015).

The finding of common perspectives across different stakeholder groups (sectors) is often encountered using the Q-method (Cross, 2005; Steeves and Filgueira, 2019) and likely reflects the individual values of stakeholder participants, rather than simply their current affiliation/employment (Given, 2008). The following discussion covers key priorities raised in stakeholder discussions concerning consensus Q-statements and contentious Q-statements driving different stakeholder perspectives (P1 to P3).

4.1. Importance of microbiological water quality and reliable indicators for ensuring shellfish food safety

All stakeholders agreed that both short- and longer-term exceedance of microbial water quality and shellfish quality standards significantly constrain the shellfish mariculture industry. However, there remains considerable uncertainty around the sources (municipal versus agricultural) and durations of microbial contamination events and impacts on shellfish and human health. Disparities in monitoring results for faecal indicator organisms (FIOs) in shellfish waters and in shellfish under the Water Framework Directive (WFD: 2000/60/EC) compared with shellfish monitoring results gathered under Food Hygiene Regulation (EC) No. 854/2004 have been highlighted by CEFAS (2011). These disparities relate to variations in sampling locations, timings and local environmental variables influencing bacterial transport and survival in seawater and accumulation in shellfish (CEFAS, 2011). Stakeholders question the value of current strategies based on random spot sampling and testing of FIOs in water and in shellfish, rather than risk-based (i.e. flood or spill event-based) sampling and testing.

For example, stakeholders highlighted that one (potentially) anomalous elevation in *E. coli* counts in shellfish meat (for which the statutory limit for direct human consumption: 230 counts per 100 g of shellfish flesh; EC, 2004c) can result in the downgrading of shellfish waters from class A to B for 3 years. The same B classification can be given to shellfish waters where *E. coli* counts may be elevated for protracted periods. As such, shellfish from the two areas referred to above can carry different human health risks, but incur the same preventative measures (e.g. purging/depuration). The reliability of 'spot' sampling and analysis based on existing measures was also questioned by several stakeholders because FIOs (i.e. *E. coli* colony forming units) may not reliably indicate pathogen exposure. For example, pathogens such as norovirus are not currently quantified and compared with *E. coli* (Hassard et al., 2017). Furthermore, some stakeholders highlighted that FIO colony counts can exhibit extreme spatial and temporal variability in estuaries and coastal waters, depending on varying light intensity and penetration of the water column, water mixing, sewage content and suspended particulate matter. There is growing consensus in the published literature that more integrated and reliable risk assessments could be achieved by linking information on catchment hydrology (including monitoring of episodic high flows and CSO spills), land use, and FIO loads from sewerage-related sources versus livestock production areas (Campos et al., 2013). This integrated approach to source apportionment, dubbed 'quantitative microbial source tracking and apportionment', has potential for directing appropriate investment in sewerage infrastructure and/or adjacent farming activities (Kay et al., 2008; Stapleton et al., 2011). Several stakeholders highlighted that viral detection techniques (Jones et al., 2015a) may be more reliable than quantifying FIOs to assess pathogen risk and source apportionment. To date, standardised viral detection methods and quality assurance measures have been lacking (Hassard et al., 2017). However, methods quantifying human-specific gut-associated bacteriophages have recently been developed and applied to track human wastewater contamination in river catchments, estuary water, sediments and bivalve shellfish (Farkas et al., 2019).

The most contentious statement was whether protecting bathing water quality (WQ) in coastal areas helps protect shellfish quality, with Q-scores being polarised between strong agreement and disagreement. According to regulatory stakeholders, a more comprehensive picture of microbial water quality and risk to mariculture is being built from the synthesis of monitoring data for the 500 bathing waters and 124 shellfish waters, designated in England and Wales (DEFRA, 2020). Regulators are aware that establishing links between water quality and shellfish quality is not trivial and must take into account local and distant sources and sinks, including sediments and other environmental factors affecting microbial transport, uptake and accumulation in shellfish (Campos et al., 2011). Currently some stakeholders (particularly the shellfish industry) perceive unexplainable local variations in water quality between adjacent bathing waters and shellfish waters. For example, at the mouth of the Exe estuary there are five designated bathing water sampling points, which routinely achieve good microbial quality or better ($\leq$500 *E. coli* or $\leq$200 intestinal enterococci per 100 mL) under the EU Bathing Water Directive (2006/7/EC). In contrast, in adjacent shellfish waters there are 15 representative monitoring points, where microbial water quality is periodically found to be poor ($>$300 *E. coli* per 100 mL) under the WFD (CEFAS, 2013; MMO, 2016). The disparity between these different assessments of microbial water quality is likely due to spatial and temporal differences an between sampling points, as well as different water quality criteria for bathing waters compared with shellfish waters. Taking a wider view of water quality monitoring data throughout catchments indicates that distant sources (upstream), as well as local sources (estuarine and coastal) can contribute significantly to deterioration and variation in microbiological quality of bathing waters and shellfish waters (CEFAS, 2013). Regulatory stakeholders including DEFRA, the UK Environment Agency and Marine Management Organisation favour holistic studies of potential pathways, and see source tracking and catchment modelling as being invaluable tools for informing schemes to improve bathing and shellfish water quality. Furthermore, these authorities recognise that employing diverse measures to improve water quality driven by the WFD, Bathing Water Directive, Drinking Water Directive (98/83/EC) and the Urban Waste Water Treatment Directive (91/271/EEC) can greatly improve the outcomes, including for shellfish quality (DEFRA, 2020; EA, 2015; MMO, 2016). This diversified approach, driven by multiple legislative instruments, has led to the adoption of both upstream nature-based and downstream sewerage infrastructure-based approaches in Asset Management Planning (AMP) cycles delivered by UK Water companies over the last three decades.

4.2. Importance of chemical water quality for shellfish mariculture

All three stakeholder perspectives acknowledged (to varying degrees) the importance of chemical contaminants that are known to be toxic to humans, and the need for their inclusion in water quality and shellfish quality assessments. EU Hygiene Regulations (EC, 2004a, 2004b and 2004c) set maximum threshold concentrations for a range of chemical contaminants in shellfish meat that include lead (1.5 mg/kg), cadmium (1 mg/kg), mercury (0.5 mg/kg), dioxins (4 μg/kg and dioxins + DL-PCBs 8 μg/kg), and the poly-aromatic hydrocarbon (PAH) benzo [*a*]pyrene (10 μg/kg). Other chemicals of concern for marine and estuarine ecosystem health (including shellfish health) identified by the International Council for the Exploration of the Sea (ICES) and Oslo and Paris Conventions (OSPAR) include other PAHs; organometallic compounds (TBT); priority substances listed in Annex II of Directive 2008/105/EC4; and synthetic compounds (pesticides, antifoulants, and pharmaceuticals) (Beyer et al., 2017).

The impact of chemical contaminants on water quality and shellfish quality was ranked highest by participants with an Upstream thinking perspective, who were concerned about the risk of contamination from pesticides and veterinary chemicals used in arable and livestock farming, respectively. Broad and Downstream thinking perspectives also highlighted the potential for contamination from municipal and industrial sources of bioaccumulative and toxic heavy metals and organic chemicals, including WFD priority substances (EC, 2013b), detected in rivers throughout England in 2019 (EA, 2020). Prior to these updated classifications, only in exceptional cases in the UK (in industrialised estuaries) have priority substances been found to accumulate in bivalve shellfish to such an extent that they exceed Tolerable Daily Intakes (TDIs) for human consumers (Liang et al., 2004). However, there is growing evidence from elsewhere in Europe that chronic low-level exposures to chemical mixtures can have more widespread, significant impacts on bivalve shellfish health, notably on growth (Brooks et al., 2009) and disease resistance e.g. Pacific oyster herpes virus OsHV-1 (Moreau et al., 2015a), which can in turn reduce bivalve shellfish production. Significant risks to shellfish health potentially exist for widely used (upstream and downstream) and recalcitrant pesticides, such as the molluscide metaldehyde (Moreau et al., 2015b), and metals (Guéguen et al., 2011; Ogunola, 2017). Site-specific chemical risk assessment can be facilitated by validated and regulatory approved biological uptake and effect models (Luoma and Rainbow, 2005; Arnot and Gobas, 2006; Smith et al., 2015). Source Apportionment Geographical Information Systems (SAGIS) are also available for tracking point and diffuse sources of persistent organic pollutants and metals (and nutrients) in river systems (Comber et al., 2013), but such models have yet to be developed for estuarine and coastal systems, which are characterised by fluctuations in tidal flows. Stakeholders generally agreed that modelling diffuse sources of contamination and the environmental fate and behaviour of recalcitrant and biodegradable contaminants (as well as pathogens) throughout catchments (Oliver et al., 2016) are important areas for further research and development.

4.3. *The efficacy of upstream versus downstream interventions for managing microbial and chemical water quality and shellfish quality*

Opposing perspectives on the risk of water contamination from ‘Upstream’ versus ‘Downstream’ sources and their impacts shellfish quality reflect differing stakeholder opinions on the principle sources of FIOs and the importance of proximity of microbial (and chemical) contaminant inputs to shellfish farms located in estuaries and coastal waters. Additional factors contributing to these opposing perspectives include differences in the perceived cost versus the effectiveness of upstream and downstream interventions for protecting water quality and shellfish farming. Upstream interventions are generally considered by all stakeholder participants to be low cost, ‘nature-based’ or ‘soft-engineering’ options, although overall costs can be high in large agricultural catchments (CEFAS, 2011). Interventions include Catchment Sensitive Farming (CSF) and landscape management practices, such as continuous cropping/ crop rotation to avoid bare soil, to reduce soil erosion and agricultural run-off (Gooday et al., 2014). Other interventions involve Natural Flood Management (NFM) through creation of integrated constructed wetlands, riparian filter strips (Kay et al., 2008) and restoration of natural wetland and woodland habitats (Nisbet et al., 2011) to reduce water pollution and flooding. Downstream interventions are generally considered by stakeholders to be high cost, ‘hard engineering’ solutions for improving sewage treatment or sewer and drainage systems to minimise spills from combined sewer overflows. However, Downstream interventions can also include soft engineering solutions, such as Sustainable Urban Drainage Systems (SUDs) and urban green infrastructure, which aim to manage the quality and quantity of surface water runoff in ways which mimic natural processes (Fletcher et al., 2015). These green infrastructures include green roofs, rain gardens, expanding urban parks and rainwater harvesting and re-use (Woods Ballard et al., 2015). Stakeholders with a ‘Broad view’ were more aware of intimate interconnections between rural and urban landscapes and the potential for SUDs to mitigate flood risk and contaminant spills/runoff, in combination with upstream interventions.

The effectiveness of different upstream and/or downstream interventions for managing water and shellfish quality are likely to vary for different catchments depending upon hydrology and land use. The UK Environment Agency have recently published evidence of the effectiveness of CSF interventions in reducing nutrient, sediment and FIO concentrations (5–22 % reduction), and reducing pesticide concentrations previously exceeding the drinking water standard of 0.1 μg/l (34 % reduction) across monitored CSF catchments in the UK (EA, 2019). Other upstream interventions directly targeting pesticides such as metaldehyde have also proven to be very effective in lowering environmental concentrations, by encouraging more responsible pesticide use (Castle et al., 2017), including stopping use in certain areas (Smith et al., 2017). These improvements in water quality have been achieved via advisory services, grant application schemes and payments for ecosystem services i.e. the provisioning of clean fresh water, rather than via regulation. Large scale habitat restoration projects, for example woodland restoration projects, are also likely to be very effective in upstream areas and riparian zones, but it may take some considerable time before the full benefits are realised (Nisbet et al., 2011). Downstream interventions, notably improvements in sewerage infrastructure, via the installation of UV disinfection at sewage treatment works, sanitary sewer overflows and the control of intermittent discharges (from CSOs) in SW England have also been shown to be effective (Pateman et al., 2018). Improvements in effluent treatment in particular have led to notable reductions in faecal coliform (including *E. coli*) and Enterococci fluxes of 40–88 % and 36–94 %, respectively, across catchments, but there is still significant potential for reduction of intermittent discharges from CSOs (CEFAS, 2011).

4.4. *Assessing and managing multiple constraints on shellfish mariculture*

Realising significant growth in UK aquaculture in the next two decades (DEFRA, 2017) will require expansion of existing sites or licencing of new sites. Marine spatial planning was widely acknowledged by stakeholder participants as a major constraint on growth for the mariculture industry, due to conflict for space with other water uses, including public amenity, fishing and conservation areas, as well as negative public perception of mariculture. Stakeholders with a ‘Downstream perspective’ and those with a ‘Broad view’ felt moderately strongly that spatial planning constraints on mariculture were comparable to water quality constraints, but were only marginally convinced that there is scope in the current marine spatial planning process to facilitate mariculture expansion.

The importance of spatial planning is highlighted in various documents, including the UK Multiannual National Plan for the Development of Sustainable Aquaculture (DEFRA, 2015), River Basin Planning (EA, 2015) and Marine Spatial Planning (MMO, 2020). Recent mapping of Dorset and East Devon coastal areas (up to 6 nautical miles offshore) has been performed to assess their suitability for mariculture development (CEFAS, 2019). Exclusion zones were placed around long sea outfalls, due to the potential for impaired microbial water quality. Stakeholders agreed with the conclusion in the CEFAS (2019) report, that tackling water quality problems at source is a key priority. Marine Protected Areas (MPAs) occupying 28% of suitable space for mariculture were also highlighted as possible exclusion zones in the CEFAS (2019) report. However, excluding mariculture from MPAs may be overly conservative, since there are existing locations nearby, such as Poole Harbour, in which mariculture and MPAs coexist well (Poole Harbour Steering Group, 2011). Furthermore, in Lyme Bay, mariculture has been reported to increase biodiversity and enhance local fisheries (Sheehan et al., 2018). There is an urgent need to gain wider understanding of the positive and negative interactions between aquaculture sites, fishing and conservation areas, in order to develop ‘general rules’ and targeted advice to facilitate mariculture development. There is also a growing need to evaluate the perceived public impression versus the measurable visual impact of aquaculture, alongside the positive and negative environmental impacts on water quality and natural habitats (Bacher et al., 2014; Stanley et al., 2019). Stakeholders with Broad view and Downstream thinking perspectives considered that shellfish aquaculture can make a substantial contribution to maintaining/improving water quality and that shellfish farming in polluted estuaries should attract payments for this ecosystem service. The potential for shellfish to bio-remediate nutrient pollution is evidenced widely in the peer reviewed literature (Stadmark and Conley, 2011; Petersen et al., 2014). Nutrient removal by mariculture, curbing eutrophication, in EU coastal waters alone is valued at US$20 to 30 billion per year (Ferreira et al., 2009).

4.5. *Future drivers and uncertainties affecting mariculture*

Long-term management of water quality in river basin management plans and marine spatial plans must account for human population growth, climate change and changing environmental, agricultural and fisheries policies. In the first instance, the human population in SW England (served by South West Water) is expected to grow by ~20 % (from 1.71 million in 2012 to 2.045 million by 2039), with greatest growth predicted around existing urbanised coastal areas (SWW, 2019). Stakeholders with a Downstream thinking perspective expressed concern over increasing demands for the supply of freshwater and the containment and treatment of wastewater for urban developments, whilst also coping with climate change. Projected climate changes for SW England include wetter winters, drier summers, more common heavy rainfall events, and more variable winter and spring precipitation (UK Met Office, 2018). Risk of flood events is high following heavy rainfall in the relatively steep, low porosity catchments typical of many SW areas (SWW, 2019) and such events are likely to impact negatively on water quality through increased land runoff and CSO spills. In preparation for the next cycle of Asset Management Planning (AMP 7), SWW and other UK water companies are currently working with the Environment Agency to map water quality (pollutant loads) and spill duration from CSOs (Pateman pers comm.) in order to inform the selection and location of hard and soft engineering solutions.

Future changes in environmental, agricultural and fisheries policies are inevitable in the UK and will depend to a large extent upon implementation of DEFRA's 25 Year Environment Plan (DEFRA, 2018a) and the new Agriculture Bill (2020), which adopt a 'public money for public goods' approach. For example, Environmental Land Management Schemes (ELMS) established through the Agriculture Bill will pay land managers to improve the environment and increase its resilience to climate change through provision of public goods, including via wetland and woodland restoration schemes (DEFRA, 2018b; Committee on Climate Change, 2020). Consequently, the future of agriculture versus alternative forms of food production, including aquaculture, in the UK and elsewhere, will also depend on production efficiency and the provisioning of other key ecosystem services, such as carbon sequestration, nutrient cycling, regulation of water quality (Froehlich et al., 2018). Some stakeholders with a Broad view highlighted that, while shellfish may contribute significantly to nutrient removal in coastal waters, their contribution to carbon sequestration may be limited or neutral at best. Nevertheless, this is an overwhelmingly better position than that for current land-based meat production systems. Recent publications conclude that carbon sequestration through calcium carbonate shell formation by farmed shellfish may be more than compensated by CO2 production and therefore should not be included in carbon trading schemes in the future (Munari et al., 2013; Morris and Humphreys, 2019).

5. Conclusions

A diverse range of stakeholders representing industry academia, environmental policy and regulation agree that management of water quality is key to the development of aquaculture, including shellfish mariculture. Periodic impairment of microbial water quality associated with high rainfall, flooding, combined sewer overflows (CSOs) and land runoff can have immediate and long-lasting impacts on shellfish quality, leading to harvesting bans, product recalls and downgrading of shellfish beds. Long-term, low-level (chronic) exposures to chemical cocktails, including priority substances regulated under the Water Framework Directive, may also impact on shellfish health and productivity, though these impacts are more difficult to discern under current assessment regimes. Significant progress is being made in understanding that pressures on water quality can occur throughout catchments, but stakeholders are divided on whether 'upstream' or 'downstream' interventions are most cost-effective. Stakeholders are uncertain on how pressures are likely to change in response to human population growth, future climate change and agri-environment and urban planning policy changes. Nevertheless, there was consensus among stakeholders that water quality should be managed by targeting sources of contaminants (including agricultural, municipal and industrial sources), and the vast majority agreed that this can be facilitated by whole catchment-based approaches to land, water quality and flood management.

Ethical statement

All stakeholders consented to take part in the Q-sort and for their anonymised data to be used and published in this research study.

CRediT authorship contribution statement

A Ross Brown: Conceptualization, Data curation, Formal analysis, Supervision, Writing - original draft, Writing - review & editing. **James Webber:** . **Sara Zonneveld:** Data curation, Formal analysis. **Donna Carless:** Resources, Software, Investigation, Methodology. **Benjamin Jackson:** Resources, Software, Investigation, Methodology. **Yuri Artioli:** Resources, Software, Writing - review & editing. **Peter I. Miller:** Writing - review & editing. **John Holmyard:** Writing - review & editing. **Craig Baker-Austin:** Writing - review & editing. **Simon Kershaw:** Writing - review & editing. **Ian J. Bateman:** Writing - review & editing, Funding acquisition. **Charles R. Tyler:** Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Summary of the analysis of participant Q-sorts using the R package 'qmethod'

Software: qmethod (v 1.5.4) (Zabala, 2014)
1) Participant Q-sorts were compiled in a table (example csv.file below)
Participants

Statements	AC1	GA1	ND1	ND2	IC1	RE1	OI1	RE2
sta_1	0	2	0	0	0	0	−2	0
sta_2	2	3	2	−1	1	−2	3	3
sta_3	2	0	0	−1	1	−1	0	−1
sta_4	−1	0	1	2	2	0	1	3
sta_5	−4	0	−3	0	1	−3	−1	0
sta_6	0	1	4	3	0	2	1	4
sta_7	1	1	−1	0	1	0	2	−2
sta_8	−1	−2	−4	0	−1	1	−3	0
sta_9	0	1	2	0	0	2	1	1
sta_10	−1	−3	−3	−4	−3	−4	−4	−3

2) Evaluation of the similarity of Q-sorts made by individual participants was undertaken using a Pearson correlation matrix, whereby a correlation of 1 represents two participants sorting the statements identically.

3) A principal component analysis (PCA) was performed to identify distinct groups of participants with similar Q-sorts and to identify ‘factors’ characterising the ‘perspectives’ of each participant group on “the importance of water quality management options versus other actions for ensuring the sustainability of shellfish mariculture”. The contribution of these factors towards explaining the variance in the combined Q-sort data was evaluated using varimax orthogonal rotation. Statistically significant ‘factors’ were determined to be those that explained >10% of the variance in the Q-sort data and had eigenvalues of >2.00 (i.e. at least two Q-sorts correlated significantly with each other).

4) Factor analysis was undertaken to create an ‘idealized Q-sort’ for each factor, based on the average of all Q-sorts which were associated (or loaded) significantly with a given factor (or perspective) (Watts and Stenner, 2005). A Pearson correlation was then made between participant Q-sorts and the idealized Q-sorts for each factor. Equation 1) was used to assess whether factor loadings for each participant were significant. Participant Q-sorts that loaded significantly either on multiple factors, or no factors, were determined to be confounded.

Equation 1: to assess if factor loadings are significant (after Brown, 1980; Watts and Stenner, 2005)

Significant factor loading ($p < 0.05$ significance level) > 2.58 / root N

Where N = number of Q- statements (in this case N = 40)

5) Z-score analysis was used to evaluate how much each factor agreed with each statement; z-scores were calculated as weighted average ranking values (-4 to +4) for each statement for each factor.

6) A further assessment of the validity of participant Q-sorts was also made by checking that the statements associated with each factor represented consistent, logical groupings (Weitzman and Bailey, 2019).

Appendix B. Feedback questionnaire for completion for the Q-sort

1) Please state the reasons for your choice of the statements you agreed with most.

____

____

2) Please state the reasons for your choice of the statements you agreed with least.

____

____

3) Were there any statements you didn’t understand?

____

____

4) Did we miss any significant issues? Please write additional statement(s) covering these:

____

____

Please tick the relevant box to indicate which sector you currently work in: ☐ Policy ☐ NGO ☐ Aquaculture industry ☐ Academia ☐ Regulation ☐ Other (specify): ______

Indicate number of years experience in your current sector and any previous experience: Policy:__ years NGO:__ years Aquaculture industry:__ years

Academia:__ yearsRegulation:__ years Other: ________(specify) ___ years

Appendix C. Summary of Q-sort factor analysis results quantifying the loading of individual stakeholder participants on statistically distinct factors (representing perspectives P1-P3)

Loading values of −1 and +1 represent complete disagreement and complete agreement (respectively) with perspectives.

Bold numbers represent significant loading at the p <0.05 significance level.

Sector (stakeholder group)	Individual stakeholder participant	Dominant perspective (significant factor loading)	Factor loading values		
			P1	P2	P3
Academia	AC1	P2	0.19	**0.66**	0.29
	AC2	P2	−0.12	**0.59**	0.56
	AC3	P2	0.03	**0.72**	0.37
	AC4	P2	−0.14	**0.73**	0.24
	AC5	P3	0.14	0.25	**0.67**
	AC6	P3	−0.02	0.25	**0.68**
	AC7	P3	0.31	0.18	**0.59**
Regulator -Government/Agency	GA1	P3	0.09	0.16	**0.55**
	GA2	P3	0.02	0.27	**0.69**
	GA3	P1	**0.61**	0.07	0.45
Regulator – Non Departmental Public Body (Government advisory group)	ND1	P2	0.14	**0.57**	0.52
	ND2	P2	0.17	**0.69**	0.18
	ND3	P3	−0.02	0.25	**0.69**
	ND4	P1	**0.4**	0.18	0.31
	ND5	P2	0.04	**0.63**	0.37
	ND6	P2	0.22	**0.62**	0.54
	ND7	P3	0.41	0.17	**0.49**
Independent/Charity (Conservation)	IC1	P2	−0.05	**0.42**	0.18
	IC2	P3	0.28	0.43	**0.64**
	IC3	P3	0.14	0.3	**0.77**
Shellfish Industry	SI1	P1	**0.74**	−0.27	0.07
	SI2	P2	0.05	**0.5**	0.09
	SI3	P1	**0.69**	0.16	0.06
	SI4	P1	**0.55**	−0.38	0.36
	SI5	P1	**0.7**	0.21	−0.11
Other Industry	OI1	P2	0.4	**0.61**	0.23
	OI2	P3	−0.03	0.57	**0.62**
	OI3	P2	0.15	**0.46**	0.01
	OI4	P2	0.2	**0.5**	0.47

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