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Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: a conditional process modelling

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ABSTRACT

Despite several decades of research and financial commitment, diffuse water pollution remains a major problem threatening the health and resilience of social-ecological systems. New approaches to tackle diffuse pollution emphasise awareness raising and provision of advice with the aim of triggering behavioural change. However, empirical evidence on the effectiveness of this approach remains scarce and mixed, with most studies relying on smaller datasets and case studies. Using one of the largest datasets (N=1,995) with this information, this study seeks to establish quantitatively the relationship between farmers' stated awareness of diffuse pollution mitigation measures and their compliance with them, through the analysis of Scotland's pioneer advice-driven approach. Results from a conditional process modelling suggest awareness might not directly determine compliance but influences it indirectly through the mediating effect of other environmental management practices (in this study reflected in participation in agri-environmental schemes). This mediated relationship appears to be contingent on farm type and location. This would indicate that while public efforts in awareness creation is important, awareness alone is not sufficient to improve compliance; farmers may need to consistently engage in environmental management practices to develop a deeper understanding of the problem and action strategies. In this context, agri-environmental schemes appear to provide an opportunity for the creation of tacit knowledge and understanding of diffuse pollution mitigation measures through experiential learning which may also lead to the creation of new values.

KEYWORDS: Agri-environmental Schemes; Scotland; Nonpoint Source Pollution; Pro-Environmental Behaviour; Moderated Mediation; Experiential Learning

1. INTRODUCTION

Diffuse pollution remains a major threat to ecosystems' health at the global level (UNEP, 2016; Novotny, 2013) with agriculture being one of the largest sources (United Nations, 2016; OECD, 2012; Boesch et al., 2001; Skinner et al., 1997). It is estimated that the environmental and social cost of diffuse water pollution (DWP) from agricultural sources exceeds billions of dollars annually in OECD countries (OECD, 2017; 2012). In England alone, the UK Government spent around £8 million to tackle diffuse pollution in 2008-2009 with over £140 million spent on water quality more broadly (OECD, 2017; NAO, 2010).

The pronounced impacts of diffuse pollution have led to the development of policy actions to mitigate the problem. Worldwide, strategies to address diffuse pollution have either concentrated on the implementation of single mechanisms or the integration of two or more policy options such as economic incentives, environmental regulations or advice provision (OECD, 2012; Deasy et al., 2010; Kay et al., 2009). Both single and integrative approaches have so far failed to make significant improvement in reducing diffuse pollution and other water quality problems (e.g. Kay et al., 2012). It is argued that the poor performance of attempts so far in mitigating diffuse pollution is related to the complex or 'wicked' nature of the problem (Duckett et al., 2016; Patterson et al., 2013); i.e. it is a problem with several causal factors, with multiple pathways that change overtime and are surrounded with uncertainty and ambiguity (Duckett et al., 2016; Patterson et al., 2013; Novotny, 2003).

The persistent nature of diffuse pollution particularly in rural agricultural areas has also been attributed to a number of specific barriers. These include financial issues such as complexities and bureaucracies involved in accessing funds, cultural aspects, inconsistent messages sent to land managers, uncertainty surrounding scientific evidence and lack of stakeholder awareness (Vrain and Lovett, 2016; Novo et al., 2015; Barnes et al., 2009). Some land managers do not perceive themselves as being responsible for diffuse pollution, whilst others are unaware of existing mitigation measures (Novo et al., 2015; Macgregor and Warren, 2006). Many of these barriers have an effect on land managers' behaviour (e.g. if land mangers do not ascribe to themselves the responsibility to reduce DWP, they will not act upon it, or if they are exposed to contradictory messages from scientists or regulating bodies, they may not adopt recommended mitigation measures). Therefore, there is now consensus on the fact that understanding and influencing land manager behaviour is key to enhancing uptake of mitigation measures to reducing diffuse pollution (Novo et al., 2015; Vrain et al., 2014; Martin-Ortega and Holstead, 2013; Blackstock et al., 2010; Pike, 2008; Dwyer et al., 2007).

Understanding and influencing land manager behaviour is challenging due to the complexities associated with pro-environmental behaviour (Christen et al., 2015; Blackstock et al., 2010; Dwyer et al., 2007). Nonetheless, the literature has identified a number of ways in which behaviour can be influenced (Novo et al., 2015; Martin-Ortega and Holstead, 2013; Pike, 2008; Macgregor and Warren, 2006). These can be synthesised into key areas: specifying and ensuring consistency in regulations, providing economic rewards, providing scientific evidence and raising awareness. Indeed information provision and awareness raising is a cross-cutting theme that accompanies the other suggested factors (Blackstock et al., 2010). It has been argued that information provision and awareness raising has the ability to influence land manager behaviour particularly when the approach adopted is evidence-based and one-to-one (Blackstock et al., 2010; Dwyer et al., 2007). Working directly with land managers and providing them with the required advice is expected to make them part of the process, enhance their understanding, create trust, allow for knowledge exchange and co-construction, and hence likely to be more effective than top-down regulations and/or provision of general recommendations (Martin-Ortega and Holstead, 2013; Pike, 2008).

However, empirical evidence from the wider field of behavioural studies suggests that, while provision of information and advice might be important, they do not necessarily result in pro-environmental behaviours. For instance, after a critical review of factors influencing pro-environmental behaviours, Kollmuss and Agyeman (2002) concluded that there appeared to be many more intervening or situational factors (e.g. economic) that influence pro-environmental behaviour. Bamberg and Moser (2007) reaffirmed these findings using a meta-analytical structural equation modelling. Others have highlighted how message framing and delivery can influence the role of knowledge on behavioural change (e.g. Baek and Yoon, 2017; Hovland and Kelley, 1953) as well as the role of tacit knowledge and experiential learning (Science for Environment Policy, 2017; Kolb and Kolb, 2012; Boiral, 2002). This demonstrates the complex nature of the knowledge-behaviour nexus and raises new questions regarding the effects of awareness and how it translates into pro-environmental behaviours. Such questions need to be clarified if policies targeting behaviour regarding diffuse pollution mitigation measures are to be successful (Martin-Ortega and Holstead, 2013; Blackstock et al., 2010). Further evidence on the effectiveness of awareness-focused approaches may redirect the focus and strategies of policies that aim at influencing behaviours related to diffuse pollution mitigation and provide insights into new directions and areas to target (Kay et al., 2012).

This paper adds to the scarce body of literature that empirically examines whether and how awareness of measures to mitigate diffuse pollution influences farmer behaviour regarding their uptake (e.g. Vrain et al., 2014; Macgregor and Warren, 2006). Using what is to our knowledge one of the largest existing databases on this topic (N = 1,995), this study seeks to establish quantitatively the relationship between farmers' stated awareness of diffuse pollution mitigation measures, specifically in this case Scotland's General Binding Rules (GBRs), and their compliance with them. This is done through the analysis of Scotland's Priority Catchment Approach, a pioneer advice-driven approach (Novo et al., 2015). Specifically, this study aims to establish whether there is a statistically significant relationship between farmers' awareness of and compliance with the GBRs, as well as understanding the interplay between these relationships with other factors at the farm level, using conditional process modelling.

2. CASE STUDY: SCOTLAND'S PRIORITY CATCHMENT APPROACH

Diffuse pollution is one of the major causes of poor water quality in Scotland (Scottish Environment Protection Agency [SEPA], 2014; 2013). Eighteen percent of water bodies in the Scotland River Basin district have been classified as having less than good quality attributable to diffuse pollution (DPMAG, 2015). To address this problem, a Diffuse Pollution Management Strategy (DPMS) was developed as part of the River Basin Management Plan (RBMP) (2009-2015). RBMP are produced as part of the implementation of the European Water Framework Directive, which is the regulatory framework for water management in the European Union[1]. SEPA is the agency in charge of the regulation of environmental management activities in Scotland and are directly responsible for the implementation these frameworks. The RBMP[1] was produced by SEPA on behalf of Scottish Government; it covers a summary of the state of the water environment, pressures impacting on the ecological conditions of the water environment where it is in less than good condition, activities to safeguard and improve the water environment and a summary of results after implementation. As part of the DPM strategy, SEPA has established a Diffuse Pollution Management Advisory Group (DPMAG) that focuses on protecting and improving Scotland's water environment by reducing rural diffuse pollution. DPMAG has a two tiered strategy to reduce diffuse pollution. First, it includes a national campaign to improve the status of water bodies and prevent further deterioration, with specific focus on promoting awareness and ensuring compliance with diffuse pollution GBRs, which provides a statutory baseline of good practice. GBRs represent essentially a set of compulsory guidelines which cover specific low risk activities, such as storage and application of fertilizer and pesticide, cultivation of land and the discharge of water run-off, mining, groundwater abstraction, etc. This study focuses on those GBRs that apply to agricultural activities

Second, SEPA has established a so-called Priority Catchment Approach, covering fourteen catchments in the first cycle (2012 -2015) and up to 32 in the second cycle (2015 – 2021). These are the catchments that are deemed to have poor ecological status within Scotland. In the Priority Catchment Approach, catchment coordinators have been appointed to investigate the sources of pollution and to liaise with land managers to implement mitigation measures. The idea is to enable catchment coordinators to tap into farmers' extensive local knowledge and allow for the co-construction of solutions and deeper understanding of diffuse pollution in the catchment. The catchment coordinators focus on the priority catchments through a range of catchment walks, workshops and one-to-one farm visits to provide information to land managers about the required steps to improve water quality. Land managers are also advised on diffuse pollution GBRs and the voluntary measures contained in the Scottish Rural Development Plan (SRDP), the EU Common Agricultural Policy (EU CAP) agri-environmental schemes prevailing in Scotland.

[1] https://www.sepa.org.uk/environment/water/river-basin-management-planning

The Priority Catchment Approach represents a transition from a purely 'punitive' approach to a pioneer 'advice-centred' and targeted approach with emphasis on raising awareness and working with the land manager on a one-to-one basis (Novo et al., 2015). This is in line with trends that seek to raise awareness to foster behavioural change through dialogical learning and co-construction of solutions as opposed to the traditional approaches which are 'one-way', top-down and emphasise punitive measures (DPMAG, 2015; Environment Agency, 2011).

3. MATERIALS AND METHODS

3.1 Materials

This study uses secondary data from a survey conducted by SEPA as part of the Priority Catchment Approach. Through one-to-one farm visits, SEPA gathered data from 1,995 farmers across the 14 catchments during the first cycle of this approach (Figure 1). Data collected included farm type, location, farmers' stated awareness of GBRs as well as their participation in agri-environmental schemes, practice of nutrient budgeting and soil testing. Information regarding uptake of diffuse pollution mitigation measures was also collected by observing and recording whether farmers complied with GBRs and whether there was a potential risk of breaching the rules. Most data was collected by asking the farmer directly, except compliance that was observed on-site through routine visits by SEPA field officers and tracked with a Global Positioning System (GPS). In what follows, we provide an overview of the variables used in the study on the basis of the information collected by SEPA in this way (see Table 1). It should be noted that in order to comply with data confidentiality and protection, individual data that could identify specific farmers or farms were omitted from the database

Table 1: Description of variables used in the study

Variable	**Description**
Farm type	The farm type practised by the farmer: Mixed farming (=1), Livestock (=2), Arable (=3)
Catchment /location	Location of the farm (South =1; North = 0)*.
Awareness of GBRs	Whether a farmer is aware (=1) of the GBRs or not (=0).
Agri-environmental scheme	Whether a farmer participates (=1) in an agri-environmental scheme or not (=0).
Nutrient budgeting	Whether a farmer practised (=1) nutrient budgeting or not (=0).
Soil testing	Whether a farmer practised (=1) soil testing or not (=0).
Compliance with GBRs	Whether the farmer complies (=1) with the GBRs or not (=0).

*SEPA's Priority Catchment Approach was applied to 14 catchments, but data on one of them, the River Ugie, was not included in the database made available to the authors. Hence, this study looks at 13 catchments. For compliance and location, N =1,995, for all other variables, N=1,564

3.1.1 Awareness of GBRs

Awareness of the GBRs was assessed by SEPA officers using a dichotomous response, i.e. yes/no answers, from the farmers to the question "are you aware of the Diffuse Pollution GBRs?". This enabled us to discern those who are aware from those who aren't, however does not reflect nuances or levels of awareness. For instance, a farmer might be aware of the GBRs but may not fully understand them, or there might be farmers that have higher level of awareness than others but that is not reflected in the dichotomous answers. Moreover, being stated rather than revealed awareness, data might suffer from acquiesce bias (Schuman and Presser, 1981; Jackman, 1973), i.e. some farmers might have responded "yes" to present themselves as environmentally minded people. This is likely to have been reinforced by the lack of neutrality of the interviewer, especially in this situation where the interviewer (a SEPA member of staff) is the regulator.

3.1.2 Agri-environmental schemes

Agri-environmental schemes are the major mechanisms in the UK that support land managers on the implementation of farm management strategies that embrace wildlife-friendly recommendations as well as general environmental management measures, developed in the context of EU's Common Agricultural Policy. While agri-environmental schemes in Scotland are varied in terms of specific focus (for example, some concentrate on the protection of single-species or specific sites, while others focus on a multitude and cross-cutting issues), almost all schemes aim to enhance the conservation of biodiversity, the preservation of historical features and the maintenance of aesthetic qualities of the landscape. As such, some schemes target more directly water quality problems by promoting specific land management practices which aim to enhance water quality[2] (Burton and Schwarz, 2013; Scott Wilson Scotland Ltd, 2009). Information on participation in agri-environmental schemes was collected by SEPA field officers by asking farmers the question "do you participate in agri-environmental schemes?". The responses were coded as yes or no answers for those who participated and those who did not respectively. Just as the nature of the question on awareness of the GBRs, data might suffer from acquiesce bias and details on the specific measures implemented through these schemes were not collected.

3.1.3 Nutrient budgeting

Nutrient budgeting is a management tool that can help farmers monitor the flow of nutrients (input vs output) such as nitrogen, phosphorous or potassium, through the farm system. In so doing, farmers are able to discover nutrient losses which can allow management decisions to be made that may decrease losses to the least possible (Oenema et al., 2003; Brouwer, 1998). Thus, practising nutrient budgeting helps farmers to make better use of nutrients across the farm; it can save them money and reduce diffuse pollution risks and ultimately minimise negative environmental outcomes such as exportation

[2] http://www.gov.scot/Publications/2009/10/23140921/3

of nutrients to water resources (e.g. Maguire and Sims, 2002). SEPA assessed whether farmers practised nutrient budgeting or not by asking the following question to farmers: "do you engage in nutrient budgeting?" Just like the question on awareness of the GBRs and participation in agri-environmental schemes, data for this variable was self-reported, and dichotomous thus could have similar limitations. For instance, information on frequency of nutrient budgeting, the mechanism through which the activity is carried implemented i.e. whether by farmers themselves, an agronomist or a contractor, are not captured.

3.1.4 Soil testing

While soil testing may be carried out using various approaches such as the degree of phosphorus saturation, the overall goal is to identify soils high or low in pH, phosphorus, potassium and other nutrients (Maguire and Sims, 2002). Soil testing will point out if some fields require work to adjust soil pH, or may require additional or less nutrients than are being presently applied. The practice of soil testing has become a common approach in Scotland for this purpose because it is inexpensive, has been shown to be well correlated with soluble and bioavailable phosphorus and can be useful in monitoring nutrient losses/leakages (e.g. Maguire and Sims, 2002). To determine whether farmers engage in soil testing, SEPA field officers asked the question: "do you engage in soil testing?" The responses were coded as yes or no for those who engaged in the practice and those who did not respectively and suffer from the same limitations than the other variables as indicated above.

3.1.5 Compliance with GBRs

The database contained compliance data for the 22 specific GBRs that apply to agricultural activities (see Appendix A). These were consolidated in one new variable named General Compliance and used as the dependent variable in our study. General Compliance refers to a situation where farmers comply with all the applicable regulations (based on the type, nature and anticipated impact of the agricultural activity on the environment) in all farm sites (as determined by SEPA). Compliance data regarding all 22 GBRs was collected by SEPA through the application of Global Positioning System (GPS) and routine or regular field visits by SEPA field officers. A farmer is deemed to have complied if s/he consistently observed all rules that applied to all their farm sites. On the other hand, where a farmer failed to comply with some regulations (when they applied to their farm sites), they were classified as non-compliant. Boxing all non-compliant farmers together facilitates the analysis however it overlooks the fact that some farmers may be doing better than others. As can be noted in Appendix A, many of these measures refer to physical features that can be visually observed (e.g. position of livestock feeders, distance of the cultivated land, existence of fences, existence of significant erosion, etc.). However, there are a few of these measures for which it might have been difficult for the inspector to obtain reliable answers (e.g.19b, 18ciii or 23ci). Nonetheless, it should be noted that these inspections are carried out by SEPA personnel, who are professionally trained for this and are also the statutory body in charge of regulation compliance. Hence, while we acknowledge that there might be a certain deviation from actual practice regarding e.g. the application of fertilizer, the data are, as good as it can be realistically best expected in this field of work.

Additionally, it should be noted that, being of secondary nature, the data were not collected specifically to test the effect of awareness of GBRs on compliance, and hence it lacks information on other factors that are known to affect compliance. For example, educational levels of farmers, income, time required to understand and to implement mitigation measures, land topography, climate and soil composition of the farm, farm tenure, and whether farmers use contractors or carry our land management practices by themselves, have been shown in the literature to play a role in influencing pro-environmental behaviours (Vrain et al., 2014; Environment Agency, 2014; 2011; Blackstock, 2007; Dwyer et al., 2007; Kollmuss and Agyeman, 2002; Hines et al., 1986), but are missing from this dataset.

Despite all the above limitations, this dataset still represents a highly valuable resource to undertake this analysis, not the least because it is probably one of the very few of its kind, but mostly because of its size and reliability. Any research study attempting to collect this volume of quantitative information through primary data collection is likely to only be able to do so for a much smaller number of observations, considering the resources that such undertaking would normally require. Moreover, it is based on observed (rather than stated) compliance. In addition, while we miss a number of factors, such as farmers' characteristics, that are known to influence behaviour, some of them are partly confounded in the farm type and farm location variables, for which we do have data. Like in any quantitative study, the approach of data aggregation applied here has the advantage of ease of computation, usefulness in generalising findings (due to the relatively large sample size) and may help to devise appropriate mechanisms/policy responses to improve compliance/uptake of such mitigation measures at the catchment, regional or national scale.

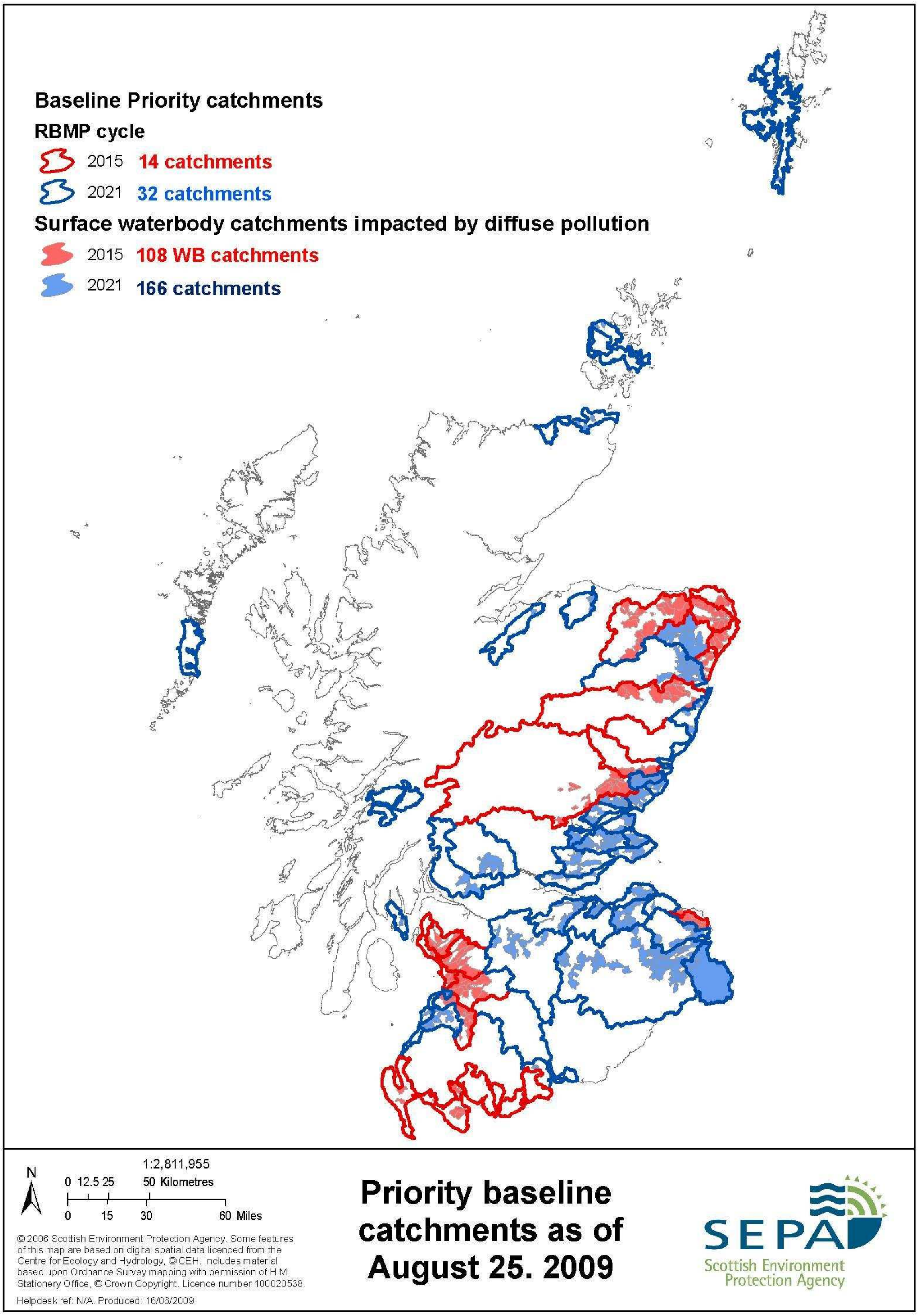


Figure 1: Priority Catchments in Scotland for the First cycle and proposed catchments
Source: SEPA (DPMAG, 2015)

3.2. Modelling procedure

To begin the modelling process, we first tested relationships between various variables using chi square test of independence and binomial logistic regression. This was aimed at a first exploration, helping us know whether and how awareness of the GBRs might be related to compliance with them. Initial results from a binomial logistic regression revealed that awareness does not explain compliance (χ^2 (1564) = 3.56, p-value >0.10). Additionally, the chi square test of independence indicated a non-significant difference on compliance between those farmers having stated to be aware of the GBRs and those who were not ($\chi2$ (n = 1564, df = 1) = 0.069, p = 0.793) (Appendix B1). However, other results from the chi square test of independence showed that awareness of the GBRs was associated with participation in agri-environmental schemes, practice of nutrient budgeting and soil testing, and that compliance was also associated with participation in agri-environmental schemes (see Appendix B1). These results suggested the possibility of some linkages among the variables under study (i.e., awareness could affect compliance indirectly through the mediating effects of other factors such as engagement in soil testing, nutrient budgeting and/or participation in agri-environmental schemes). Following this, we formulated the following hypothesis, which we tested using a conditional process modelling.

H_0 = awareness does not affect compliance with the GBRs
H_1 = awareness affects compliance indirectly through the mediating effect of one or more of the following variables: participation in agri-environmental schemes, practice of nutrient budgeting and practice of soil testing

The conditional process modelling (run here using the R software), is particularly suitable for the purposes of this study due to its ability to help identify relationships between various variables as well as the mechanisms (i.e., how) through which each variable transmits its effects on other variables and the conditions (i.e., when) under which this happens (Hayes, 2013; 2012). Conditional process modelling allows for the inclusion of several variables in a single interaction analysis. Adding these variables helps to account for confounding and epiphenomenal relationships and allows for identifying potential links among all variables (Hayes, 2013).

In our hypothesis, factors such as participation in agri-environmental scheme and engagement in soil testing or nutrient budgeting may be mediating factors, that is, variables through which an independent variable (awareness of GBRs) transmits its effects onto a dependent variable (compliance with GBRs). We argue that engaging in specific experiential activities such as nutrient budgeting, soil testing or participating in agri-environmental schemes, provides farmers with the opportunity to acquire, share, and practise environmental management knowledge. These activities might enhance their knowledge and understanding about diffuse pollution and the complex relationships in the system, which in turn, might make them more likely to comply with the GBRs. For example, nutrient budgeting and soil testing helps monitor the amount and content of major agriculture diffuse pollutants such as phosphorus and nitrogen (ADAS, 2008; Maguire and Sims, 2002; Boesch et al., 2001) making farmers more knowledgeable of the process and effects of implementing them on their land. Farmers engaged in agri-environmental schemes are more likely to receive [diffuse pollution] specific management training and/or might be more pro-environmentally motivated. This is consistent with findings from Floress et al., (2017), Vrain et al. (2014) and ADAS (2008), who found that farmers who participated in agri-environmental schemes or environmental stewardship activities were also more likely to take up measures for the mitigation of diffuse pollution for improvement of water quality.

Farm characteristics have also been identified as factors that influence farmers' pro-environmental behaviour (e.g. Vrain et al. 2014) and hence could potentially influence the relationship between awareness of and compliance with the GBRs. Following this, we included farm type and location in the models as moderators through multi-group analysis. A moderator is a variable which contingently influences the statistical significance, direction and/or strength of a relationship between two or more other variables (Hayes, 2013). Both farm type and location have been shown, in the literature, to affect participation in agri-environmental schemes and adoption of diffuse pollution mitigation measures. This is because location and farm type may be connected to certain land uses, specific activities, farm characteristic (e.g. farm size), that may create variation in environmental management requirements for different farmer categories (Vrain et al. 2014; ADAS, 2008; Macgregor and Warren, 2006; Wilson, 1997). For procedural reasons, farm location (i.e. catchment in our dataset) was clustered into two main areas relating to the biophysical characteristics of the lowlands and the uplands in Scotland (North and South) (see Appendix C for the details on each of the specific catchments included in each of the clusters).

4. RESULTS

4.1. Overview of farmers' responses

Table 2 reports on the descriptive statistics on the data set. The majority of farmers (84.1%) stated to be aware of the GBRs. However, less than half (46.2%) of them complied with all the GBRs relevant to their farm sites. Almost three quarters (73.4%) of farmers reported to have engaged in soil testing, slightly over half (55.3%) had engaged in nutrient budgeting, with less than half (37.8%) stating that they have participated in agri-environmental schemes. About half the sample practises mix farming (53%) and about a third (34%) are livestock farms, with only a minority of arable (13%). See Appendix B2 for responses by farm type and location.

Table 2: Results of descriptive statistics

Variable	Description	Percentage of farmers
Aware of GBRs	No	15.9
	Yes	84.1
Participated in agri-environmental Schemes	No	62.2
	Yes	37.8
Engaged in nutrient budgeting	No	44.7
	Yes	55.3
Engaged in soil testing	No	26.4
	Yes	73.4
Complied with GBRs	No	53.8
	Yes	46.2
Farm type	Mixed farming	53
	Livestock	34
	Arable	13
Location	South (lowlands)	38.3
	North (uplands)	61.7

For compliance, N =1,995; for all other variables, N=1,564.

4.2 How does awareness of GBRs interact with other factors that might affect compliance?

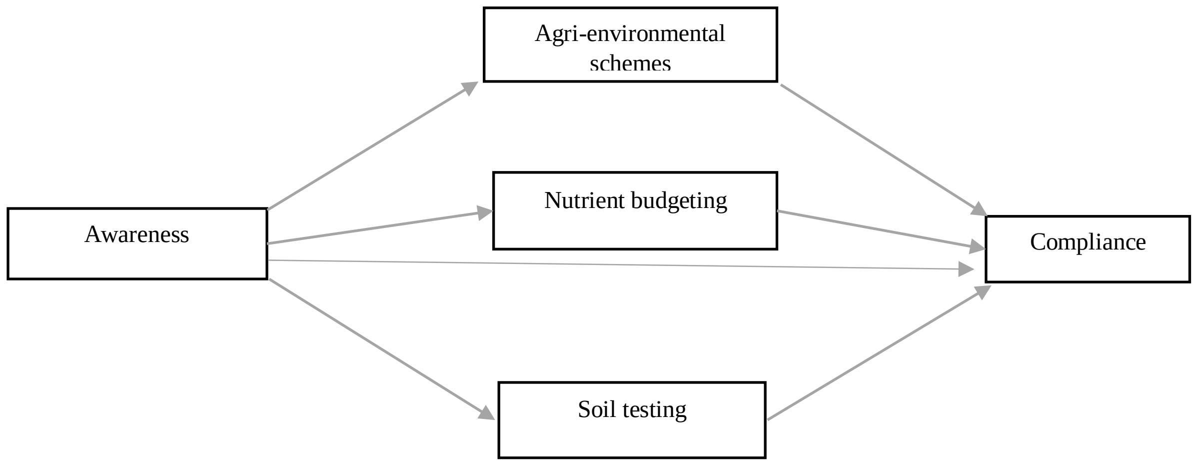
Following best-practice recommendations, we present the full story of our modelling trajectory to increase transparency and enable research repeatability and reproducibility (Garson, 2015; Kline, 2011). Where necessary, diagrams have been used to show hypothesized (in thin line) and outcome (in thick line) models.

The first proposed model (Figure 2) is essentially a multiple mediation model with five variables: awareness of GBRs as the independent variable, compliance with GBRs as the dependent variable and participation in agri-environmental schemes, practice of nutrient budgeting and soil testing as mediators. To appraise model fit, we employed a multipronged approach by including a mix of indices from both absolute and incremental categories as diverse indices reveal different aspects of model fit (Hooper et al., 2008; Brown 2006; Hu and Bentler, 1999). For instance, while the chi-square value is used as the traditional measure for judging overall model fit and evaluates the extent of variation between the sample and fitted covariances matrices (Hu and Bentler, 1999), the root mean square error of approximation (RMSEA) "tells us how well the model, with unknown but optimally chosen parameter estimates would fit the populations covariance matrix" (Hooper et al., 2008: 54). We note that although there are no "golden rules" regarding benchmarks for model evaluation, there have been some consistent recommendations in the literature that serve as a guide for best practices. For instance, for the chi square value, a good model fit would yield a nonsignificant result at a 0.05 threshold, meaning that values below this threshold suggests a poor fit (Barrett, 2007). For the RMSEA, a stringent upper limit of 0.07 appears to be the widely recommended guide for a good fit model (Hooper et al., 2008; Hu and Bentler, 1999) (see Hooper et al., 2008 for an overview of other model indices used in the present study).

The fit of the proposed model was evaluated by means of Chi square (χ^2), the comparative fit index (CFI), the root mean square error of approximation (RMSEA) and the standard root mean square residual (SRMR). The results revealed unsatisfactory fit with the data: χ^2 ($n = 1564$, $df = 6$) = 0.000, $p<0.001$; CFI = 0.035; RMSEA=0.560; SRMR = 0.305. The path from awareness to compliance through nutrient budgeting and the path linking awareness and compliance through soil testing were non-significant. The only ‘complete path’ that was significant was the path linking awareness and compliance through agri-environmental schemes, albeit at varying degrees of significance: awareness-agri-environmental schemes ($p<0.01$) and agri-environmental schemes-compliance ($p<0.1$).

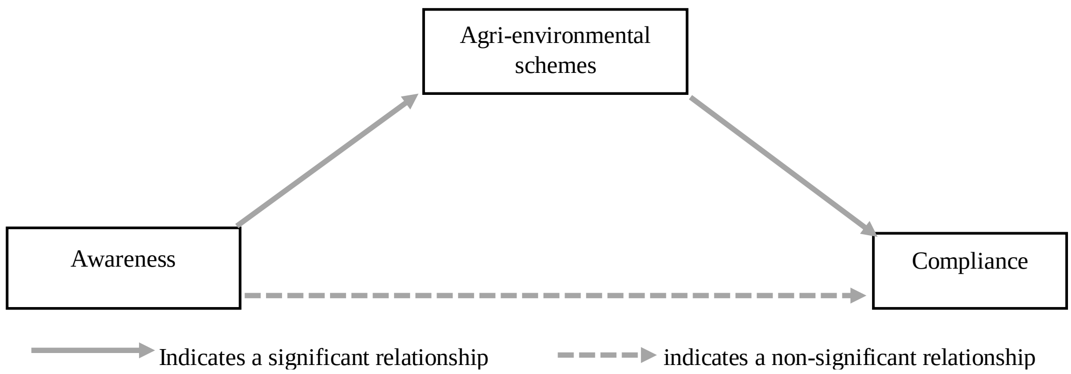
To improve the model, the non-significant paths (the awareness-nutrient budgeting-compliance path and the awareness-soil testing-compliance path) were removed from it. This improved model shows satisfactory fit (χ^2 ($n = 1564$, $df = 1$) = 1, $p>0.05$; CFI = 1.000; RMSEA=0.000; SRMR = 0.000). The results in Table 3 show that the path linking awareness and agri-environmental schemes ($p<0.01$) and the path from agri-environmental schemes to compliance ($p<0.1$) are significant, indicating then that awareness affects participation in agri-environmental schemes and this in turn affects compliance (see also Figure 3, Model 2). Thus, farmers who were aware of the GBRs were more likely to have participated in agri-environmental schemes and their involvement in such schemes made them more likely to comply with the regulations. Consequently, the results suggest a mediating effect of participation in agri-environmental schemes, confirming our hypothesis that awareness may affect compliance through the transmission of its effects on participation in agri-environmental schemes, which offer an experiential activity that enhances knowledge on the links between farm activities and water pollution.

We then tested the moderating effect of other factors, notably farm type and location, and found that this mediated relationship is indeed contingent on them (Figure 4, Model 3, see also Table 4). Specifically, we found that this mediated relationship between awareness and compliance exists in mixed-farms ($p<0.01$; $p<0.05$, for awareness -agri-environmental schemes and agri-environmental schemes- compliance, respectively) but not in arable ($p>0.1$) and livestock ($p>0.1$) only farms. Similarly, the relationship between awareness and participation in agri-environmental schemes exists for farmers in Northern Scotland ($p<0.001$) but not in the Southern group ($p>0.1$). It should be noted though, that these two variables (farm type and location) are not fully uncorrelated and a confounded effect might play a role (there are more mixed farmers in the North than in the South and majority of farmers in the North are mixed farmers).



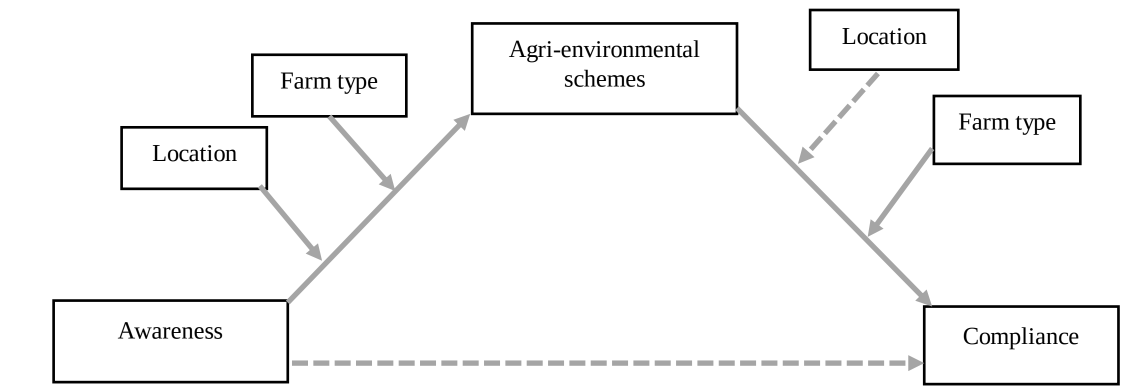
Note: All paths indicate a hypothesized positive relationship

Figure 2: Initial proposed model testing multiple mediation (Model 1)



Note: All significant paths are positive relationships

Figure 3: Model after testing for mediation (Model 2)



Note: All significant paths are positive relationships

Indicates a non-significant relationship   indicates a significant relationship

Figure 4: Final model after testing for moderation (Model 3)

Table 3: Results of regression paths for Model 3

Dependent variable	**Independent variable**	**Estimate**	**Std. err.**	**P-value**
Environmental Schemes	Aware of GBR	0.275	0.091	002**
Compliance	Aware of GBR	0.009	0.088	0.92
Compliance	Environmental Schemes	0.073	0.041	0.07*
Conditional indirect effect	-	0.020	-	0.03*

Note: ***p-value <0.01, * *p-value <0.05, *p-value <0.1

Table 4: Results of regression paths for Model 4

Location				
Group 1: Northern Group				
Dependent variable	Independent variable	Estimate	Std. err.	P-value
Agri-environmental Schemes	Aware of GBR	0.455	0.108	0.00***
Compliance	Aware of GBR	0.114	0.106	0.28
Compliance	Agri-environmental Schemes	0.055	0.041	0.29
Group 2: Southern Group				
Dependent variable	Independent variable	Estimate	Std. err.	P-value
Agri-environmental Schemes	Aware of GBR	-0.034	0.174	0.85
Compliance	Aware of GBR	-0.108	0.169	0.52
Compliance	Agri-environmental Schemes	0.030	0.070	0.67
Farm type				
Group 1: Mixed farming				
Dependent variable	Independent variable	Estimate	Std. err.	P-value
Agri-environmental Schemes	Aware of GBR	0.391	0.127	0.00***
Compliance	Aware of GBR	0.049	0.126	0.70
Compliance	Agri-environmental Schemes	0.116	0.055	0.04**
Group 2: Livestock				
Dependent variable	Independent variable	Estimate	Std. err.	P-value
Agri-environmental Schemes	Aware of GBR	0.168	0.159	0.29
Compliance	Aware of GBR	0.059	0.150	0.70
Compliance	Agri-environmental Schemes	-0.011	0.074	0.88
Group 3: Arable				
Dependent variable	Independent variable	Estimate	Std. err.	P-value
Agri-environmental Schemes	Aware of GBR	0.146	0.247	0.55
Compliance	Aware of GBR	-0.486	0.252	0.55
Compliance	Agri-environmental Schemes	0.119	0.111	0.28

Note: ***p-value <0.01, * *p-value <0.05, *p-value <0.1

5. DISCUSSION

Previous research indicates contradictory findings regarding the role of awareness alone in predicting farmers' pro-environmental behaviour. For instance, Guagnano (2001) found that there may be instances where awareness solely influences behaviour to a desired state (see also Wynveen and Sutton, 2017, who reported that environmental knowledge and climate related behaviours are related). By contrast, Gobster et al. (2016) found that knowledge has a low explanatory power regarding support for ecological restoration activities while beliefs play a great role. Nonetheless, awareness of the problem and action strategies is generally considered as a necessary step towards influencing behaviours in a desirable direction (Blackstock et al., 2010; Bamberg and Moser, 2007).

While awareness of the GBRs appeared to have a non-significant direct effect on compliance in the present study, the results from the conditional process modelling indicate that awareness affects compliance through the mediating effects of participation in agri-environmental schemes. Our findings are in line with the results of Floress et al.'s (2017), who found that environmental stewardship activities mediate the relationship between awareness and farmers' willingness to take up actions to protect water quality in Indiana (although authors did note that intentions to act do not automatically translate into actions). Our results are also in agreement with the findings of earlier works on factors that influence participation in agri-environmental schemes (e.g. Mills et al., 2017; Lastra-Bravo et al., 2015; Espinosa-Goded et al., 2010; Barreiro-Hurlé et al., 2010; Dupraz et al., 2003; Wynn et al., 2001; Wilson and Hart, 2000; Wilson, 1997) and factors that affect uptake of diffuse pollution mitigation measures (Vrain and Lovett, 2016; Vrain et al., 2014; ADAS, 2008). Dupraz et al. (2003) for instance note that environmental awareness has a positive effect on farmers' decision to participate in agri-environmental schemes while stressing that this behaviour cannot be generalised given that in some contexts, decisions are influenced by the satisfaction derived from the provision of these services. It should be noted, though, that none of these earlier works explored the links and interactions among the three variables (as we have done in this study); they only established associations between two of them at a time. The added value of our study therefore lies in the methodological approach employed i.e., the conditional process modelling, that enabled us to explore the mechanisms through which they affect one another as well as the conditions under which these mechanisms operate. This more complex analysis consolidates the evidence that while awareness promotion and public investment in awareness creation is important, awareness alone is not sufficient: other factors may facilitate or constrain farmers' pro-environmental behaviour.

The importance of awareness and participation in agri-environmental schemes in influencing compliance may be understood in the context of social and experiential learning, and the production and application of tacit knowledge (Kolb and Kolb, 2012; Bandura, 1977). People who are aware of the environmental problem and mitigation measures and at the same time participating in agri-environmental schemes get the opportunity to learn through observation and interaction with the environment, share experiences with colleagues, learn through reflection on doing and this reinforces further awareness and deepens understanding of mitigation measures (Kolb and Kolb, 2012; Jackson, 2005). Experiential learning and tacit knowledge have been shown to be relevant in environmental management particularly in the identification of pollution sources (Boiral, 2002). Consistent engagement in this process can activate farmers' awareness of environmental problems, enhance their understanding and boost their willingness and ability to be part of the solution process through actions (e.g. Environment Agency, 2014; 2011; Boiral, 2002). As noted by the report Science for Environment Policy (2017), the fact that land managers with more experience in agri-environmental schemes were more successful in establishing wildlife friendly habitats suggests that part of the learning takes place through the implementation of such schemes, hence they are more likely to comply with environmental standards i.e. quality conditions required for the realisation of positive environmental outcomes.

Based on the above argument, it can be reasoned that although awareness of the problem (i.e. diffuse pollution) and action strategies (such as the GBRs) play a role in influencing behaviour, farmers may need to also go through a process that: intensifies their awareness and consciousness of the problem, and provides them with a deeper understanding of the link between farm management or practices and environmental outcomes as well as knowledge of proposed solutions (e.g. Smallshire et al., 2004). This requires an approach that increases understanding and appreciation of the problem context and how to effectively address the problem, which cannot be addressed by mere transfer of environmental knowledge to farmers (e.g. Lobley et al., 2013; Tsouvalis et al., 2000). The preconditions mentioned above are more likely to be satisfied through experiential learning: a process that allows for reflection, provides the capacity to relate given knowledge to the socio-ecological setting and improve the solution mechanisms by constantly engaging in the practice and the feedback and learning process (Science for Environment Policy, 2017; Environment Agency, 2014; 2011; Boiral, 2002). Through participation in agri-environmental schemes and consistent engagement in environmental management measures, farmers gain confidence which may be related to their locus of control (Lobley et al., 2013; Kollmuss and Agyeman, 2002). A deeper understanding of mitigation measures raises farmers' locus of control which in turn increases the likelihood of them taking actions to mitigate the environmental problem (Kollmuss and Agyeman, 2002; Hines et al., 1986). This may explain why participating in agri-environmental schemes mediates the relationship between awareness and compliance as found in this study.

Our results also indicated that this mediated relationship between awareness of and compliance with the GBRs is contingent on farm type and location. This is consistent with previous findings, in which farm type and size are found to affect farmers' decision to participate in environmental schemes (e.g. Wynn et al., 2001; Wilson and Hart, 2000; Wilson, 1997). Specifically in this case, the relationship between awareness and compliance is statistically significant in mixed farms and in the North. Farms that are found in the uplands are commonly grasslands with lower shares of permanent crops and arable lands (i.e., mixed uses), and tend to fit well into several agri-environmental schemes (Capitanio et al., 2011; Defrancesco et al., 2008). As indicated in section 3, soil and climate characteristics may also moderate this relationship as they affect the decision to participate in agri-environmental schemes particularly where measures do not yield additional cost of compliance (Sattler and Nagel, 2010). On the other hand, for some intensive livestock farmers, participation in land-based agri-environmental schemes and compliance with nutrient-focused regulations may require some de-stocking and result in income losses (e.g. Macgregor and Warren, 2006). As Morris et al. (2000) noted, one of the key determinants of scheme adoption is 'goodness of fit', i.e. how well schemes requirements fit into current farm activities since changing management practices might be very challenging. This might explain why livestock (29.7%) and arabale (37.9%) farmers recorded the lowest forms of participation in agri-environmental schemes (Appendix B2) and probably why the mediating effect of participation in schemes was non-significant in such groups.

We note that though our initial proposed model hypothesized that awareness of the GBRs may affect compliance through the practice of nutrient budgeting and soil testing, the model indices suggested an unsatisfactory fit with the data, and results for those paths were non-significant. This may be due to the generic nature of the question in the SEPA survey (as mentioned in section 3). It may be the case that some farmers practised soil testing or nutrient budgeting only once because there was an opportunity to do it, without truly engaging in any of these practices. As Macgregor and Warren (2006) noted in a qualitative study in Scotland, some farmers only engaged in soil testing and/or nutrient budgeting in one occasion when there was a trial project. They came to the conclusion that the practice of nutrient budgeting is not extensive in Scotland. However, because of the vague and dichotomous nature of the survey question and data used in the present study, detailed information on the frequency and mechanisms of operation, i.e. whether these practices were carried out by a contractor, an agronomists or by farmers themselves, are missing. Thus farmers who have engaged in the practices for just one time are still classified as individuals who carried out such practices even though the practice is not fully embedded in their land management strategies and may therefore not benefit from it experientially (i.e. in terms of the knowledge and understanding required). Further qualitative research could enrich these findings. Additional information on the extent of engagement with agri-environmental schemes and the frequency and means through which soil testing and nutrient budgeting are carried out can provide further insights on the role of experiential learning in mediating the link between awareness and pro-environmental behaviour.

6. CONCLUSIONS

Diffuse water pollution is a major problem affecting socio-ecological systems. Given farmers' key role as 'environmental managers' at the farm and catchment levels, and the fact that much of the diffuse pollution management challenges are of a behavioural nature, influencing farmer behaviour has gained great prominence in new policy responses. This has resulted in the development of new approaches that rely on raising awareness and fostering behaviour change to increase uptake of diffuse pollution mitigation measures. Unlike earlier awareness-focused mechanisms that are predominantly ‘one-way’ and top-down, novel approaches emphasise dialogical learning and co-construction of solutions between environmental regulators and farmers. However, evidence on whether such novel awareness-focused approaches affect farmer behaviour pro-environmentally, remains relatively scarce and mixed. This paper contributes to address this knowledge gap by using a conditional process model to assess whether and how awareness of diffuse pollution mitigation measures (in this case, General Binding Rules) affects compliance with them. We note that the relationship between environmental knowledge and pro-environmental behaviour is notoriously complex and requires more data than available to this study, complemented by further qualitative analysis that can provide deeper understanding of such relationships. However, our study already provides an extra layer of complexity over previous studies, by exploring the mechanisms through which they affect one another as well as the conditions under which these mechanisms operate.

Our findings demonstrate the potential role that awareness plays in influencing farmers’ behaviour regarding diffuse pollution mitigation. While a direct effect between awareness of and compliance with the GBRs could not be established, our results show that an indirect effect exists, through participation in agri-environmental schemes. As expected, this relationship is also contingent on contextual factors such as farm type and location. Agri-environmental schemes seem to provide an avenue for experiential learning through which farmers can develop and deepen tacit knowledge and understanding of diffuse pollution mitigation measures. Participation in agri-environmental schemes may encourage the development of new values, transforming awareness into a higher likelihood of implementing diffuse pollution mitigation measures.

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APPENDICES: SUPPLEMENTARY MATERIALS

Appendix A: List of GBRs

GBR	Description
GBR18	The storage and application of fertiliser (except where regulated under The Sludge (Use in Agriculture) Regulations 1989, Environmental Protection Act 1990, Waste Management Licensing Regulations 1994 or The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Scotland) Regulations 2003.
18ai	Fertiliser must not be stored on land that is within 10m of any river, burn, ditch, wetland, loch, transitional water or coastal water;
18aiii	Fertiliser must not be stored on land that is waterlogged;
18ci	Organic fertiliser must not be applied to land that is within 10m of any river, burn, ditch, wetland, loch, transitional water or coastal water
18cii	Organic fertiliser must not be applied to land that is within 50m of any spring that supplies water for human consumption or any well or borehole that is not capped to prevent water ingress;
18ciii	Organic fertiliser must not be applied to land that has an average soil depth of less than 40cm and overlies gravel or fissured rock, except where the application is for forestry operations;
18cv	Organic fertiliser must not be applied to land that is sloping, unless it is ensured that any run-off of fertiliser is intercepted (by means of a sufficient buffer zone or otherwise) to prevent it from entering any river, burn, ditch, wetland, loch, transitional water or coastal water towards which the land slopes.
18di	Inorganic fertiliser must not be applied to land that is within 2m of any river, burn, ditch, wetland, loch, transitional water or coastal water;
18dii	Inorganic fertiliser must not be applied to land that is within 5m of any spring that supplies water for human consumption or any well or borehole that is not capped to prevent water ingress;
18e	Fertilisers must not be applied to land in excess of the nutrient needs of the crop.
GBR19	Keeping of livestock
19a	Significant erosion or poaching of any land that is within 5m of any river, burn, ditch, wetland, loch, transitional water or coastal water must be prevented.
19b	Livestock must be prevented from entering any land that is within 5m of a spring that supplies water for human consumption or any well or borehole that is not capped to prevent water ingress.
19c	Livestock feeders must not be positioned where run-off from around the feeders could enter any river, burn, ditch, wetland, loch, transitional water or coastal water, and in any case, positioned no closer than 10m from any river, burn, ditch, wetland, loch, transitional water or coastal water.
GBR20	Cultivation of land
20ai	Land must not be cultivated for crops if it is within 2m of any river, burn, ditch, wetland or loch, as measured from the top of the bank, or within 2m of any transitional water or coastal water as measured from the shoreline;
20aii	Land must not be cultivated for crops if it is within 5m of any spring that supplies water for human consumption or any well or borehole that is not capped to prevent water ingress; or waterlogged.
20c	Land must be cultivated in a way that minimises the risk of pollution to any river, burn, ditch, wetland, loch, transitional water or coastal water.
GBR21	The discharge of water run-off via a surface water drainage system to the water environment (rural land activities).
21a	Run-off must be discharged in a way that minimises the risk of pollution to any river, burn, ditch, wetland, loch, transitional water or coastal water.
21b	Drainage must not result in destabilisation of the banks, or bed of the receiving river, burn, ditch, wetland, loch, transitional water or coastal water.
GBR23	The storage and application of pesticide
23a	The preparation of pesticide for application and the cleaning or maintenance of pesticide sprayers must not be undertaken within 10m of any river, burn, ditch, wetland, loch, transitional water or coastal water, and done in a manner that prevents any spillages, run-off or washings from entering any river, burn, ditch, wetland, loch, transitional water or coastal water.
23ci	Pesticide sprayers must not be filled with water taken from any river, burn, ditch, wetland or loch unless a device preventing back siphoning is fitted to the system;
GBR24	Operating sheep dip facilities
24a	Sheep must be prevented from having access to any river, burn, ditch, wetland, loch, transitional water or coastal water while there is a risk of transfer of sheep dip fluid from its fleece.
24c	Sheep dipping facilities must not discharge underground, leak or overspill.
24e	Sheep dip facilities shall be emptied within 24 hours following completion of dipping. (Please be aware that disposal of any sheep dip requires appropriate authorisation under CAR).

Appendix B1: Association between Variables

Variables		Number of observations (n)	Chi square (X)	Degree of freedom	p-value
Awareness	Agri-environmental schemes	1564	8.615	1	0.00***
Awareness	Nutrient budgeting	1564	65.486	1	0.00***
Awareness	Soil testing	1564	35.022	1	0.00***
Awareness	Compliance	1564	0.069	1	0.79
Agri-environmental schemes	Compliance	1564	3.068	1	0.08*
Nutrient budgeting	Compliance	1564	0.000	1	1.00
Soil testing	Compliance	1564	0.007	1	0.93
Location	Awareness	1564	18.153	1	0.00***
Location	Compliance	1995	19.692	1	0.00***
Location	Agri-environmental schemes	1564	22.964	1	0.00***
Location	Nutrient budgeting	1564	10.883	1	0.00***
Location	Soil testing	1564	57.086	1	0.00***
Farm type	Awareness	1541	0.966	2	0.612
Farm type	Compliance	1564	14.728	2	0.00***
Farm type	Agri-environmental schemes	1541	24.758	2	0.00***
Farm type	Nutrient budgeting	1541	94.625	2	0.00***
Farm type	Soil testing	1541	188.865	2	0.00***

Note: ***p-value <0.01, **p-value <0.05, *p-value <0.1

Appendix B2: Responses by farm type and location

Group	Response	
	Awareness of GBRs	
-	Aware	Not aware
Arable	83.3%	16.7%
Livestock	83.0%	17.0%
Mixed	85.0%	15.0%
North	80.9%	19.1%
South	89.2%	10.8%
	Participation in agri-environmental schemes	
-	Participate	Do not participate
Arable	37.9%	62.1%
Livestock	29.7%	70.3%
Mixed	43.2%	56.8%
North	42.4%	57.6%
South	30.2%	69.8%
	Compliance with GBRs	
-	Comply	Do not comply
Arable	53.1%	46.9%
Livestock	38.1%	61.9%
Mixed	40.1%	59.9%
North	50.2%	49.8%
South	39.9%	60.1%

Appendix C: Geographical clustering of catchments

South (Scottish lowlands)	North (Upland)
Stewartry Coastal	River Tay
River Irvine	River Dee (Grampian)
Galloway Coastal	River Deveron
North Ayrshire Coastal	Buchan Coastal
River Ayr	River South Esk (Tayside)
River Doon	
River Garnock	
Eye Water	

Appendix D: Modelling Results

Appendix D 1: Effect of various variables on compliance

Variable	Regression weight	Standard error	Wald	Degree of freedom	p-value
Aware of GBR	.141	.147	.918	1	0.34
Agri-environmental Schemes	.170	.110	2.390	1	0.12
Nutrient Budgeting	.009	.133	.005	1	0.95
Soil Testing	-.153	.153	.990	1	0.32
Livestock Farming	-.255	.184	1.910	1	0.17
Mixed Farming	-.435	.154	8.022	1	0.01**
Location of Catchment	-.537	.131	16.854	1	0.00***
Constant	.075	.200	.141	1	0.71

Note: ***p-value <0.01, **p-value <0.05, *p-value <0.1

Appendix D 2: Model fit indices for initial model (Model 1)

N	χ^2	degrees of freedom	P-value (χ^2)	CFI	RMSEA	90% conf. int. (RMSEA)	SRMR
1564	0.000	6	0.000	0.035	0.560	0.543, 0.577	0.305

Appendix D 3: Regression paths for initial model (Model 1)

Dependent variable	Independent variable	Estimate	Std. err.	P-value
Agri-environmental Schemes	Aware of GBR	0.275	0.091	0.00***
Compliance	Aware of GBR	0.013	0.101	0.89
Compliance	Agri-environmental Schemes	0.073	0.041	0.07*
Nutrient Budgeting	Aware of GBR	0.723	0.090	0.00***
Soil testing	Aware of GBR	0.515	0.089	0.00***
Compliance	Nutrient Budgeting	-0.001	0.041	0.98
Compliance	soil testing	-0.007	0.044	0.87

Note: ***p-value <0.01, **p-value <0.05, *p-value <0.1

Appendix D 4: Model fit indices for Model 3

N	χ^2	degrees of freedom	P-value (χ^2)	CFI	RMSEA	90% conf. int. (RMSEA)	SRMR
1564	1.000	1	1.000	1.000	0.000	0.000, 0.000	0.000