Stakeholder perceptions of public good provision from agriculture and implications for governance mechanism design

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Stakeholder perceptions of public good provision from agriculture and implications for governance mechanism design

Abstract:	Agriculture provides many public goods; however the costs and benefits of these are rarely well distributed. Maintaining public good provision often relies on external governance mechanisms, in turn reliant on the existing socio-ecological system. With two groups of stakeholders (practitioners and academics) we created cognitive maps of socio-ecological systems linking agriculture, public goods, and governance mechanisms in north-east Scotland. Fuzzy cognitive mapping was used to explore stakeholders' perceptions and experiences, and to assess alternative governance options for the local socio-ecological context. We find agreement for perceptions of the system between stakeholders, but differences in each group's focus. Models predicted little change in the provision of public goods from agriculture in relation to different governance mechanisms. We find that stakeholder participation can aid understanding of the impacts of proposed governance changes at the local level, improving comprehension of stakeholder perception of impacts and understanding of stakeholders' reactions to particular governance mechanisms.

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1 **Abstract**

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3 well distributed. Maintaining public good provision often relies on external governance

4 mechanisms, in turn reliant on the existing socio-ecological system. With two groups of

5 stakeholders (practitioners and academics) we created cognitive maps of socio-ecological

6 systems linking agriculture, public goods, and governance mechanisms in north-east Scotland.

7 Fuzzy cognitive mapping was used to explore stakeholders' perceptions and experiences, and

8 to assess alternative governance options for the local socio-ecological context. We find

9 agreement for perceptions of the system between stakeholders, but differences in each group's

10 focus. Models predicted little change in the provision of public goods from agriculture in

11 relation to different governance mechanisms. We find that stakeholder participation can aid

12 understanding of the impacts of proposed governance changes at the local level, improving

13 comprehension of stakeholder perception of impacts and understanding of stakeholders'

14 reactions to particular governance mechanisms.

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16 **Keywords:** Agriculture, Public Goods, Fuzzy Cognitive Mapping, Governance, Land

17 Management

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1   Introduction

Agricultural systems are well recognised for the provision of ecosystem services (Cooper, Hart, & Baldock, 2009; Hunter, Guarino, Spillane, & McKeown, 2017; Potschin, Haines-Young, Fish, & Turner, 2016; Swinton, Lupi, Robertson, & Hamilton, 2007), defined as benefits humans derive from environmental systems (Millenium Ecosystem Assessment, 2005). Although some of these services, such as food production, are market goods which can be traded, many, such as views of agricultural landscape, recreation or biodiversity, are 'public goods'. Public goods include all goods which are, in varying degrees, non-excludable (no person can be prevented from using the service) and non-rivalrous (use of the service by one individual does not reduce the availability to others). Public goods are not limited to ecosystem services, and include goods such as education, and not all ecosystem services act as public goods (e.g. sale of fishing licences). Public goods fall outside of traditional markets, and promoting public goods on agricultural land can incur private cost to landowners and managers (Westhoek, Overmars, & van Zeijts, 2013). Policy and governance mechanisms, (e.g. regulations, green labelling) may therefore be needed to incentivise public good production (Westhoek et al., 2013). An overview of ecosystem services, both as market and public goods, can be found in Swinton et al. 2007.

Agricultural land is therefore the site of many competing interests, involving both public and private goods such as increasing crop yield, reducing soil run-off, and maintaining public access. Management is therefore characterised by uncertainty and often does not conform to traditional assumptions about the existence of a single optimal solution (Duckett, Feliciano, Martin-Ortega, & Munoz-Rojas, 2016). Additionally the connections between agricultural, ecological and social systems are often data-poor and context-specific. Under these circumstances stakeholders themselves can therefore hold valuable knowledge which may reduce uncertainty and increase data availability (Voinov & Bousquet, 2010).

3

1

2 Stakeholders have a unique understanding about the systems they work and live in, and how

3 governance mechanisms interact with these systems (Voinov & Bousquet, 2010), for example

4 how timing of forage cutting may alter cattle stocking rate (Vanwindekens, Stilmant, & Baret,

5 2013), or the impact of bureaucracy on uptake of management (Christen, Kjeldsen, Dalgaard,

6 & Martin-Ortega, 2015). The inclusion of a diverse range of stakeholders can therefore

7 improve policy mechanism design. This involvement should take account of the heterogenous

8 nature of stakeholders, recognising that they do not all hold the same views, beliefs or

9 motivations or operate under the same socioeconomic realities and face the same barriers and

10 opportunities. Accounting for a diversity of actors (e.g. farmers, researchers and policy

11 makers), perspectives (e.g. organic and conventional farmers) and institutions (e.g.

12 governmental, non-governmental and community groups) improves the ability of policy to

13 engage with broad issues, identify novel approaches and increases support and reduces

14 resistance to new or changed governance mechanisms (Anggraeni, Gupta, & Verrest, 2019;

15 Baird et al., 2019; Doukas & Nikas, 2019; Reed, 2008). Stakeholder knowledges of

16 agricultural systems are based not just in individually held ideas, but also in relation to the

17 network of connections they make to other actors and biotic and abiotic elements of the system.

18 Stakeholders and stakeholder knowledges therefore influences final behaviours, tied to the

19 context of the agricultural, ecological and social systems (Allen, Quinn, English, & Quinn,

20 2018; Bremer et al., 2018; Thompson, Reimer, & Prokopy, 2015). Accordingly, inclusion of

21 stakeholders in development of governance mechanisms can improve their chances of success,

22 although it is important to note that this will only be effective where this insight is carried

23 through to policy design and implementation, and is experienced as more than a 'tick-box

24 exercise' (Anggraeni et al., 2019; Reed, 2008). Capturing stakeholder insight is particularly

25 timely for EU agricultural policy post 2020, when member states will have higher flexibility in

4

1   administering the Common Agricultural Policy (CAP, European Commision, 2018), and for

2   the UK following Brexit (e.g. Health and Harmony consultation on Green Agriculture after

3   Brexit (Department for Environment Food and Rural Affairs, 2018).

4

5   The success of governance mechanisms in promoting public good provision depends not just

6   on the design of the promoted interventions (e.g. how and when do hedgerows benefit

7   biodiversity) but also their implementation (e.g. how hedgerows are planted following PES

8   scheme) and uptake (e.g. how many hedgerows are planted following PES scheme) (Figure

9   One). Uptake is influenced by stakeholders' perceptions of the mechanisms, the perceptions

10   of the mechanisms within the community, individual socioeconomic realities and fit with

11   existing practices, as well as the ways in which the mechanisms interact with the socio-

12   ecological system, and how stakeholders evaluate these interactions and potential outcomes

13   (Allen et al., 2018; Bremer et al., 2018; Morris, Mills, & Crawford, 2000; Thompson et al.,

14   2015). Taken together, this influences the acceptability and success of particular mechanisms

15   and hence their direct impacts on public goods, because uptake of mechanisms, however

16   theoretically impactful, will be low if this impact is not perceived.

17   **[Figure One here]**

18   Mental modelling provides one method for facilitating stakeholder participation (Doukas &

19   Nikas, 2019; Fairweather & Hunt, 2011). Mental models involve the creation of diagrammatic

20   representation of a system, identifying concepts, and the links between them, to explore how

21   changes are perceived to move through the system. This creates a more formal representation

22   of stakeholders' own conceptual models of how a system works (Voinov & Bousquet, 2010).

23   Fuzzy cognitive mapping (FCM) is one form of semi-quantitative mental modelling (Özesmi

24   & Özesmi, 2004). FCM expands the cognitive mapping method to include scoring of the

25   strength connections between attributes of the system (Kok, 2009; Özesmi & Özesmi, 2004;

5

1   Papageorgiou & Kontogianni, 2012). FCM provides a useful tool to link storylines to models,

2   and is generally well received by participants (Vliet, Kok, & Veldkamp, 2010). Because FCM

3   captures perceptions of the system, rather than empirical data (although this can be added to

4   models), they do not necessarily produce a single 'true' model, but one which represents the

5   expectations of the stakeholders. Involvement of a broad, well targeted, range of stakeholders

6   is therefore important (Anggraeni et al., 2019; Baird et al., 2019; Christen et al., 2015; Doukas

7   & Nikas, 2019). The participatory aspect of FCM also brings limitations, most obviously the

8   potential to code incorrect data, that data collected is limited by the stakeholders involved, and

9   context surrounding the links may be lost (Gray et al., 2015; Kok, 2009; Özesmi & Özesmi,

10   2004). FCM can also be used as part of a larger research or policy design exercise, which may

11   incorporate more traditional methods of data collection, such as surveys of users or ecological

12   surveys. We do not explore the models underlying FCM in this paper, nor do we contribute to

13   FCM theory and modelling, as this has been carried out extensively elsewhere (e.g. Özesmi

14   and Özesmi (2004), Papageorgiou and Kontongianni (2012), and reviewed by Doukas and

15   Nikas (2019)).

16

17   FCM is of particular use in environmental and agricultural systems because it is able to create

18   a tangible representation of stakeholder perceptions, including not only direction of links, but

19   their strength, increasing knowledge of, and reducing uncertainty surrounding, these often data-

20   poor systems. FCM can prove particularly valuable for increasing the visibility of assumptions

21   made by stakeholder groups, increasing opportunities for these to be scrutinised, identifying

22   areas where contention or a lack of consensus may cause difficulties, and highlighting where

23   options for intervention may be available. Because a visual map is created, stakeholders can

24   present elements of the system which may not be apparent through a direct interview, because

25   they are thought to be self-evident (Vliet et al., 2010). Because FCM is able to utilise natural

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

1   language to formalise outcomes of discussion and exploration of a system by stakeholders there

2   is the opportunity not just for stakeholders to contribute their knowledge, but to view and adjust

3   the resulting models, and use these model to explore uncertainties within the system (Kok,

4   2009; Özesmi & Özesmi, 2004; Vliet et al., 2010). This can be particularly valuable for

5   highlighting the stewardship values associated with managing agricultural systems, which have

6   been linked to increased environmental action (Allen et al., 2018; Thompson et al., 2015). With

7   regards to public goods stakeholder participation through FCM has been used to understand

8   breaches of regulations regarding bank erosion and diffuse pollution (Christen et al., 2015).

9

10   Through FCM, this study seeks to understand how distinct stakeholder groups perceive public

11   good provision from agriculture, and how these groups perceive the impacts of governance or

12   policy changes. We use the case study of the Ugie river catchment, Aberdeenshire, Scotland

13   (UK), which was identified with stakeholders as an area of high priority for public good

14   provision, in particular for biodiversity and water quality.

15   **2   Materials and Methods**

16   *2.1   Study area and wider project*

17   The river Ugie is located in North East Aberdeenshire (Figure Two). The catchment is

18   dominated by mixed farming, predominantly of beef and cereal, with potatoes, oilseed rape,

19   pigs, sheep and poultry also produced. Mean farm size is 47ha (Aberdeenshire Council, 2017).

20   The Ugie is a source of drinking water and one of the Scottish Environmental Protection

21   Agency's diffuse pollution priority catchments due to failing to meet environmental standards

22   (SEPA, 2015). Previous research (as part of PROVIDE H2020, for full explanation of project

23   see Appendix A) with stakeholders in Aberdeenshire (e.g. representatives from environmental

24   organisations and the forestry sector) has identified this area as of high priority for public

25   goods, in particular water quality and biodiversity (Creaney, Novo, Byg, & Faccioli, 2017).

26   Stakeholders previously identified appropriate governance and policy to improve provision of

7

1 these goods, including different forms of subsidies, taxes, regulation, cooperative approaches,

2 awareness, public opinion and market mechanisms. These mechanisms were identified as

3 important either due to their large impacts on farm viability (e.g. subsidies), successful trials

4 carried out elsewhere (e.g. catchment partnerships), or potential for changing the mechanism

5 in the future (e.g. likely shift in agricultural policy in the UK post-Brexit). The mechanisms

6 identified form the basis of the fuzzy cognitive mapping exercise. For full explanation see:

7 Byg, Novo, Faccioli, & Kyle, 2017.

8

9 **[Figure Two here]**

10

11 *2.2   Fuzzy Cognitive Mapping*

12 FCM is a semi-quantitative, typically participatory, conceptual mapping approach. FCM is

13 made up of 'Concepts' representing elements of a system (e.g. crop yield) which are joined by

14 single direction links, although concepts may be linked by two links in opposing directions

15 (e.g. yield have small positive impact on amount of crop planted, and amount of crop planted

16 a large positive impact on yield), the underlying assumptions for multiple links must be

17 carefully considered in the context of the system. Links can be positive (increase in one concept

18 leads to an increase in the second) or negative (increase in one concept leads to a decrease in

19 the second) and are assigned a score for their strength compared to other links in the system

20 (Kok, 2009; Özesmi & Özesmi, 2003, 2004). Because these are relative scores they cannot be

21 used to estimate absolute magnitude of impact (Papageorgiou & Kontogianni, 2012). FCM

22 may involve individuals or groups, and maps can be combined to create a consensus map.

23

24 Maps can be described in terms of the number and types of links they contain, known as matrix

25 indices, providing information on the structure of the system as perceived by stakeholders. The

26 number of links, concepts, and connection density (i.e. the number of connections per concept)

8

1   indicates the relatedness of concepts within the system as perceived by the stakeholders

2   involved in the FCM. This is important when altering the system, such as through policy

3   change, as a more interlinked system has larger potential for side effects (Özesmi & Özesmi,

4   2004), although the diversity of stakeholders involved in the FCM must also be considered,

5   with more complexity often seen with more diverse stakeholder involvement (Baird et al.,

6   2019).

7

8   Models are created from these maps using the scores given to links between concepts. This

9   process is typically first carried out using stakeholder assigned values, representing the baseline

10   or calibrated model. To understand how changes to model concepts can influence other

11   concepts, the models can be simulated by changing the concept values, indicating an increase

12   or decrease in the importance of the concepts. Comparing equilibrium scores between the 'no

13   changes' and the 'changes' models estimates how concept changes may impact throughout the

14   system. Jetter and Kok (2014) provide an accessible overview of FCM in practise, and for a

15   full explanation of FCM models see Özesmi and Özesmi 2003 and 2004.

16

17   *2.3   Stakeholders*

18   Stakeholders included academics researching Scottish agriculture (based at the James Hutton

19   Institute) and land managers (practitioners e.g. farmers, fishery managers, land agents) working

20   in the Ugie river catchment. Academic stakeholders were selected for their knowledge of wider

21   agricultural systems and governance mechanisms and included natural and social scientists.

22   Practitioners provided in-depth knowledge of the context of agriculture along the Ugie.

23   Inclusion of practitioners was of particular importance as they are often excluded from such

24   consultations. Within the wider project (PROVIDE, see Appendix A) policy-makers and a

25   wider array of stakeholders (e.g. representatives from environmental organisations and the

26   forestry sector) have also been consulted through four workshops, including identification of

9

1 potential governance mechanisms for public good provision which have been used in this FCM

2 exercise, and later evaluation of the results of the FCM models. However, policy makers were

3 not consulted directly to create FCMs, due in part to funding and time limitations, and

4 understanding that policy maker voices are heard by default in design of state-led governance

5 mechanisms (Takacs, 2019). The work presented here therefore sought to identify the data

6 normally missing from such discussions. Separate workshops were held for academics and

7 practitioners, with 11 and 8 participants respectively. While mixed workshops are good for

8 promoting dialogue and creating a shared understanding of a system amongst different

9 stakeholders we chose to hold separate workshops to enable clearer identification of the

10 differences in perceptions held by distinct stakeholder groups.

11 *2.4 Workshop design*

12 Workshops began by introducing participants to the case study and public goods. To facilitate

13 map creation we used the Mental Modeller interface (Gray & Cox, 2013). This provided a

14 canvas onto which concepts and links could be drawn and results directly exported. The

15 interface enabled simple models to be created, allowing stakeholders to view, validate and

16 modify the outcomes of their mapping.

17

18 Participants were split into groups to consider either biodiversity or water quality. In order to

19 decrease the cognitive burden on the participants they were presented with maps already

20 containing key concepts identified through previous stakeholder workshops (Byg et al., 2017;

21 Creaney et al., 2017), but were told that they could add or delete concepts to create a model

22 that matched their understanding of the system (Table One). Participants discussed the

23 presented concepts and altered concepts according to perceptions. Discussions included the

24 definition of each concept that would later be used to match concepts between maps. This

25 ensured that we were able to match concepts in terms of the definitions used by stakeholders

26 (i.e. concepts which had the same definition but different names by stakeholders could be

10

1   1 compared due to the explicit discussion of definition), which may have differed to prescribed

2   2 definitions. Some concepts were later merged (e.g. elements of biodiversity) to enable

3   3 comparison and prevent double counting of impacts. Participants added links between concepts

4   4 to illustrate how they understand the system to function. Links were restricted to between -1

5   5 (strong negative) and +1 (strong positive) but were not otherwise limited. Links and concepts

6   6 were added, edited or removed by the facilitator once a consensus had been reached among the

7   7 participants.

8 **[Table one here]**

9

10 After maps were created models were run making no changes to scores assigned by

11 stakeholders. Models were then re-run setting the scores for the links between policy and

12 governance and the public goods artificially high, for stakeholders to compare model outputs.

13 Stakeholders were able to view the outcomes of their maps and identify where mistakes may

14 have been made, or relationships needed to be adjusted (i.e. where changes to one concept

15 produced illogical changes in another concept). Giving the option to feedback on results is

16 important to fully understand stakeholder knowledges and providing stakeholders with further

17 ownership over the final models. Both will improve the quality of the model outcomes and

18 applicability.

19

20 *2.5   Scenario development*
21 Scenarios development did not involve direct stakeholder input, but were used to further

22 explore implications of the models after the workshops had been conducted. Scenarios were

23 developed from the maps to include those governance mechanisms which were most closely

24 linked to either water quality or biodiversity, because these were the focus of our study. We

25 identified concepts directly linked to either water quality or biodiversity, and those concepts

26 indirectly linked to water quality or biodiversity (i.e. connected through one intermediate link)

11

1 (e.g. public pressure impacts green agriculture, which in turn impacts water quality). Due to

2 the form of the model (i.e. dilution of impacts where concepts are linked more distantly) these

3 concepts were most likely to have the largest impacts on public goods, and therefore are the

4 concepts best targeted for change in governance mechanisms. Concepts were then thematically

5 grouped to represent consistent governance changes. Concepts separated by more than two

6 links (i.e. with more than one intermediate step connecting them to water quality or

7 biodiversity) were not altered in scenarios because they are expected to have smaller impact on

8 public goods, and always through an intermediate concept which was included within the

9 scenarios. These concepts remain in the model as a whole. All mechanisms chosen for

10 alteration within the scenarios were initially identified as important in either the workshops

11 presented here, or previous workshops (Byg et al., 2017). Scenarios are described in the results

12 section. The percentage change in equilibrium values (i.e. the final values of each concept after

13 the model has been run) between the modelled and no changes scenario were compared. These

14 are relative values and are therefore grouped into high, medium or low change, to prevent false

15 comparison.

16

17 *2.6 Quantitative analysis*
18 Quantitative analysis did not involve further stakeholder engagement.

19

20 The maps created by stakeholders were exported from the Mental Modeler interface. All

21 analysis was carried out in R using the FCMapper (V1.1) package (Turney & Bachhofer, 2016).

22

23 Matrix indices provide a means to quantitatively compare map structures. Matrix indices were

24 calculated (function: matrix.indices) for the academic and practitioner maps for water quality

25 and biodiversity. Because each group had the opportunity to alter concepts, the maps created

26 by academics and practitioners for each public good varied and concepts considered were

12

1   compared. For full details of calculation of matrix indices we refer readers to Özesmi and

2   Özesmi (2004).

3

4   To enable comparisons between models, concepts that had been split (e.g. biodiversity in the

5   academic water quality map) were recombined, and the mean value was used (Papageorgiou

6   & Kontogianni, 2012). Although stakeholders had been able to set links to any value between

7   0 and 1, discussion surrounding the links referred instead to qualitative levels (e.g. low,

8   medium and high). To reflect this we therefore rounded each value to the nearest quarter,

9   reducing the potential for false accuracy.

10

11   Models were initially simulated with no fixed concepts (i.e. the values given by the

12   stakeholders, function: nochanges.scenario) to estimate equilibrium values (i.e. the values of

13   each concept once the model becomes stable, concept values do not fluctuate with additional

14   iterations) for the current system. Transformation was by the logistic function, and simulations

15   were run for 20 iterations and considered converged if $i19=i20$. This was then repeated for each

16   governance mechanism scenario with selected concepts fixed to 1 (function: changes.scenario).

17   Scenario development is described in the preceding section. The equilibrium values of the no

18   changes and changed models were compared (function: comp.scenarios).

19

20   Finally academic and practitioner models were combined. To estimate the link between each

21   concept the mean value was taken for those links where a non-zero value was present in both

22   models. For example, if the link between public pressure and green agriculture was 0.2 in the

23   academic model and 0.4 in the practitioner model the combined model would estimate this link

24   as 0.3. If concepts were only related in a single model then in the combined model the link was

25   equal to the value given in the model in which the link was present (e.g. agri-environment

13

1 schemes link to green agriculture was considered only in the practitioner model for biodiversity

2 and not in the academic model). This method of combining was selected as the common links

3 between models were largely similar but differing expertise of academics and practitioners led

4 them to identify different links from one another. The selection of this method of combining,

5 rather than assuming missing links represented zero links and calculating the mean in all cases,

6 was supported by the discussions with stakeholders while creating the models, in that no

7 stakeholders explicitly stated zero for any link, but rather expressed uncertainty.

8 **3   Results**

9 *3.1   Building maps*

10 In all groups, creating conceptual maps led to lively discussions about not only linkages

11 between different concepts, but also the meanings of the concepts themselves. Some of these

12 discussions were reflected in the final models through renaming, splitting, deleting or adding

13 concepts, while other aspects were captured in the recorded discussions and the researchers'

14 notes. An example of an FCM can be seen in Figure Three, for all others see Appendices B:D.

15 **[Figure Three here]**

16 *3.1.1 Biodiversity*

17 Despite providing pre-populated maps drawing on previous stakeholder workshops, there are

18 differences between academic and practitioner maps in terms of concepts considered when

19 conceptualising the public goods related to agriculture (Table One). The practitioner map

20 focused on concepts with direct impacts on agriculture (e.g. splitting 'Agricultural supply

21 chain' into input and output supply chain), while the academic map placed emphasis on

22 different types of biodiversity and green agriculture (e.g. splitting 'Biodiversity' into farmland

23 birds, soil fauna, pest species, aquatic species, arable weeds, and pollinators). Structures of

24 both maps are similar.

14

3.1.2   Water quality

The differences between academic and practitioner maps for water quality are fewer than those in the biodiversity maps. Practitioners split regulations and subsidies into more specific measures, while the academics added green subsidies and retail pressure (Table One). The practitioner map contained one more concept than the academic map. Both maps have similar structures.

3.2   *Combined fuzzy cognitive maps from academics and practitioners*

3.2.1   Biodiversity

The combined model contains all links present in each individual model, and therefore contains a higher number of connections per variables than either model individually. As a result changes to concepts may be higher in the combined model than either individual model. The number of links present in the combined biodiversity model was 64, across 30 concepts.

Equilibrium values for the no-changes scenario indicates the baseline level of each concept, to which scenarios can be compared. Differences between models above 0.2 (as recognised a large compared to other concepts) are seen for: farm viability, biodiversity, water quality, agricultural yield, water flow and water security (for full results see appendix F).

Links between concepts which appeared in both the academic and practitioner models agreed with regards to the direction (i.e. they were either both positive or both negative). This indicates there was agreement in the type of interaction between concepts, though the perception of strength may differ. For all links that appeared in both models the mean link value was taken for the combined model. Where a link appeared in only one model this value was used in the combined model. Although taking the mean values of links has the potential to create a model which represents neither view well and neutralises differences across stakeholders (Özesmi &

15

1 Özesmi, 2004) this would be of limited impact in our case because no links were in direct

2 opposition.

3 *3.2.2   Water quality*

4 The combined water model contains 43 connections across 23 concepts. Therefore equilibrium

5 values in the combined model can exceed those on each individual map.

6

7 The link between green agriculture and agricultural yield took opposing values in the water

8 quality maps, being negative in the academic map, and positive in the practitioner map.

9 Because of this, taking the mean value for this link would not have represented either map

10 accurately (i.e. the link would have been shown to be zero, where this is not true in either map).

11 To avoid this we created three alternative combined models with the link between green

12 agriculture and agricultural yield set to 0 or the level expected from the practitioner (0.63) or

13 academic (-0.28) models. We ran these models and compared equilibrium values to understand

14 the impact of the link between green agriculture and agricultural yield on other concepts.

15 Because equilibrium values showed little difference between models we carried out all further

16 analysis with this link set to 0. Because the link between green agriculture and agricultural

17 yield was removed the combined model cannot be used to describe agricultural yield.

18

19 Comparisons of equilibrium values between the combined, academic and practitioner models

20 showed only water flow with a difference of over 0.2.

21

22 **3.3   Scenarios**

23 To design governance change scenarios we identified those concepts with the highest influence

24 on water quality or biodiversity to simulate situations in which governance mechanisms

25 worked to their highest potential as opposed to the current perception. Because green

16

1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34   35   36   37   38   39   40   41   42   43   44   45   46   47   48   49   50   51   52   53   54   55   56   57   58   59   60

1 agriculture had the largest direct impact, we also identified the concepts linked to green

2 agriculture. Stakeholders were not involved in scenario design.

3

4 *3.3.1 Biodiversity*

5 The concepts with the highest, positive impact on green agriculture (as identified above as the

6 strongest link) were grouped into three scenarios:

7   1. Improved policy: Agri-environment schemes and CAP increased

8   2. Changed agriculture: Promoting traditional crops and shortening the agricultural supply

9   chain increased

10   3. Improved technology: Technological advances increased.

11

12 Biodiversity is predicted to improve to some extent in all scenario models, with highest changes

13 in the improved technology scenario (Table Two). Full results can be seen in the Appendices

14 H:J.

15 *3.3.2 Water quality*

16 The concepts with the largest predicted impacts on water quality via impacts on green

17 agriculture were organised into three scenarios:

18   1. Improved policy: catchment partnerships, agricultural regulations and green subsidies

19   increased.

20   2. Public and retail pressure: Public and retail pressure increased.

21   3. Increased education: Education increased.

22

23 Water quality increases were predicted for all models, with highest changes in the improved

24 policy scenario (Table Two).

25 **[Table Two here]**

17

1 **4   Discussion**

2 *4.1   Maps and Models*

3 The maps created by academics and practitioners varied in the concepts and links considered,

4 despite stakeholders beginning with maps pre-populated with the same concepts, which had

5 been identified in previous workshops. Academic maps focused on biodiversity and green

6 agriculture, while practitioner maps were more concerned with direct agricultural effects. This

7 difference in focus of academic and practitioner maps relates to the differing expertise, and

8 likely to the different values, held by both groups. Although practitioners involved in this

9 process supported mechanisms to improve farm ecosystems, their primary concern, and

10 therefore primary expertise, is on how changes will impact their outputs, and therefore their

11 livelihoods. Although academics involved in the process understand that agricultural outputs

12 must be maintained, their priority, and expertise, is environmental outcomes. The difference in

13 concepts considered by varied groups of stakeholders highlights the importance of multiple

14 stakeholder views and priorities in policy design, and particularly of including practitioners

15 alongside academic 'experts' (Anggraeni et al., 2019; Baird et al., 2019; Bosma, Glenk, &

16 Novo, 2017; Christen et al., 2015) in order to perceive links which may not be observable to a

17 single group. While such differences can also be elicited and documented in other ways, FCM

18 increases the visibility of assumptions held by different stakeholders through the creation of a

19 literal visual representation of the perceptions of stakeholders, leading to connections being

20 presented that may not be verbalised through interviews because they are believed to be self-

21 evident. In the case of the Ugie river catchment through FCM we were able to recognise that

22 stakeholders held different, but not opposing, assumptions. In policy making experience by

23 practitioners is often excluded not by design, but through the mechanism by which evidence is

24 gathered in responses to a wide, relatively unspecific, call (e.g. Department for Environment

25 Food and Rural Affairs, 2018), or though implicitly favouring views of the proponents of

26 change (often industry or governments) or research (Takacs, 2019). Our results using FCM

18

1   indicate that this exclusion may lead to a restricted number of implications of policy change

2   being considered, even where there is general agreement in the way in which the system

3   functions.

4

5   The collaborative and discursive nature of stakeholder participation through FCM has

6   advantages over traditional modelling, either from empirical data or existing literature, in

7   allowing for increased understanding of concepts to different stakeholders, and improved

8   confidence in the links between concepts. In our Ugie river case study practitioners noted that

9   although they could make links between promotion of traditional crops and other concepts, the

10   lack of markets and interest to take what was, to their mind, a step back in progress meant that

11   the mechanism would not be adopted. This deeper understanding, which could only be captured

12   through stakeholder participation, is of high importance to policy making and mechanism

13   design, as well as a research tool. FCM is able to formalise the outcomes of the discussions

14   and exploration around the mapping exercise, and create models of highly complex systems

15   under imperfect data, incorporating knowledges, perceptions and beliefs from multiple

16   stakeholders. Beyond only contributing their knowledge stakeholders can view the outcomes

17   of their modelling, adjust models to best reflect their realities, and use the models to explore

18   uncertainties within the system. On viewing the outcomes of the water quality model the

19   academic group were able to better consider the consequences and rationale for links to water

20   in particular. Although no changes were made as a result of this deliberation it provided a

21   catalyst for considering more carefully the links created, and therefore increased certainty in

22   the resulting model. Participation not just in providing data, but also in analysing the results,

23   can increase ownership of the process for stakeholders, improving accuracy of data, and

24   applicability for policy decisions.

25

19

1 The concepts perceived to impact biodiversity or water quality were similar in academic and

2 practitioner maps. However, outgoing links were fewer in the practitioner maps than the

3 academic maps. While academics recognised public goods as impacting yield and water quality

4 (biodiversity model) and biodiversity and habitat (water quality model), practitioners perceived

5 a link only from water quality to reduced health concerns. While this may be an artefact of the

6 task focus on the production of public goods, this may also indicate that practitioners do not

7 perceive wider benefits of public goods, while academics may be biased towards perceiving

8 larger benefits due to the focus of their work. If it is the case that practitioners are less aware

9 of the benefits of public goods to agricultural production this would likely reduce the uptake

10 of governance mechanisms, given that no personal benefit would be perceived. Future study of

11 the benefits of public goods to agricultural production, and management to communicate and

12 harness these, may therefore serve to improve uptake of management of public goods.

13

14 We combined academic and practitioner maps into a single model using mean link values.

15 Combining maps is common practice (Özesmi & Özesmi, 2003, 2004; Vanwindekens et al.,

16 2013).; however, combined maps also run the risk of diluting links, creating a model which

17 does not represent any stakeholder accurately (Fairweather & Hunt, 2011). Across our maps

18 we identified a single area where stakeholder perceptions disagreed. Within the water quality

19 map academics predicted a negative relationship between green agriculture and agricultural

20 yield, while practitioners predicted a positive relationship. When modelling outcomes this link

21 was of little consequence, as yield did not link back to public goods, directly or indirectly.

22 However, understanding the reasons behind opposing views between stakeholder groups is

23 important for the success of changes in governance mechanisms, and identifying such opposing

24 links is a benefit of FCM making links visible. While it appears that practitioners have a more

25 positive view of the impacts of green agriculture on agricultural yield than academics, we did

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1   not define specific actions of 'green agriculture'. It would be expected that practitioners do not

2   consider mechanisms which would reduce yield to be worth considering, while academics may

3   perceive that reductions in yield are acceptable for improvements to public goods. Because we

4   cannot unpack the reasons for drawing the links in this way further exploration of the

5   relationship to green agriculture would be valuable. This also highlights a weakness in our

6   approach through not providing a definition for green agriculture.

7

8   Although no opposing links were found within the biodiversity map, the scores for farm

9   viability showed large variation, being highest in the academic model. This may reflect higher

10   optimism in the academic model for farm adaptation, which is not recognised by the

11   practitioners. Because our models identify only perceived relationships we cannot identify

12   which perception is more 'correct', however regardless of actual outcome practitioners will

13   not, and would not be expected to, support governance mechanisms which they perceive will

14   negatively impact farm viability. The link between governance mechanisms and farm viability

15   is therefore one which would benefit from further empirical study, to ensure that farm viability

16   is not unduly impacted, and any impacts can be appropriately compensated.

17

18   *4.2   Scenarios*

19   Overall our models predicted little change in water quality or biodiversity through alternative

20   governance scenarios. Though the models predict only small changes to biodiversity and water

21   quality it is important to recognise that these are relative values. These values are therefore

22   useful for policy development in identifying where the largest comparative changes may be

23   made, but cannot be used to estimate the absolute magnitude of change, rather forecast the

24   likely dynamics. In our models the largest changes were predicted for technological change,

25   such as precision farming. In recent years precision farming has been recognised as a potential

26   mechanism to increase yield and farm sustainability, and is supported through pillar two of the

21

1 CAP (Lind & Pedersen, 2017), and has received substantial funding from the UK Government

2 (Agri-Tech Centres, 2018). While this is encouraging for technological development for

3 improving the provision of public goods from agricultural land, this may also highlight a

4 potentially unfounded 'hope' in technology. In our models practitioners perceive that

5 technological change will deliver increased yields alongside improved environmental

6 outcomes. However, this relationship would also reduce pressure on practitioners to take other

7 actions, which may not have the same positive impacts on yield. While the positive relationship

8 between technological change and biodiversity signposts a mechanism to be considered, further

9 work to understand this link, and to relate this to the wider phenomenon of technological

10 optimism, is needed.

11

12 Although we can estimate comparative change, overall change is small across all models. This

13 likely reflects the already high level of environmental policy and regulation in Scottish

14 agriculture, as well as the tendency for stakeholders to consider only incremental, rather than

15 radical, changes to governance, policy and management.

4.3 Limitations

17 As with all models FCM is limited. Models are not able to incorporate non-linearity, a problem

18 identified by the water quality practitioner group, who noted that more restrictive policy would

19 only have a positive relationship to green agriculture until a threshold of costs to the practitioner

20 was reached. Once policy becomes too restrictive uptake would be reduced, and the positive

21 impact on green agriculture would decline, despite the 'greenness' of the policy itself

22 increasing. This inability to code for non-linearity has been identified as a challenge

23 particularly in models which aim to incorporate ecological relationships (Skov & Svenning,

24 2003). Agent based FCM provides one option for incorporating non-linearity (Lee, Lee, Lee,

25 & Lim, 2013). Though we are not aware of such models being used currently to answer

26 environmental management questions, gains in modelling of such questions would be

22

1. expected. In a related problem concepts may also be dependent on different time scales. This

2. presents particular challenges to incorporating climate change into models, as each link is

3. presumed to occur within an equal time step. Rule based FCM provides one option to introduce

4. varied time schedules and time lags (Carvalho & Tomé, 2001), transforming weights into time,

5. and addition of time variation through simulation (Doukas & Nikas, 2019).

6.

7. The restriction to a single link, with no context, was also identified as a limitation by all groups.

8. The context of agri-environmental systems is highly important, and a link that is positive in

9. one situation may be negative in another. Presenting only the average link could therefore lead

10. to policy decisions which do not reflect reality for all practitioners, particularly damaging if

11. changes were made to regulations. Alternative cognitive mapping methods, such as adapted

12. form of systems mapping (Nikas, Doukas, Lieu, & Tinoco, 2017), can provide such contexts,

13. but also increase the complexity of the task and outputs.

14.

15. As with all models, FCMs are only as good as the data used to create them. Though stakeholder

16. participation is a benefit of these models, relying on stakeholder knowledge has the potential

17. to code incorrect data that do not reflect underlying biophysical realities. Through assigning

18. numbers to indicate the strength of links FCMs may also present false accuracy, as there is

19. limited opportunity to incorporate uncertainty (Gray et al., 2015; Kok, 2009; Özesmi &

20. Özesmi, 2004). Although the basic FCM is subject to the limitations detailed above, extensions

21. to the method must be carefully considered to ensure that additions reflect the system, and do

22. not increase the potential for false accuracy (Jetter & Kok, 2014), particularly for social

23. components, which may not have a definite 'correct' value. While this is a strength of the

24. method to represent multiple understandings across stakeholders, it also presents challenges

25. for combining and representing all understandings, and it may not be possible to identify a

23

1 single 'true' model. In order to ensure that the models created are relevant to the question at

2 hand users must therefore pay close attention to selection of representative and knowledgeable

3 stakeholders and the process of participatory modelling, including knowledges of the

4 biophysical systems as well as the social systems, and incorporating qualitative data to account

5 for nuances and uncertainties not captured in the quantitative modelling. This includes the

6 discussions and reasonings brought to play in the participatory modelling process. Although

7 FCM provides a method to code vital, and often excluded, understandings of complex systems

8 it remains most useful when used alongside empirical models. When FCM provides an

9 alternative, rather than an expanded, view of the current understanding it may better contribute

10 to identifying avenues for further empirical study, or areas where dialogue between

11 stakeholders needs to be increased.

12

4.4   Future Work
14 Our models predict only small changes to water quality and biodiversity as a result of

15 governance or policy changes, possibly because stakeholders are only able to imagine changes

16 to policy or governance that they themselves have experienced. A wider understanding of

17 revolutionary changes to agricultural policy or governance, which may result in larger changes

18 to biodiversity and water quality, may therefore require more in depth and exploratory

19 participatory methods.

20

21 Because FCM is participatory it does not intend to create a single 'objective' model, but seeks

22 to code stakeholder knowledges. This increases the potential for incorrect data to be coded. In

23 the case of the Ugie river catchment it would be beneficial to extend the models of public good

24 provision for agriculture to include existing ecological and biophysical data which characterise

25 the relationships between land use and biodiversity or water quality. Linking this model to

26 spatial variation would further extend the applicability of the model to land management,

24

1   although would be computationally expensive. Incorporating FCM as a starting point to

2   conceptualise problems and solutions would be a valuable avenue to explore where biophysical

3   modelling is expected to have a real-world policy implication.

4

5   Conclusions

6   Policy and governance mechanisms to improve provisions of public goods must act within

7   complex agri-environmental systems. The interlinked socio-ecological concerns, as well as

8   high context specificity, means that decisions must often be taken with imperfect information.

9   We applied FCM in the Ugie river catchment in Aberdeenshire as one method to capture

10   stakeholder knowledges. We found that academics and practitioners provided different, but

11   complementary, understandings of the provision of public goods from agriculture, although

12   models did not predict large changes to either provision of biodiversity or water quality with

13   changes to policy or governance. FCM was an effective method for formalising the mental

14   models of both academics and practitioners, but had limitations in that the scenarios considered

15   were fairly normative, and thus other methods may be better suited to identifying consequences

16   of radical policy or governance change. FCM may therefore be a useful tool for policy makers

17   and planners to increase understanding of the potential wider consequences of policy or

18   management changes, encouraging design of mechanisms which will limit negative side-

19   effects, or prompting measures to be put in place to compensate those negatively impacted.

20   The accessible nature of FCM makes it a valuable tool to facilitate transdisciplinary

21   involvement in co-design of governance mechanisms, while its flexibility enables

22   accommodation of multiple stakeholder interest. The participatory nature of FCM in not only

23   providing data, but also allowing participants to engage with and interpret the results increases

24   stakeholder by in and therefore the legitimacy of imposed change. While stakeholder

25   participation through FCM allows the integration of different stakeholder knowledges, beliefs

26   and perceptions, and enables a deliberative process through model creation, limitations have

25

1 been identified by stakeholders, including the inability to code non-linear relationships,

2 threshold effects, or time. Thus, the combination of FCM with ecological, biophysical data

3 and cost-benefit analysis could enrich policy designs by integrating a mix of approaches and

4 knowledges.

6 Acknowledgements

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Table 1 Environmental outcomes and governance mechanisms presented for creation of FCMs. These were altered by all groups during the mapping process. Based on Byg et al., 2017 and Creaney et al., 2017. Biodiversity and water quality mechanisms were identified independently.

Biodiversity	Good water quality
Governance mechanisms	Governance mechanisms
CAP greening	Green subsidies
Changes in agricultural supply chain	Public pressure
Promote traditional crops	Catchment partnerships
Regulation of agriculture	Regulation of agriculture
Green labelling	Green labelling
Change in narratives on agriculture	Education and extension
Production subsidies	Production subsidies
Green agriculture[1]	Green agriculture
	Taxes on damaging practices
Environmental/Agricultural outcomes	Environmental/Agricultural outcomes
Agricultural yield	Agricultural yield
Good water quality	Biodiversity and habitat
Food security	Food security
Normal water quantity/flow	Water flow/quantity

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[1] 'Green agriculture' was not strictly defined and included all aspects of agriculture which had an environmental consideration included in some aspect. This included actions which both promoted good environmental outcomes and reduced poor outcomes.

Table 1 *Change in concepts with altered governance scenarios for the combined model. From low (+ (light blue) or – (light orange): less than 1%) to high (+++ (dark blue) or - - - (dark orange):over 5%) change, positive or negative.*

|	Biodiversity			Water quality		
	Improved policy	Changed farming	Improved technology	Improved policy	Public and retail pressure	Increased education
Biodiversity	+	+	+++	++	+	+
Water quality	+		+++	++	+	+
Water flow				++	+	+
Habitat	+	+	+			
Broadleaf trees	+++					
Green agriculture	++	+	++	+++	++	++
Traditional crops	+		+			
Mixed farming	+++	+	++			
Yield	+	+	+++			
Farm viability	+++	+++	+++			
Supply chain	+		+++			
Jobs	++	+	- - -			
Food imports	+	-	+			
Food security	+	+	+	+	+	+
Green labelling	+	+++	+			
Technological change				+		+
Pollution	+		+			
Consumer behaviour	+	-	-			
Health priorities				-	+	-
Political pressure				+	- -	-
Public pressure				+		+++
Retail pressure				+		+
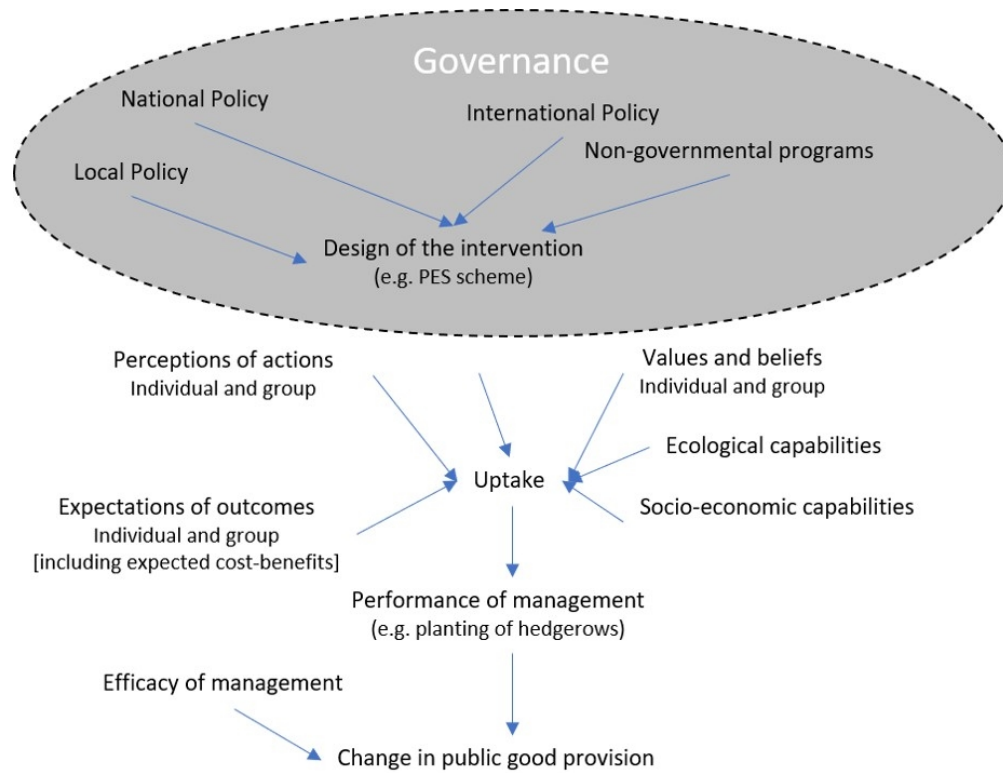
Figure 1 Relationship between governance, policy, intervention and management

157x122mm (149 x 149 DPI)

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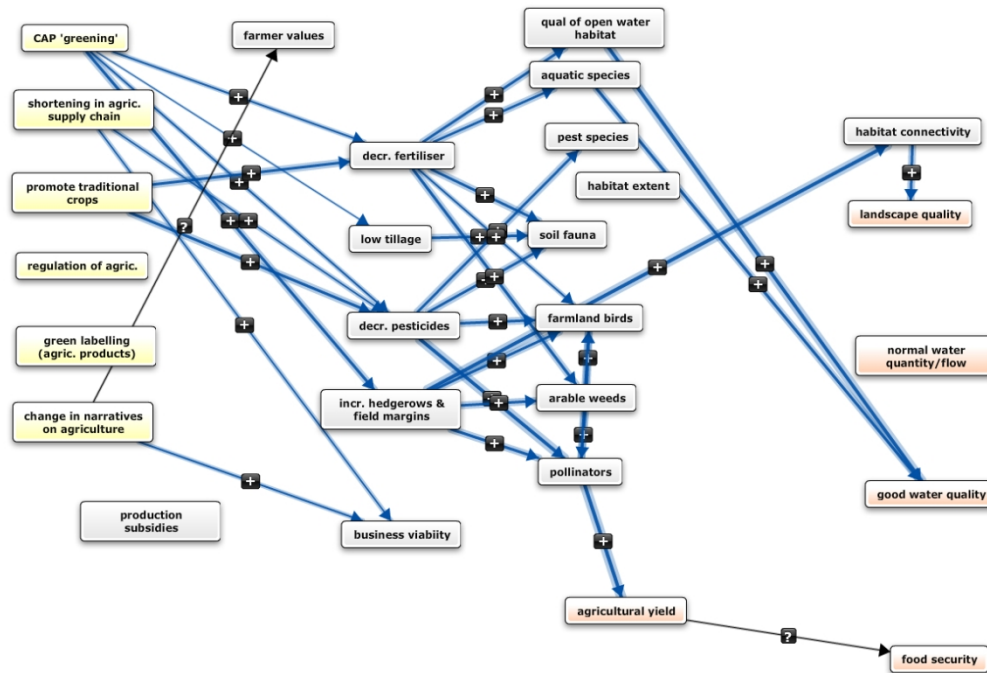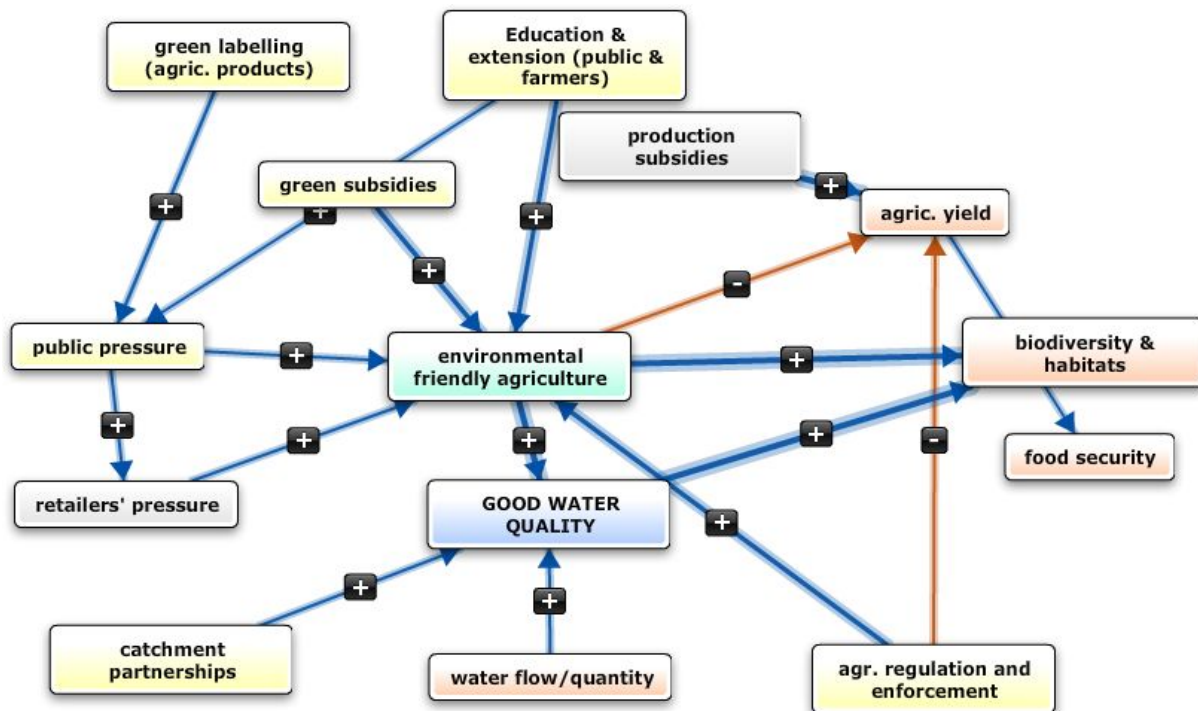Figure 2. Map of case study area, Ugie river catchment. Red area indicates Aberdeenshire (Google Maps, 2018)

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Figure 3 Example FCM: Biodiversity – academics. For others see appendix

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

1 **Appendix A –** Situation of project within PROVIDE H2020 project

2 This work was situated within the PROVIDE H2020 project

3 (www.provideknowledgeplatform.eu), of which the Ugie river catchment is a case study. The

4 PROVIDE project was concerned with the provision of public goods from agriculture and

5 forestry and was built around four stakeholder workshops. These workshops invited

6 stakeholders to identify important public goods and case studies within their region, support in

7 the design and evaluation of valuation of public goods within the case studies, discuss

8 governance mechanisms for public good provision, and evaluate the potential for transferability

9 of governance mechanisms for the production of public goods. The fuzzy cognitive mapping

10 exercise described in this case study built upon the governance mechanisms recognised a

11 potentially useful by stakeholders to aid understanding of the impacts that these governance

12 mechanisms may have. The results from this work were also combined with data from 12 other

13 European partners to understand similarities and differences across Europe.

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15 **Appendix B –** Fuzzy cognitive map for biodiversity created by practitioners

16 Arrow colours: Blue= Positive relationship, Orange=Negative relationship, Black=Unknown

17 relationship. Line thickness indicates strength of relations (e.g. thicker line= stronger

18 relationship). Box colours: Yellow= Policy or governance indicated by researchers, Orange=

19 Outcomes indicated by researchers, Grey= Concepts added by stakeholders. Green and Blue=

20 Key concepts for consideration when producing the map.

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2 **Appendix C -** Fuzzy cognitive map for water quality created by academics

3 Arrow colours: Blue= Positive relationship, Orange=Negative relationship, Black=Unknown

4 relationship. Line thickness indicates strength of relations (e.g. thicker line= stronger

5 relationship). Box colours: Yellow= Policy or governance indicated by researchers, Orange=

6 Outcomes indicated by researchers, Grey= Concepts added by stakeholders. Green and Blue=

7 Key concepts for consideration when producing the map.

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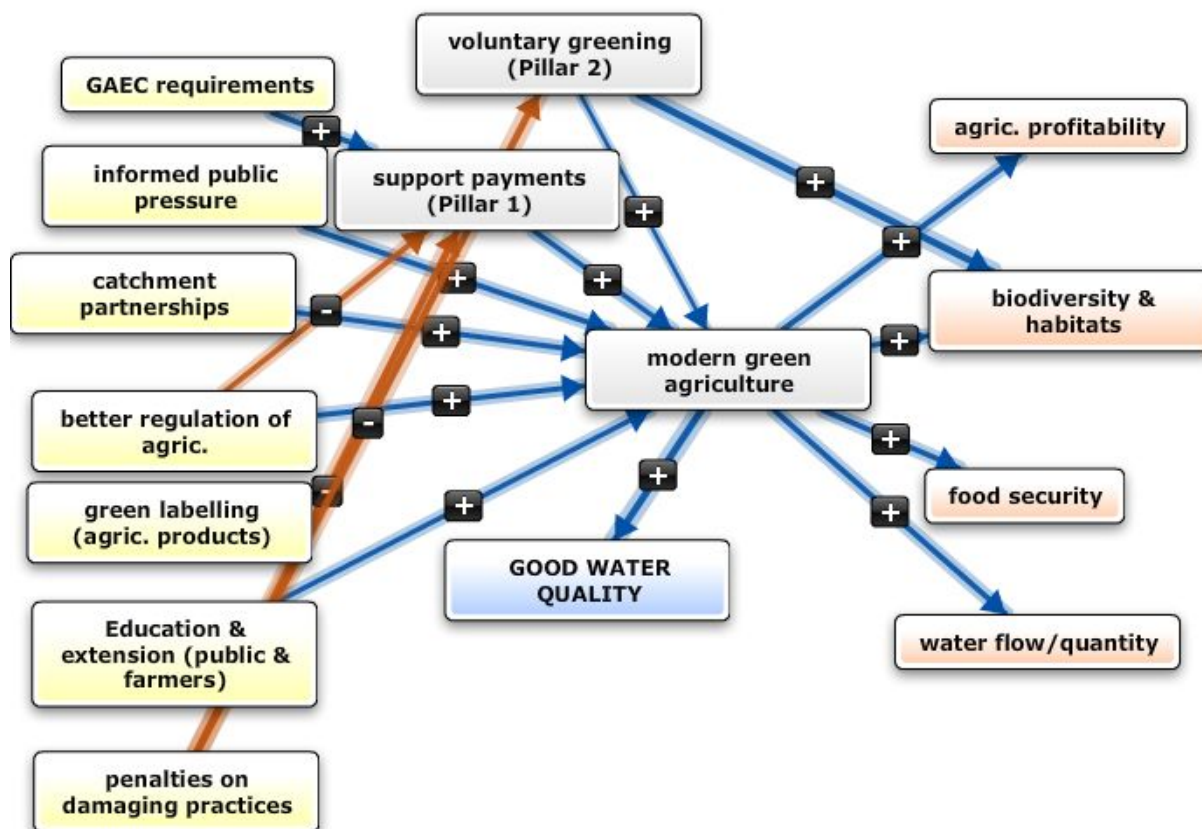45
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2 **Appendix D -** Fuzzy cognitive map for water quality created by practitioners

3 Arrow colours: Blue= Positive relationship, Orange=Negative relationship, Black=Unknown

4 relationship. Line thickness indicates strength of relations (e.g. thicker line= stronger

5 relationship). Box colours: Yellow= Policy or governance indicated by researchers, Orange=

6 Outcomes indicated by researchers, Grey= Concepts added by stakeholders. Green and Blue=

7 Key concepts for consideration when producing the map.

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voluntary greening (Pillar 2)

GAEC requirements

agric. profitability

informed public pressure

support payments (Pillar 1)

catchment partnerships

biodiversity & habitats

better regulation of agric.

modern green agriculture

green labelling (agric. products)

food security

GOOD WATER QUALITY

Education & extension (public & farmers)

water flow/quantity

penalties on damaging practices

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2 **Appendix E -** Matrix indices for FCMs produced by academics and practitioners, and

3 combined maps

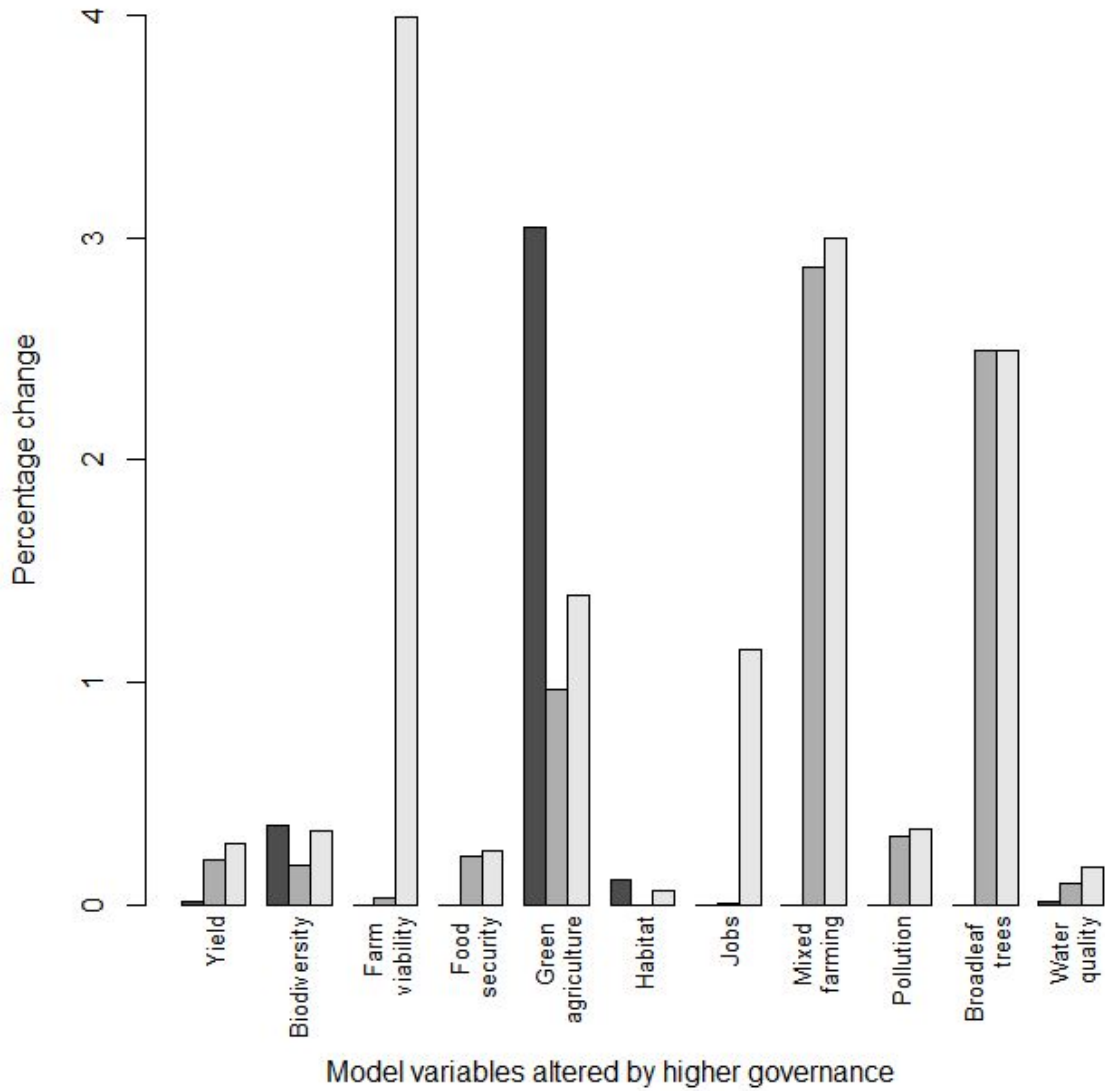|	Biodiversity			Water		
	Academic	Practitioner	Combined	Academic	Practitioner	Combined
Connections	43	46	64	26	28	43
Connection density	0.05	0.08	0.06	0.08	0.08	0.08
Concepts	30	24	30	18	19	23
Transmitters	7	9	8	8	5	10
Receivers	7	5	3	2	4	2
Connections/ variable	1.4	1.9	2.1	1.4	1.5	1.9

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1 **Appendix F –** Equilibrium (baseline) values for no changes scenarios for Academic (black),

2 practitioner (dark grey), and combined (light grey) FCM models – biodiversity.
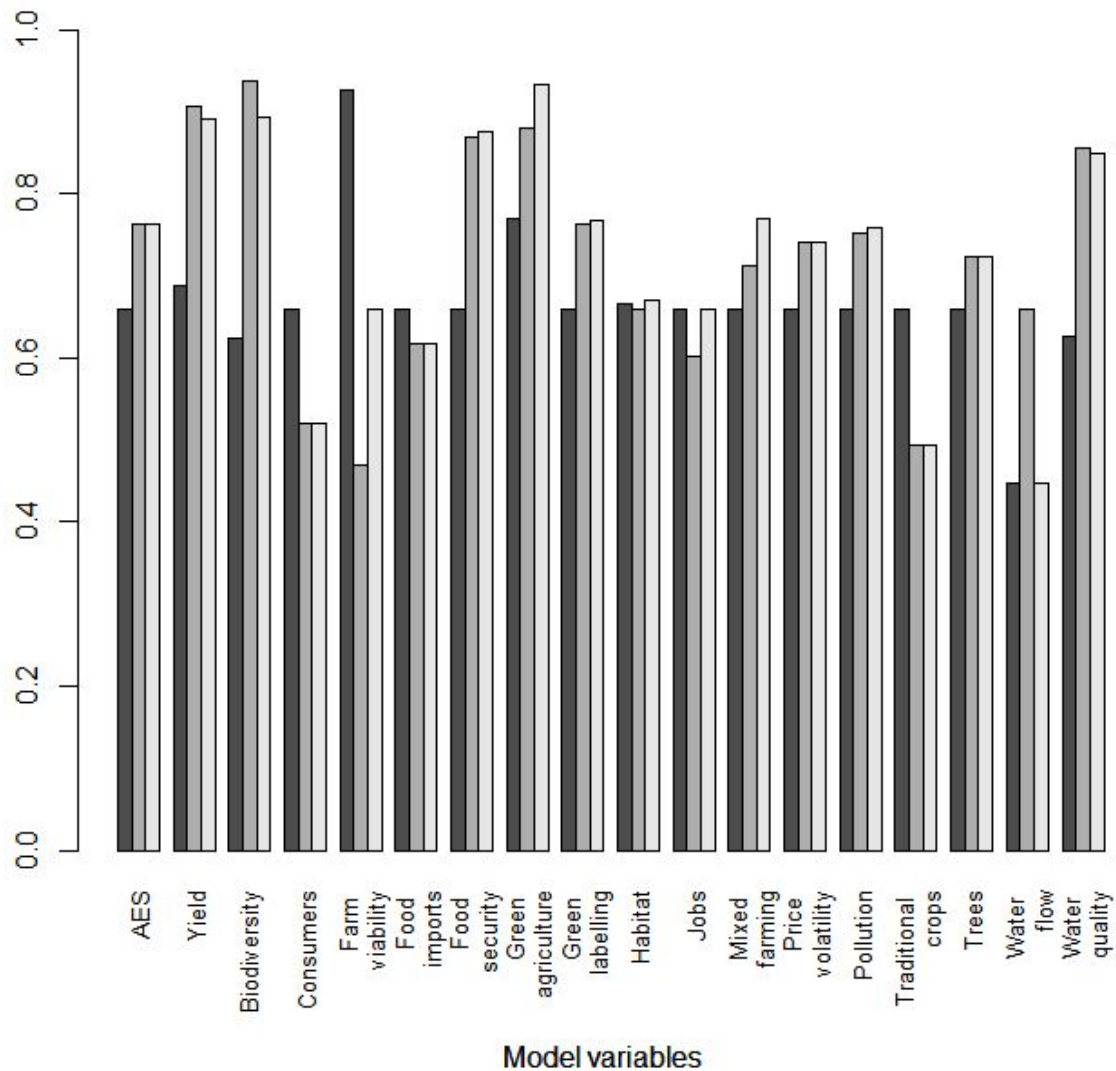
3

4 **Appendix G -** Equilibrium (baseline) values for no changes scenarios for academic (black),

5 practitioner (dark grey), and combined (light grey) FCM models - water quality. 0 link between

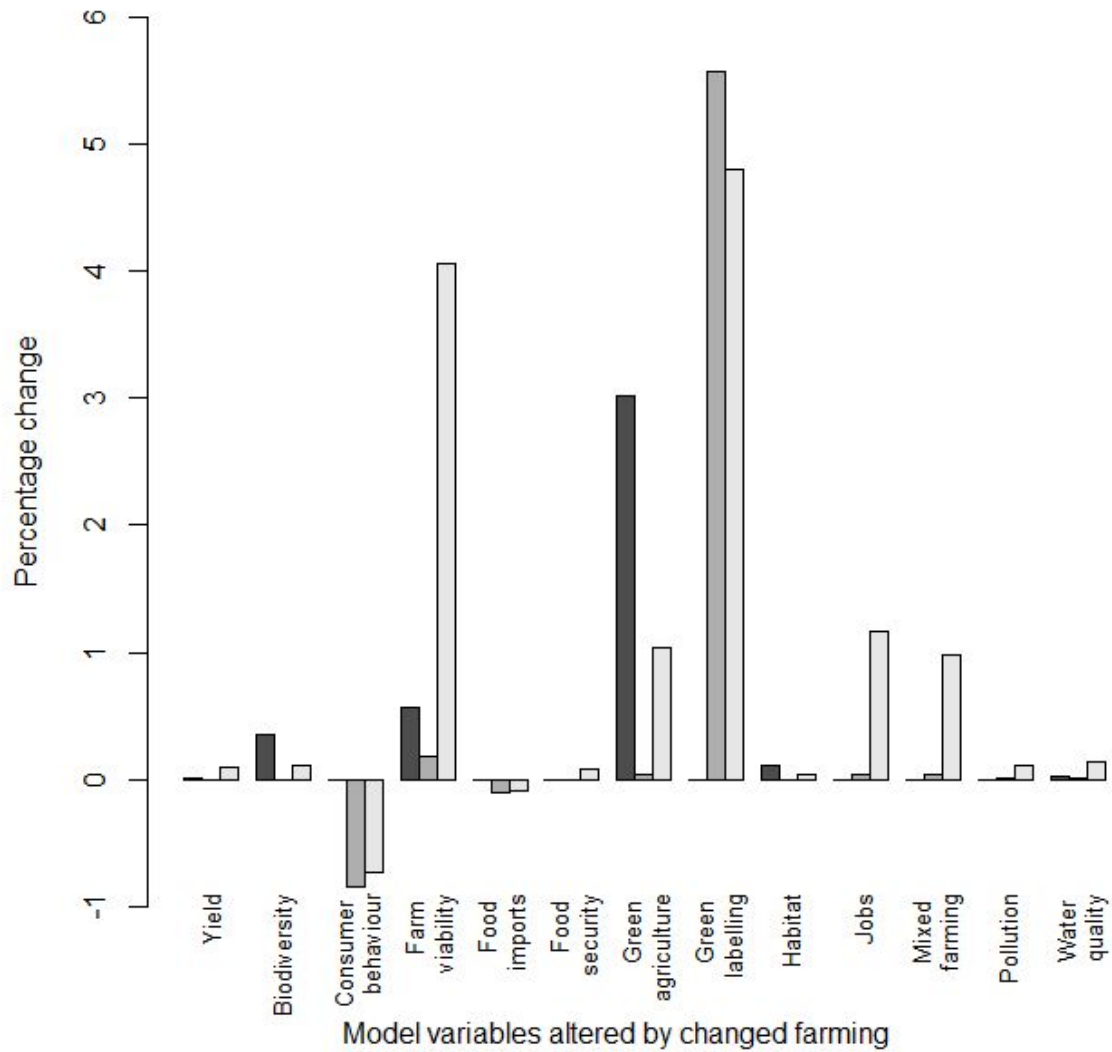6 green agriculture and agricultural yield in combined model

5
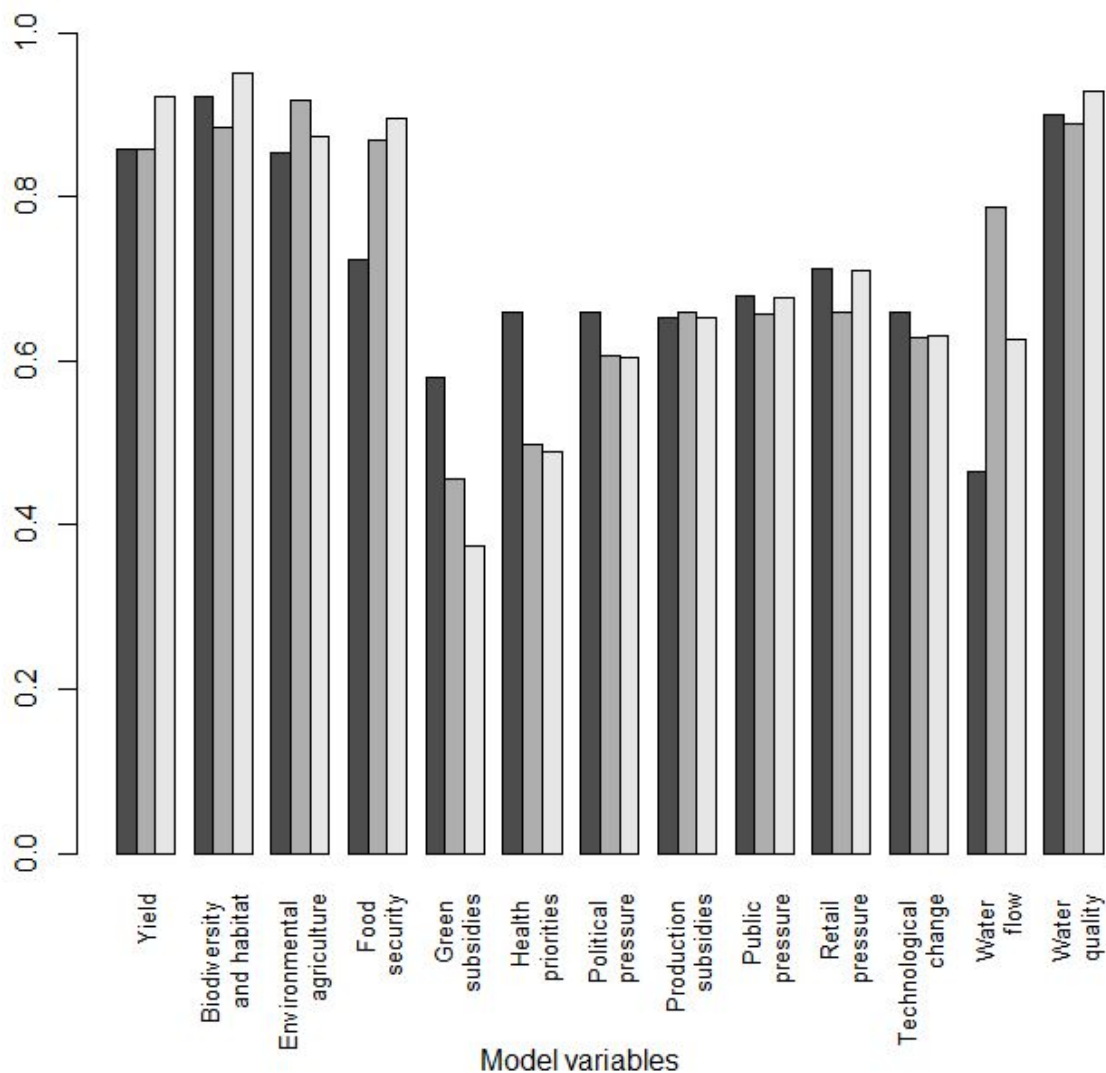
Appendix H Factors impacted by increased governance in Expert (black), Practitioner (dark grey), and combined (light grey) models. Agri-environment Schemes and CAP set to 1.
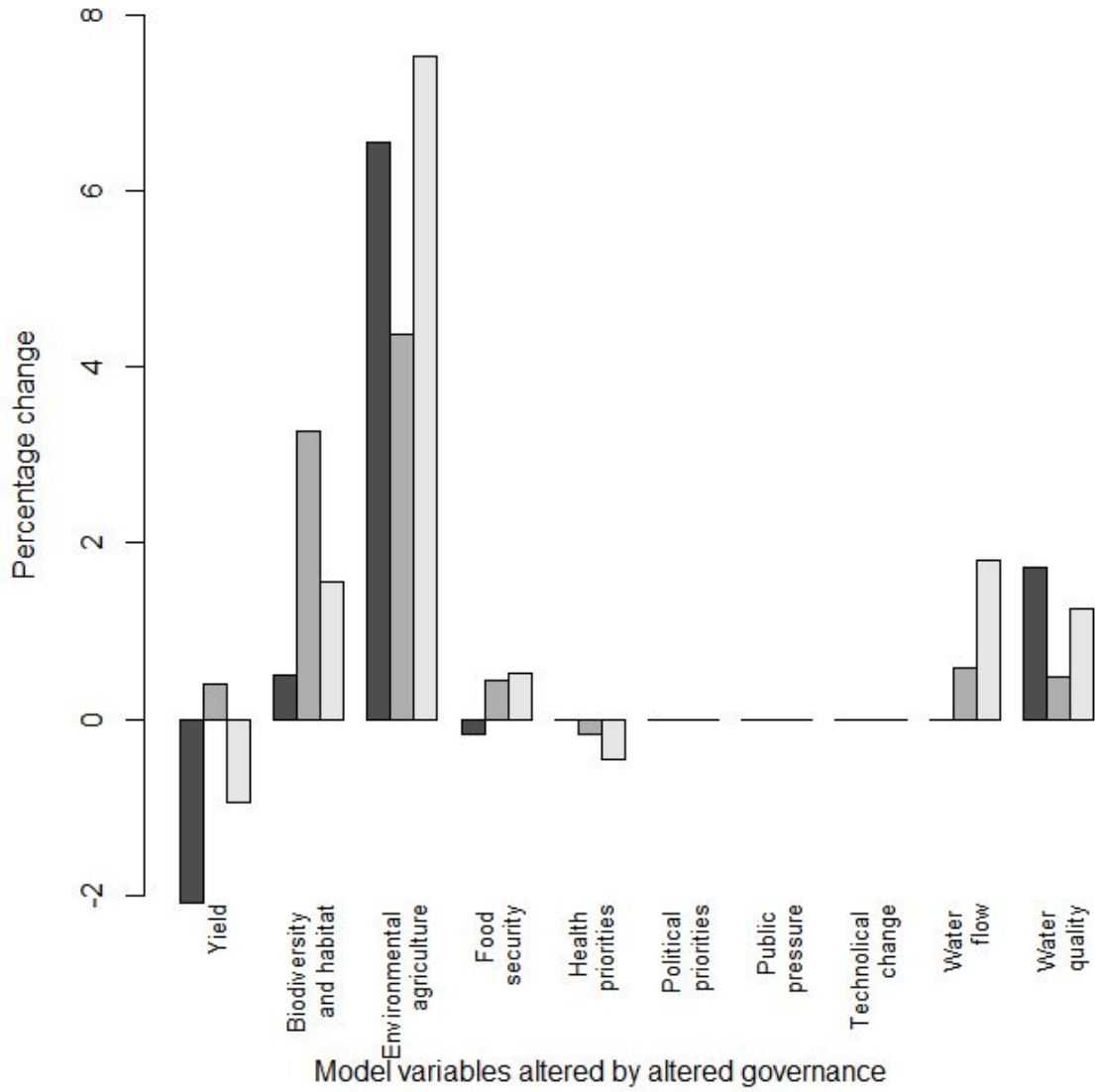
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3 **Appendix I** Factors impacted by changed farming in Expert (black), Practitioner (dark grey),
4 and combined (light grey) models. Traditional crops and shortened agricultural supply chain
5 set to 1.
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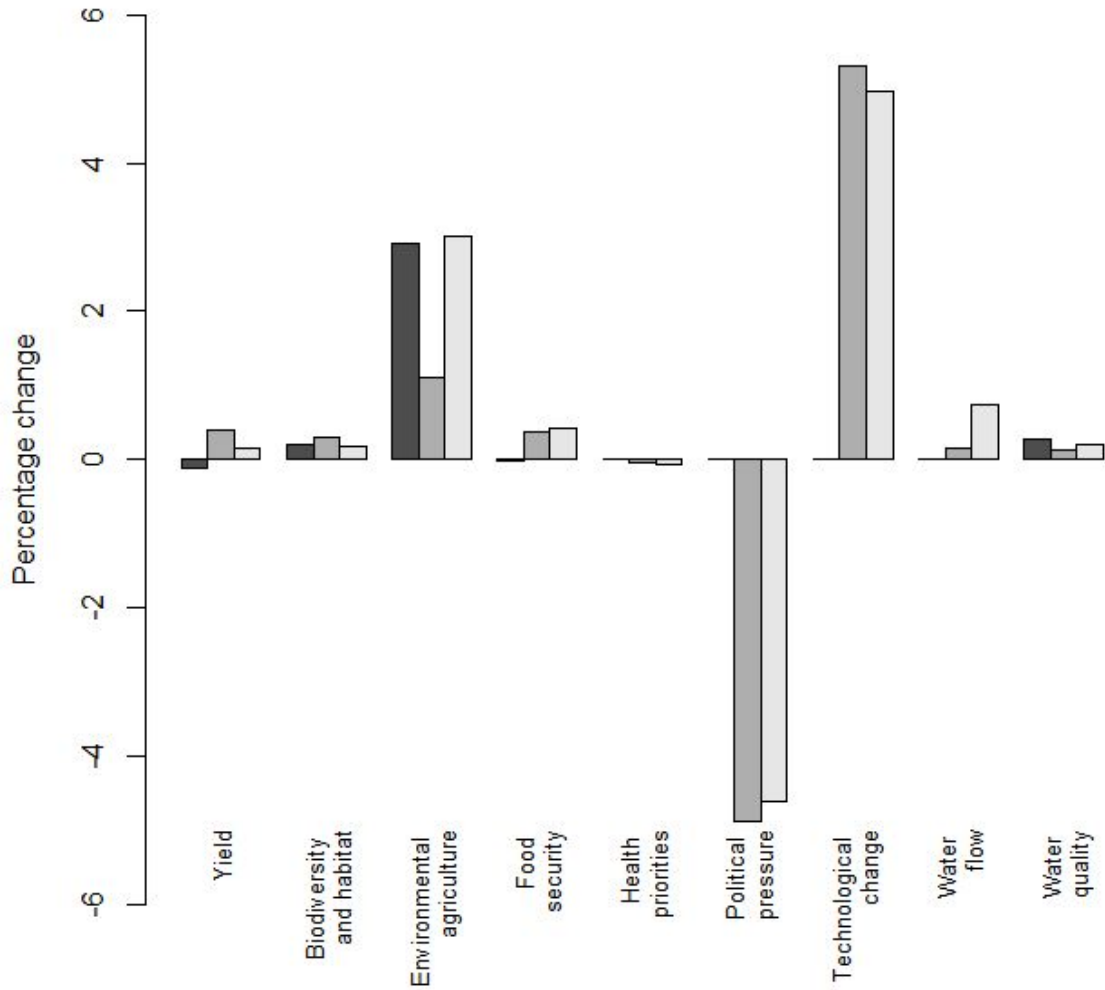51
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Appendix J Factors impacted by improved technology in Expert (black), Practitioner (dark grey), and combined (light grey) models. Technological breakthroughs set to 1.
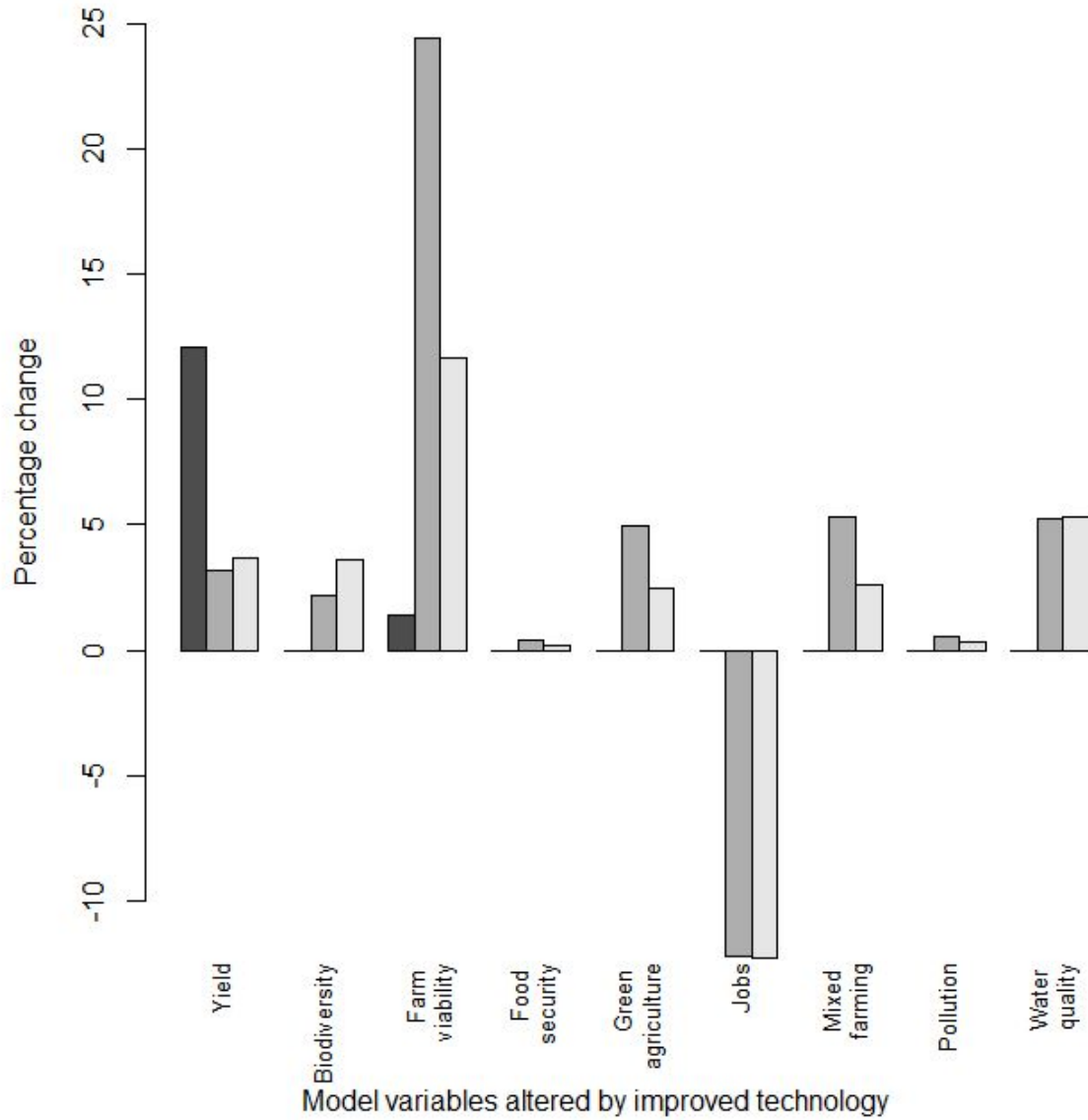
Appendix K Factors impacted by altered governance in Expert (black), Practitioner (dark grey), and combined (light grey) water quality models. Catchment partnerships, agricultural regulations and green subsidies set to 1.
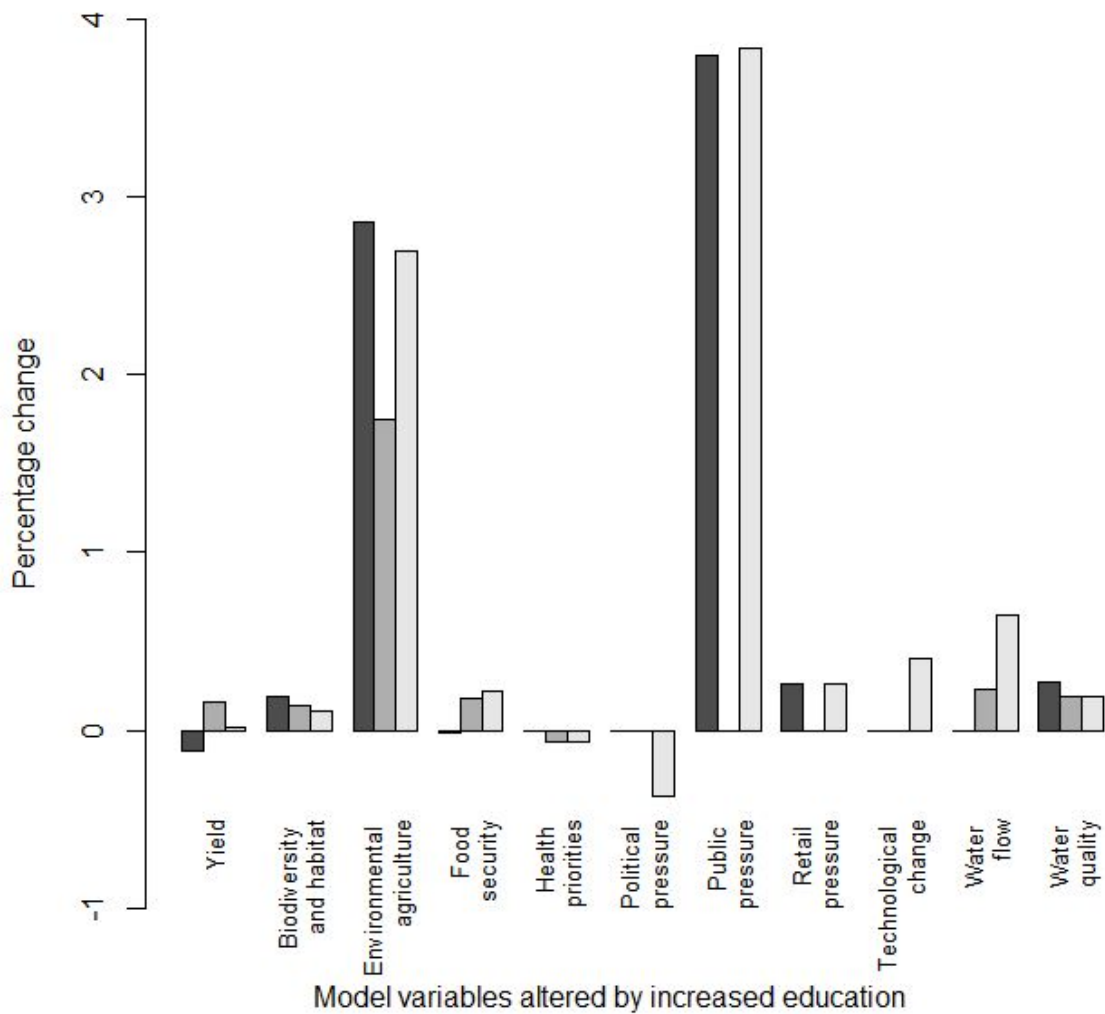
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2 **Appendix L** Factors impacted by altered public and retail in Expert (black), Practitioner (dark
3 grey), and combined (light grey) water quality models. Public pressure and retail pressure set
4 to 1.

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2 **Appendix M** Factors impacted by increased education in Expert (black), Practitioner (dark
3 grey), and combined (light grey) water quality models. Education set to 1.

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