Mitigating Diffuse Water Pollution from Agriculture:
An Interdisciplinary Approach using Behavioural and Catchment Science

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The candidate confirms that the work submitted is his own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work is explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others. This thesis is presented as an alternative thesis. This is deemed suitable as three chapters (2, 3 and 4) have already been published, a fourth chapter (chapter 5) is under revision after a first round of minor revisions and chapter 6 is at an advanced draft stage, almost ready for submission. Below, I outline the status of each chapter and the authors' contributions.

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The research was conceived and led by Murat Okumah and Prof. Julia Martin-Ortega. Murat Okumah identified conditional process modelling as the appropriate technique to explore the complex link between awareness and adoption of measures to mitigate diffuse water pollution from agriculture. Prof. Julia Martin-Ortega and Dr. Paula Novo provided guidance to refine research ideas, conceptualisation and operationalisation. Murat Okumah analysed the data and wrote the manuscript, while . Prof. Julia Martin-Ortega and Dr. Paula Novo provided feedback. Murat Okumah led the revisions and editing of the manuscript with input from Prof. Julia Martin-Ortega and Dr. Paula Novo.

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To
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What will I do without you? Many thanks for your consistent and unquestionable support, encouragement and guidance all these years!
I love you daddy.

Abstract

Evidence shows that conventional agricultural systems, which currently dominate global food production, are a key contributor to diffuse water pollution from agriculture (DWPA). This threatens ecosystems' and human health, reduces the recreational value of water bodies and increases water treatment costs, adding further impediments towards achieving the UN Sustainable Development Goals (SDGs). Therefore, integrating agricultural and environmental policies to sustain food production systems while safeguarding water quality is one of today's most pressing challenges.

Previous studies have shown that generally, farmers lack a strong understanding of the link between their practices and DWPA whilst others are unaware of existing best management practices (BMPs). Therefore, in their search for measures to tackle DWPA, policymakers are increasingly focussing on how to improve farmers' awareness, under the expectation that this will lead to increased adoption of BMPs and improvements in water quality. This suggests an awareness-behaviour-water quality pathway. To date, however, the study of the awareness-behaviour-water quality pathway has been fragmented and insufficient.

In this PhD research I applied state-of-the-art interdisciplinary approaches, combining behavioural and catchment science to further our understanding of the complexities of the relationship between farmers' awareness, behaviour and water quality. This PhD research adopted a collaborative approach, with a focus on the UK. This collaborative approach helped to uncover two key findings. First, awareness influences farmers' adoption of BMPs, however, this relationship is moderated by experiential learning. It

is therefore important that farmers are offered the opportunity to engage in action-oriented learning. The second finding is that awareness influences farmers' adoption of BMPs and this, in turn, does influence water quality. However, this pathway is moderated by several psychosocial and biophysical factors. This finding suggests that awareness-focussed approaches are promising, but policymakers and catchment managers need to consider these complex factors critically influencing policy outcomes.

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Abbreviations

ABC………………………………………………Attitude-Behaviour-Context Model

AES…………………………………………...Agri-environement scheme

AFBI………………………………….…Agri-Food and Biosciences Institute

ANOVA ………………………………….…..Analysis of Variance

APAEs ………………………………….………Action Plans for the Aquatic Environment

ASSIA ………………………………………Applied Social Sciences Index and Abstracts

BBSRC………………………………………….Biotechnology and Biological Sciences Research Council

BMPs…………………………………………….Best Management Practices

BS……………………………………………...Buffer Strips

Ca……………………………………….Calcium

CaBA…………………………………………Catchment-based Approaches

CAFRE …………………………………...College of Agriculture, Food & Rural Enterprise

CAP………………………………………..Common Agricultural Policy

CFI …………………………………………...Comparative Fit Index

CPM………………………………………………Conditional Process Modelling

CSF……………………………………………..Catchment Sensitive Farming

DAERA………………………………………….Department of Agriculture and Rural Affairs

Defra…………………………………………..Department for Environment, Food and Rural Affairs

df……………………………………………..Degrees of Freedom

DPMAG……………………………………………Diffuse Pollution Management Advisory Group

DPMS ……………………………………………Diffuse Pollution Management Strategy

DWPA…………………………………………..Diffuse Water Pollution from Agriculture

EC……………………………………………European Commission

EFS…………………………………………….Environmental Farming Scheme

EQIP………………………………………Environmental Quality Incentive Programme

ESRC…………………………………...Economic and Social Research Council

EU EAA SSAS ……………………….…European Union Exceptional Adjustment Aid Soil Sampling and Analysis Scheme

GBRs…………………………………General Binding Rules

GPS…………………………………..Global Positioning System

K……………………………………..Potassium

LOI …………………………………..Loss-on-Ignition

MCPA………………………………..2-Methyl-4-Chlorophenoxyacetic Acid

MASEM …………………………………Meta-Analytic Structural Equation Modelling

Mg……………………………….……....Magnesium

N………………………………………Nitrogen

NAO…………………………………..National Audit Office

NAP…………………………………Nitrates Action Programme

NEP ………………………………….New Environmental Paradigm

NERC…………………………………Natural Environment Research Council

NI……………………………………..Northern Ireland

NICMS ………………………….…......Northern Ireland Countryside Management Scheme

NVZ………………………………......Nitrate Vulnerable Zones

OECD…………………………………Organisation for Economic Co-operation and Development

P……………………………………..Phosphorus

PCA…………………………………Priority Catchment Approach

PEB…………………………………Pro-environmental Behaviour

RePhoKUs…………………………………The role of Phosphorus in the Sustainability and Resilience of the UK Food System

RBMP…………………………………River Basin Management Plan

RMSEA……………………….………..Root Mean Square Error of Approximation

SEM…………………………………Structural Equation Modelling

SEPA…………………………………Scottish Environmental Protection Agency

SPSS…………………………………Statistical Package for the Social Sciences

SRDP …………………………………………...Scottish Rural Development Plan

SRMR…………………………………………...Standard Root Mean Square Residual

TLI…………………………………………….Tucker Lewis Index

TN…………………………………………….Total Nitrogen

UBC…………………………………………...Upper Bann Catchment

UK…………………………………………….United Kingdom

UN…………………………………………….United Nations

UNCCD……………………………..............United Nations Convention to Combat Desertification

WFD…………………………………………..Water Framework Directive

UNEP………………………………………….United Nations Environment Programme

WTO………………………………………….World Trade Organisation

WTWs……………………………………………Water Treatment Works

Chapter 1

Introduction

1.1 Agricultural land management, diffuse water pollution and policy

Agriculture is both the cornerstone of global food security and one of the main drivers of environmental degradation (Hosonuma et al., 2012, United Nations, 2016, United Nations Environment Programme, 2017). Conventional agricultural systems, which currently dominate global food production, contribute to biodiversity loss, soil degradation, water pollution and climate change (Hutchins, 2012, OECD, 2012, United Nations World Water Assessment Programme, 2015, Novotny, 2013). One of the most pervasive environmental problems attributable to agriculture is diffuse water pollution (ibid). The impacts of diffuse water pollution from agriculture (DWPA) include threat to ecosystems' and human health, increased water treatment costs and reduction in the recreational value of water bodies (Hutchins, 2012, OECD, 2012, United Nations World Water Assessment Programme, 2015, Novotny, 2013). Evidence shows that the annual socio-environmental costs of DWPA sums up to billions of dollars in OECD countries (OECD, 2012, OECD, 2017).

DWPA is likely to increase as the pressure to augment food production increases with population growth, agricultural production continues to intensify, and climate change creates substantial alteration to the hydrological cycle (UN World Water Assessment Programme, 2015). This could hinder the realisation of the UN Sustainable Development Goals, particularly SDGs 6 and 15 (United Nations, 2016a, 2016b, United Nations Environment Programme, 2017). Therefore, measures that integrate agricultural and environmental policies are needed to sustain (global) food production

systems while safeguarding water quality (UN General Assembly, 2015, UNCCD, 2015, 2017, OECD, 2017).

Strategies to mitigate DWPA have often included either one or a combination of the following: advice provision, regulations and economic incentives to land managers. All these are aimed at increasing farmer's adoption of best management practices (BMPs), which include a range of measures to reduce inputs of chemical pollutants in watersheds or catchments (e.g. limiting the use of chemicals), reduce the transport of contaminants from agricultural fields (e.g. better soil management) and capture pollutants along hydrological flow paths before they enter surface waters (e.g. buffer zones) (Kay et al., 2009). However, generally, these strategies have so far failed to substantially reduce DWPA (e.g., OECD, 2017, Kay et al., 2009). Besides the time lag between the introduction of those measures and observed changes in water quality (Meal et al., 2009, Kay et al., 2009), the persistent nature of DPWA has been attributed to a number of specific barriers including bureaucracy involved in accessing funds, 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). For instance, it has been argued that some farmers do not have a good understanding of the link between their agricultural practices and DWPA whilst others are unaware of some existing BMPs (Novo et al., 2015, Macgregor and Warren, 2006). Many of these barriers have an effect on land managers' behaviour, i.e. if farmers do not have a good understanding of existing measures to mitigate DWPA, they may be reluctant to implement them and even when they do, they may not follow best practice standards.

In their search for new strategies to tackle DWPA, policymakers are increasingly focussing on how to influence farmers' behaviour to adopt BMPs (Blackstock et al., 2010). One of the strategies adopted by policymakers has been to provide advice in order to improve farmers' awareness of the link between their practices and water pollution, and of BMPs to address the problem under the expectation that this will lead to a greater adoption of BMPs (Merrilees and Duncan, 2005, Blackstock et al., 2010). This expectation is based on the assumption of a straightforward relationship between awareness, behaviour and water quality, herein referred to as the *awareness-behaviour-water quality pathway* (Figure 1.1). Examples of such policies include the Water Quality Scheme and the Environmental Quality Incentive Programme in the United States (Winfield and Benevides, 2003), the Monitor Farms Programme in New Zealand (Dwyer et al., 2007), the Catchment Sensitive Farming Delivery Initiative in England (Environment Agency, 2011, Environment Agency, 2014) and the Diffuse Pollution Management Strategy in Scotland (DPMAG, 2015).

To date, however, the study of the awareness-behaviour-water quality pathway has been fragmented and insufficient. Previous studies have often addressed partial aspects of the pathway and have taken a disciplinary rather than an interdisciplinary perspective. For instance, some studies have focussed on land mangers' behavioural intentions, but not actual adoption of BMPs (e.g., Daxini et al., 2018, Daxini et al., 2019a, Daxini et al., 2019b, Zeweld et al., 2017, Floress et al., 2017). While these studies provide insights into factors influencing uptake of BMPs, they fail to provide a full account of the determinants of behavioural change. This is because land mangers' intentions might not always translate into behavioural changes due to the influence of contextual factors such as cost, time, available (or lack of) institutional support and farm tenure (Barnes et al., 2011, Macgregor and Warren, 2006, Inman et al., 2018,

Baumgart-Getz et al., 2012). Other studies have focussed on the link between awareness and actual adoption of BMPs (e.g., Macgregor and Warren, 2006, Vrain and Lovett, 2016), but have not considered the impact of the uptake of BMPs on water quality. Another set of studies have investigated the impact of BMPs on water quality responses (e.g., Kay et al., 2012, Collins et al., 2016) but did not include information on factors driving adoption of BMPs. Moreover, many studies exploring the awareness-behaviour link have failed to explore the complex interaction among variables linking awareness and behavioural change within the land management context. Furthermore, no study to date has studied the pathway in full, i.e. from awareness provision to actual changes in water quality.

Considering the negative effects of DWPA and the multimillion financial investments in awareness-focused approaches (EC, 2013, 2005, Environment Agency, 2014), a good understanding of the awareness–behaviour–water quality pathway is urgently needed to set the basis for assessing the full potential of these policy interventions. There is therefore need for studies that deepen our understanding of the awareness-behaviour link and also, studies that adopt a comprehensive approach to the full awareness-behaviour-water quality pathway from multiple disciplines (Giri and Qiu, 2016). This improved understanding of the awareness–behaviour–water quality pathway could help assess the effects of awareness-focused interventions and enable stakeholders to adjust policy strategies to help reverse increasing pollution of water bodies within local and national contexts (Giri and Qiu, 2016, Vrain, 2015).

Figure 1.1: The awareness-behaviour-water quality pathway

1.2 Research context: agriculture, water pollution and policy in the UK

While DWPA remains a major problem in many countries (OECD, 2017), the nature and extent of the problem varies widely across countries depending on the hydrogeological and climatic characteristics of different regions, land management systems (in particular inputs of fertilisers and pesticides) as well as the policy setting and initiatives being implemented (see Table 1.1 for a summary of initiatives towards mitigating DWPA) (Magrath, 2007, Novotny, 1999, Hollis et al., 2009). This suggests that although countries may employ similar policy strategies to tackle DWPA (Smith et al., 2015), variation in contextual factors such as climate, hydrogeology, land management systems, culture and the policy setting could create substantial differences in outcomes resulting from policy interventions (Hollis et al., 2009, Dolan et al., 2014). To be able to understand and to draw meaningful insights into the contextual factors driving farmers' awareness, behaviours and water quality outcomes, it is therefore important to employ a place-based research (Billick and Price, 2010). This PhD focusses on the UK, but it draws lessons that are expected to be of relevance more generally, especially to the Global North.

In the UK, while water pollution is attributed to a multitude of sources. Evidence suggests that about 60% of nitrate and 25% of phosphorous originate from agricultural

practices (White and Hammond, 2009). It is also thought that around 75% of sediments in water bodies come from agrarian sources (Collins and Anthony, 2008). Apart from nutrients, water pollution from pesticides (which includes herbicides, fungicides and insecticides) used on farms are a major concern in the UK (Hollis et al., 2009, Dolan et al., 2012, Defra, 2012). These pollutants have impacted the quality of water bodies with only 22%, 24%, 36% and 65% of water bodies in Northern Ireland, England, Wales and Scotland respectively meeting a 'good ecological status' according to EU's Water Framework Directive's (WFD) standards (Holden et al., 2017, DOENI, 2014, SEPA, 2015).

To address DWPA and its associated environmental and socio-economic impacts, the UK has progressively transitioned from traditional top-down and regulatory approaches to a more collaborative approach, encouraging land managers, the public and other stakeholders to play a critical role in developing and implementing mitigation strategies (Defra, 2013). In the last decade or so, the UK has increasingly adopted catchment-based approaches (CaBA), making it a great example in international efforts to tackle DWPA (Vrain, 2015). These catchment-level approaches involve advisors, farmers and other stakeholders working together to deliver a range of socio-economic and environmental benefits including the protection of water environments. This is expected to help farmers understand the "why" and "how" to achieve better environmental outcomes through knowledge co-construction and community empowerment ultimately aimed at improving water quality. The combination of advice and financial incentives is expected to improve farmers' awareness, encourage uptake of BMPs, reduce risks of DWPA at source and along flow pathways, ultimately leading to water quality improvement (Environment Agency, 2011, Environment Agency, 2014).

This transition from traditional top-down and regulatory approaches to collaborative approaches has also caused a change in the water industry (Ofwat, 2006). Water utilities traditionally relied on "end of pipe" solutions, by removing pollutants or treating polluted raw water to meet drinking water standards (EC, 1998, Dolan et al., 2012). This was found to be environmentally and socio-economically unsustainable and failed to tackle DWPA, with pollution incidents compromising the provision of safe drinking water (United Utilities, 2015). For instance, such approaches meant that pollutants in the surrounding environment (i.e., rivers and streams) were not removed – water utilities only treated water that is intended for household, industrial and public use. In the long term, the pollutants left in water bodies affect aquatic life and ultimately, ecosystem services that are sustained by rivers and streams (Ofwat, 2014). Moreover, the cost of intensive water treatment processes is borne by the customer (ibid).

Following the EU's WFD drive to change the focus away from 'investing in treatment infrastructure to preventing pollution at source' (EC, 2000), Ofwat (the economic regulator of the water sector in England and Wales) and the Drinking Inspectorate have encouraged water utilities and other stakeholders to employ upstream catchment management schemes to help address pollution at source and to help the water utilities use more cost-effective strategies to meet their environmental and drinking water obligations (Ofwat, 2014). Such policy changes have triggered a rapid change in approaches, with some water utilities now emphasising prevention at source. For instance, in Wales, Dŵr Cymru Welsh Water (hereafter referred to as Welsh Water) launched the weed wiper trial in 2015, aimed at informing farmers on DWPA and BMPs that could reduce pesticide pollution from farms (Welsh Water, 2014).

Table 1.1: Main policy instruments to promote uptake of measures to reduce DWPA

Category	Description	Key local examples	International example
Regulation	Mandatory best land management practices and restrictions, with penalties for non-compliance.	England: Defra 'Rules for farmers and land managers to prevent water pollution' and Nitrate Vulnerable Zones (NVZ) regulation (Defra, 2018b). Scotland: Diffuse Pollution General Binding Rules (GBRs) implemented through the Priority Catchment Approach (DPMAG, 2015), and the 'Prevention of Environmental Pollution from Agricultural Activity' code of good practice for farmers to help minimise pollution from farms (Scottish Executive, 2005). Northern Ireland: Nitrates Action Programme (NAP) and Phosphorus Regulations. Wales: Nitrate Vulnerable Zones (NVZ) regulation (Defra, 2018b).	The Danish Action Plans for the Aquatic Environment (APAEs) and The EU Nitrates Directive (EC, 1991)
Financial incentives	Incentivise uptake of best land management practices, or compensate for additional cost or income forgone as a result of taking up sustainable environmental management practices.	England: Countryside stewardship scheme and the Catchment Sensitive Farming Initiative (Environment Agency, 2011, Environment Agency, 2014). Scotland: The Agri-Environment Climate Scheme (Scottish Government, 2019). Northern Ireland: Northern Ireland Countryside Management Scheme (NICMS) (DAERA, 2007) and the Environmental Farming Scheme (EFS) (DAERA, 2017). Wales: Glastir Advanced (Welsh Government, 2017).	Agri-environment schemes under EU's Common Agricultural Policy - Pillar II (EC, 2013, EC, 2005).
Voluntary or advice centred	Farm advisory services to improve farmers' awareness and enhance uptake pf best land management practices (to reduce negative impacts of agriculture on water quality).	England: Catchment Sensitive Farming (Environment Agency, 2011, Environment Agency, 2014). Scotland: Advice provision through Scotland's Priority Catchment Approach (DPMAG, 2015). Northern Ireland: European Union Exceptional Adjustment Aid Soil Sampling and Analysis Scheme (EU EAA SSAS) Wales: Weed wiper trail and Pest Smart Campaign implemented by Welsh Water (Welsh Water, 2014).	Various advisory services in EU's Common Agricultural Policy - Pillar II (EC, 2013, EC, 2005).

1.3 Research aim, objectives and questions

This PhD aims to advance the knowledge frontier on our understanding of the complex awareness-behaviour-water quality pathway (Figure 1.1). To do this, I apply state-of-the-art interdisciplinary approaches, combining behavioural and catchment science to achieve two objectives (Figure 1.2):

- **The first objective** is to disentangle some of the complexities on the awareness-behavioural links. Here, I focus on exploring whether and how awareness affects farmers' behaviour regarding the adoption of BMPs. In response to this objective, the following sub-questions are pursued:

  1.1 Does awareness of DWPA and BMPs lead to uptake of such BMPs?

  1.2 Which other factors influence uptake of BMPs?

  1.3 How does awareness interact with these other factors to influence uptake of BMPs?

- **The second objective** is to, for the first time in the literature, explore the relationship between awareness, behaviour and water quality , i.e., study the pathway *in full*. To address this second objective, the following sub-questions are addressed:

  2.1 Does awareness contribute to an improvement in water quality?

  2.2 How does awareness interact with other factors to influence water quality within catchments?

1.4 Timeliness of the PhD Research

While catchment-based approaches are increasingly being employed across the UK and other countries, there are few studies that comprehensively explore whether and how they improve farmers' awareness, and whether and how this in turn leads to

uptake of BMPs, that leads to a reduction in DWPA and ultimately result in water quality improvements (Vrain, 2015, Vrain and Lovett, 2016, Vrain et al., 2014). A report from Ofwat indicated that:

> "*Companies are using a variety of approaches to prevent or reduce the amount of diffuse or other pollution entering water catchments. Early results from several of the companies suggest that some of their catchment management schemes are beginning to deliver benefits for customers. But across England and Wales there is not yet enough evidence overall to show that catchment management schemes deliver better water quality and lower treatment costs… They need to build the evidence base to show the effectiveness and benefits of particular techniques*" (Ofwat, 2014).

This PhD research is timely as it provides evidence on whether and how catchment based approaches influence land managers' awareness, behaviours and water quality as well as information needed to inform critical policy decisions at a time where there are substantial changes in Europe's geopolitical landscape. For instance, Brexit (the UK's withdrawal from the EU) means transitioning away from Common Agricultural Policy (CAP)-style direct aid payments in England (Gravey et al., 2017, Franks, 2016). The CAP is based on a two pillar structure: pillar I provides direct support to farmers and financing market measures, while pillar II enhances socio-economic and environmental areas such as innovation; provision of basic rural services and related infrastructure; sustainable management of agricultural land; and support for improvement of the environment (EC, 2013). These funds are provided to support the adoption of BMPs and technology that improves farmers' efficiency in business.

At present, the EU CAP and the World Trade Organisation rules stipulate that agri-environment compensation payments must not be greater than the profit forgone (Franks, 2016). As the UK remains in the World Trade Organisation, it cannot change this payment constraint. An important question in this context is: as Brexit is likely to impact trade between the UK and the EU, "*what would happen if farm profitability fell*

to zero and areas of marginal farmland was no longer cultivated?" (Franks, 2016, p. 11). As Franks has suggested, agri-environment payments that are based on costs incurred and a profit foregone of £0 would not be attractive to farmers. This has implications for land management and farmers' willingness and ability to adopt BMPs (Wheeler, 2018). Adapting to the impacts of Brexit requires a critical evaluation of existing policy strategies and to redesign policies that are more tailored to the specific needs and circumstances of stakeholders in UK's farming, food, water and environment sectors as well as the priorities of the British public (Gravey et al., 2017, Barnes et al., 2020).

Additional efforts are therefore needed to complement ongoing efforts to maximise the value of policies such as the UK's 25 Year Environment Plan (Defra, 2018a), The Scottish Land Use Strategy (The Scottish Government, 2016), The Northern Irish Sustainable Agricultural Land Management Strategy (DAERA, 2016) and The Welsh Wellbeing of Future Generations Act (Welsh Government, 2017), which aim to promote the sustainable use of land, increase resource efficiency, and reduce pollution. The post-Brexit Landmark Agriculture Bill is expected to replace the current subsidy system of Direct Payments under EU's CAP pillar 2 and spells out how farmers will be paid in the future for "public goods", including improved air and water quality, enhanced soil health, and strategies targeted at mitigating flooding (Gove, 2018). The post-Brexit Agriculture Bill remains a trial and thus urgent research is needed to (re)design, develop and refine the policy, making this PhD a timely and crucial source of data for this purpose.

1.5. Research philosophy: Positioning of the PhD research

My positionality in this PhD project has been shaped by my academic background, i.e. my undergraduate studies — BSc. Development Planning, at the Kwame Nkrumah University of Science and Technology (Ghana) and graduate studies — MSc. Environment and Development, at The University of Leeds (United Kingdom). These degrees are rooted in interdisciplinary sciences and focus on combining theoretical and pragmatic ideas from the environmental and social sciences to understand issues of sustainable development (e.g., social justice, ecosystems, water resources, and livelihoods) and how policy can best address such development issues. This background has thus influenced my decision to apply pragmatic approaches to address DWPA and how psychosocial, agronomic and biophysical factors interact to affect water quality.

Pragmatism hinges on the idea that truth is constructed based on individual experiences that interact to form societal reality (Pansiri, 2005). To understand how complex social phenomena operate, it is important that research looks into the different worldviews and how these views derive from lived-experiences as well as interactions in the social settings within which the phenomenon is occurring (Pansiri, 2005). DWPA is caused and impacted by different social entities – with potentially divergent opinions, experiences, competing interests and different capacities to resolve the problem (Dolan et al., 2014, Duckett et al., 2016, Patterson et al., 2013). Investigating trajectories of the problem and how different social groups relate to it could help define solutions that respond to the needs, circumstances and capacities of different stakeholders, thus providing a realistic approach to tackling the problem (Steg and Vlek, 2009). I believe that pragmatism is therefore useful in investigating farmers' behaviours, perceptions and how they are related to DWPA.

Pragmatic research focusses on what is best suited to the research questions under consideration and allows for flexibility (Pansiri, 2005). Indeed, socio-ecological science research is often faced with different challenges depending on the nature, scale and/or focus of the research. As a result, pragmatists are often faced with an important question: *what is the best technique to apply within the circumstances of the research*? This flexible attribute of pragmatic research has been useful in this PhD, as it encourages the combination of different 'knowledges' from different scientific disciplines, policymakers and local stakeholders as this can offer useful insights into understanding a social problem or phenomenon (such as the complex factors influencing behaviours and DWPA) (Morgan, 2014, Reed, 2008). As a result, interdisciplinary approaches are best suited to and increasingly being promoted in pragmatic research (Tress et al., 2005). This helps to bridge the gap between science and society. Pragmatic research also encourages the use of mixed research methods and a combination of different datasets. As will be shown in chapters 2 to 6 of this thesis, I adopted a combination of different approaches and methods in this research (see 1.5.2 for an overview of the methodology).

It is important to note that my personal experiences and cultural background plays a role in the research process. I approached the research from a different cultural background (as a Ghanaian), which seem to have projected me as an 'outsider' in the UK farming and land management landscape, without vested interest in some of the more delicate aspects of the issues being researched. It could be argued that this 'outsider' position provided a more comfortable ground for stakeholders to disclose relevant information and thus facilitated the process for interviewees to talk about issues that can be sensitive. Furthermore, my experience from previous livelihood and

sustainability projects as well as my experiences in qualitative research played a crucial role in the application of a collaborative interview style where I carefully engaged stakeholders through direct or face-to-face interactions and phone calls, using important probes and prompts. This helped to deepen our conversations, and to elicit rich contextual information.

1.6 Research strategy, methodological approach and practicalities

1.6.1 Research strategy and methodological approach

This PhD relies on an interdisciplinary approach by integrating knowledge from different disciplines to understand whether and how farmers' awareness of DWPA and BMPs influences their behaviour and results in an improvement in water quality. As Fry (2001) notes, the strength of interdisciplinary research is the opportunity it creates by enabling different disciplines to integrate ideas, knowledge, methods and data towards achieving a common goal.

The approach adopted in this PhD reflects such an integrative strategy where I worked with academic researchers and practitioners from social (psychology, sociology, environmental and ecological economics) and natural sciences (environmental biogeochemistry and catchment science), and combined different strands of data (interviews, surveys and water quality data) and analytical approaches (qualitative and quantitative), with the common goal of understanding whether and how awareness-based approaches could trigger positive behavioural changes that result in water quality improvement. This is typical of recent catchment-based studies that attempt to explore what drives land management practices and how this influences socio-ecological systems (Vrain, 2015). As will be shown later in chapters 5 and 6, I co-developed data collection tools (interview guides) with different stakeholders, and also

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integrated different forms of data including quantitative surveys, qualitative interviews, and water quality data. Also, results from the water quality analysis informed the design and analysis of the qualitative interviews. Integrating different disciplinary 'knowledges' with non-academic knowledge helps to tackle complex socio-environmental problems from multiple perspectives, reduces the duplication of efforts and potential conflicts in interventions designed to address such 'wicked problems' (Macleod et al., 2007). Interdisciplinarity offers the opportunity to harness potential synergies to devise innovative solutions and to maximise the use of resources beyond what scientists and non-academics could achieve when working in isolation (Fry, 2001).

This interdisciplinary and multi-method approach was applied in two main stages: 1) exploratory and hypotheses generation stage (chapters 2, 3 and 4), and 2) hypotheses testing stage (chapters 5 and 6):

Stage 1: exploratory and hypothesis generation
Empirical evidence on awareness-focussed approaches remains scarce and mixed, with previous studies relying on small datasets (e.g., Vrain and Lovett, 2016). At the exploratory stage, I applied conditional process modelling to investigate the awareness-behaviour link using a large dataset (N=1,995) from Scottish Environmental Protection Agency (SEPA) (Chapter 2). As part of its Priority Catchment Approach, SEPA had gathered data on farmers' awareness of their Diffuse Pollution General Binding Rules (GBRs), participation in agri-environmental schemes, practice of nutrient budgeting, soil testing and compliance with the GBRs. Making use of that data represented an extraordinary opportunity to start unveiling the awareness-behaviour link. The dataset represents a highly valuable resource for a number of

reasons: first, because of its size. Any research 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 as monitored by SEPA. In addition to this, the analytical technique used, the conditional process modelling, allows for testing complex relationships and the conditions under which such relationships operate, thus helping to start unveiling the complexity of the awareness-behaviour link within the context of land management.

To further our understanding of the awareness-behaviour-water quality pathway, two systematic reviews were undertaken: the first focussing on the determinants of pro-environmental behaviour from a theoretical perspective (Chapter 3), and the second evaluating the evidence base of the full awareness-behaviour-water quality pathway (Chapter 4).

Two key hypotheses were generated from this stage: 1) awareness influences farmers' adoption of BMPs, however, this relationship is not direct but it is moderated by experiential learning, and 2) awareness influences farmers' adoption of BMPs and this in turn influences water quality, however, this pathway is also moderated by other factors. The next stage involved testing these two hypotheses.

Stage 2: Hypotheses testing

At the hypotheses testing stage, I employed a combination of methods to gather primary quantitative and qualitative data in two different case studies in Northern Ireland (Chapter 5) and Wales (Chapter 6). The case study in Northern Ireland tested the first hypothesis "*awareness influences farmers' adoption of BMPs, however, this*

relationship is moderated by experiential learning" while the Welsh case study tested the second hypothesis "*awareness influences farmers' adoption of BMPs and this in turn influences water quality, however, this pathway is moderated by several psychosocial, agronomic and biophysical factors*".

The study in Northern Ireland involved surveys and qualitative interviews with farmers associated with the EU Exceptional Adjustment Aid Soil Sampling and Analysis Scheme (EU EAA SSAS). As the EU EAA SASS scheme focussed on information provision, knowledge transfer and soil testing, it represented a great opportunity for evaluating whether advice-focussed initiatives influence farmers' awareness and whether this contributes to uptake of BMPs. Conditional process modelling was applied to analyse the survey data while content analysis was used to explore the interview transcripts, aimed at providing deeper insights into the quantitative results. Integrating these two methods has an advantage over purely qualitative or quantitative studies as surveys help with generalisation while qualitative interviews provide deep and rich contextual information about the phenomenon being studied (Onwuegbuzie and Leech, 2005). Additionally, the conditional process modelling applied in this study enables us to unravel the mechanisms through which different variables transmit their effects onto other variables and the conditions under which these relationships operate (Hayes, 2013), while the reflexive analysis of qualitative data takes into account "meanings" and factors influencing those meanings in a range of contexts (Ragin, 2014, Schneider and Wagemann, 2012).

The fieldwork in Wales involved qualitative interviews with farmers and other stakeholders in land management, and analysis of water quality data from water treatment works (WTWs). This study was associated with a water utility's (Welsh

Water) weed wiper trial, which encouraged farmers to adopt sustainable ways of weed, pest and disease control and promotes the safe storage, use and disposal of pesticides. The aim of the weed wiper trial was to mitigate pesticide pollution in watercourses, through a free 'weed wiper' hire. Welsh Water provided data (2006-2019) on pesticide (2-methyl-4-chlorophenoxyacetic acid commonly referred to as MCPA) concentration from all WTWs in the three catchments within the weed wiper trial and for all WTWs within three catchments that had not been in the trial but were in a similar location and of similar characteristics.

To analyse interview transcripts, I applied content analysis (Strauss and Corbin, 1998) to code emergent themes from relevant sentences, while the water quality data was analysed using quantitative techniques (e.g., factorial analysis of variance). This interdisciplinary approach was adopted to overcome the limitations of partial mono-disciplinary methodologies unsuitable to addressing the complexity of 'wicked problems' (Martin-Ortega et al., 2015, Duckett et al., 2016, Termeer and Dewulf, 2019, Raymond et al., 2010, Stoate et al., 2019). Therefore, the interviews were aimed at providing meaning and context to the results obtained from the water quality analysis, in what is the first study in the literature that explores the awareness-behaviour-water quality pathway in full.

1.6.2 Practicalities and ethical concerns

Since the project involved fieldwork with human participants, and the processing and storing of individual data, ethical consideration was paramount (Linkogle et al., 2001). Ethics for this PhD research was approved by the University of Leeds Research Ethics Committee (with the reference LTSEE-083). Some important ethical issues considered in the data collection process included interviewees' consent and

anonymity. The consent of potential interviewees was sought before the interviews and respondents were asked to opt out if they found that necessary. Interviewees also had the opportunity to ignore questions they found to be confidential although anonymity was assured. I anonymised responses from interviewees to ensure that their identities were hidden (Saunders et al., 2015). Interviewees were also asked to contact me within two weeks of the interviews if they wanted their responses to be removed from the database.

Data for chapters 5 and 6 were collaboratively generated by me and various partner organisations: Department of Agriculture and Rural Affairs (DAERA), the Agri-Food and Biosciences Institute (AFBI) and Welsh Water. Collaboration with DAERA and AFBI took place in the context of the RePhoKUs[1] project (The role of phosphorus in the sustainability and resilience of the UK food system) funded by BBSRC, ESRC, NERC and the Scottish Government under the UK Global Food Security research programme, of which my main PhD supervisor is Principal Investigator. An ad-hoc collaboration agreement between the University of Leeds and the two institutions (Welsh Water and DAERA) was signed to guide the collaboration, including how data will be managed and used as well as who should be given access to the data during and after the PhD research.

An important concern with fieldwork is the health and safety of the researcher and research participants (McDonald, 2004, Linkogle et al., 2001). In chapters 5 and 6, I used primary data that was generated through fieldwork. Since the fieldwork involved interactions with stakeholders in the UK, low risk was anticipated. Accordingly, I followed the University of Leeds guidelines for low risk field assessment and got

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[1] http://wp.lancs.ac.uk/rephokus/

approval from the Health and Safety Division of the Faculty of Environment. I ensured that the location and time selected for interviews were suitable and safe for interviewees and myself.

1.7 Structure of the thesis

This introductory chapter (Chapter 1) has set out the context of the research, highlighting the motivation, core research gap, aim, objectives, positionality and methodological approach, as well as the practicalities of the research. The remainder of the thesis is structured into six chapters (see Figure 1.2). Chapter 2 presents results of the exploratory analysis that provided a first-hand understanding of the awareness-behaviour link during stage one of this thesis. This was the first activity of the PhD aimed at establishing whether and how farmers' awareness of Scotland's Diffuse Pollution GBRs influenced their compliance with the GBRs. Findings of this chapter are published in Land Use Policy (ISI impact factor 3.573) (under the reference *Okumah et al. 2018*).

Based on findings of the exploratory analysis of SEPA's data, it was important to systematically explore the literature to identify factors that could interact with awareness to trigger behavioural changes. A cursory look at the literature revealed that while this has been studied considerably in the area of environmental psychology, it has been much less explored with respect to land management. Importantly, environmental policies in the realm of land management are increasingly focussing on inducing behavioural change to improve environmental management outcomes. This is based on theories that suggest that pro-environmental behaviour can be predicted and altered based on the determinants of such behaviours. It was therefore important

to revisit these theories to assess if the evidence supports their postulations so that a more robust knowledge base can be established to inform land management policies. Following a thorough systematic literature search on theories and empirical evidence on the determinants of pro-environmental behaviour, a meta-analytic structural equation modelling technique was applied to establish the evidence base of these theories (Chapter 3), published in Land (*Okumah et al., 2020*; ISI impact factor 2.429).

The above research covered the "*awareness-behaviour*" component of the awareness–behaviour–water quality pathway. Following this, Chapter 4 set out to identify the existing evidence on the "*the behaviour-water quality*" component of the pathway, i.e. looking at whether and how behavioural changes translate into water quality improvements (Figure 1.2). This review highlighted the paucity of research on the awareness-behaviour-water quality pathway and also unpacked the potential mechanisms through which different variables affect one another. This chapter, published in the Water journal (ISI impact factor 2.524) (*Okumah et al. 2019*), helped to identify variables and components of the pathway that had received little or no attention thus supporting the identification of knowledge gaps and research objectives (see Figure 1.2).

Two hypotheses were generated from the exploratory analysis in Chapter 2 and the two systematic reviews of the awareness-behaviour-water quality pathway in Chapters 3 and 4 and needed to be tested through empirical work. Chapter 5 presents results for the first hypothesis "*awareness influences farmers' adoption of BMPs, however, this relationship is moderated by experiential learning*" while chapter 6 focusses on the second hypothesis "*awareness influences farmers' adoption of BMPs and this in turn influences water quality, however, this pathway is moderated by several psychosocial,*

agronomic and biophysical factors". The results in Chapter 5 are based on data associated with the EU EAA SSAS in Northern Ireland. This chapter is currently under review at Land Use Policy (ISI impact factors 3.573), after a first favourable revision in which only minor changes were requested.

Chapter 6 investigated whether awareness-focussed approaches to mitigating DWPA work, addressing the pathway in full using an interdisciplinary approach. Results of this chapter are based on analysis of water quality data and semi-structured in-depth interviews with institutional stakeholders and farmers in Wales. This chapter is currently in an advanced draft journal article form aimed at the Journal of Environmental Management (ISI Impact Factor: 4.010).

Finally, Chapter 7 synthesises key findings and provides the broader conclusions that it yields. The societal and academic impact of this PhD, particularly how the collaborative approach employed in this research has set the path for actual societal impact is also discussed in this chapter. Following this, recommendations for policy and future research are provided.

Introduction		**Chapter 1**
Objective 1: To further our understanding of the complexities of the awareness-behaviour link	**1.1. Does awareness of DWPA and BMPs lead to uptake of such BMPs?**	**Chapters 2, 3, 4, 5 and 6**
	1.2. Which other factors influence uptake of BMPs?	**Chapters 2, 3, 4, 5 and 6**
	1.3. How does awareness interact with these other factors to influence uptake of BMPs?	**Chapters 2, 4, 5 and 6**
Objective 2: To disentangle the complexities of the relationship between awareness, behaviour and water quality	**2.1. Does awareness contribute to an improvement in water quality?**	**Chapters 4 and 6**
	2.2. How does awareness interact with other factors to influence water quality within catchments?	**Chapters 4 and 6**
Conclusions		**Chapter 7**

Figure 1.2: Structure of thesis

References

BARNES, A., MACMILLAN, J., THOMPSON, S., SPENCER, M., HOPKINS, J., SUTHERLAND, L. & MATHEWS, K. 2020. Farmer reponses to Brexit: an examination of different outlooks to Brexit Edinburgh and Aberdeen Scotland's Rural College and The James Hutton Institute

BARNES, A. P., WILLOCK, J., TOMA, L. & HALL, C. 2011. Utilising a farmer typology to understand farmer behaviour towards water quality management: Nitrate Vulnerable Zones in Scotland. *Journal of Environmental Planning and Management,* 54**,** 477-494.

BAUMGART-GETZ, A., PROKOPY, L. S. & FLORESS, K. 2012. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of Environmental Management,* 96**,** 17-25.

BILLICK, I. & PRICE, M. V. 2010. *The ecology of place : contributions of place-based research to ecological understanding,* Chicago, Ill. ;, University of Chicago Press.

BLACKSTOCK, K. L., INGRAM, J., BURTON, R., BROWN, K. M. & SLEE, B. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the total environment,* 408**,** 5631-5638.

COLLINS, A. L. & ANTHONY, S. G. 2008. Assessing the likelihood of catchments across England and Wales meeting 'good ecological status' due to sediment contributions from agricultural sources. *Environmental Science & Policy,* 11**,** 163-170.

COLLINS, A. L., ZHANG, Y. S., WINTER, M., INMAN, A., JONES, J. I., JOHNES, P. J., CLEASBY, W., VRAIN, E., LOVETT, A. & NOBLE, L. 2016. Tackling agricultural diffuse pollution: What might uptake of farmer-preferred measures deliver for emissions to water and air? *Science of The Total Environment,* 547**,** 269-281.

DAERA 2007. Countryside Management Scheme 2007 - 2013 Information Booklet Belfast: Department of Agriculture, Environment and Rural Affairs.

DAERA 2016. *Delivering Our Future , Valuing Our Soils: A Sustainable Agricultural Land Management Strategy for Northern Ireland* [Online]. Belfast: Northern Irish Executive. [Accessed].

DAERA 2017. A Guide to Environmental Farming Scheme Belfast: Department of Agriculture, Environment and Rural Affairs.

DAXINI, A., O'DONOGHUE, C., RYAN, M., BUCKLEY, C., BARNES, A. P. & DALY, K. 2018. Which factors influence farmers' intentions to adopt nutrient management planning? *Journal of environmental management,* 224**,** 350-360.

DAXINI, A., RYAN, M., O'DONOGHUE, C. & BARNES, A. P. 2019a. Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour. *Land Use Policy,* 85**,** 428-437.

DAXINI, A., RYAN, M., O'DONOGHUE, C., BARNES, A. P. & BUCKLEY, C. 2019b. Using a typology to understand farmers' intentions towards following a

nutrient management plan. *Resources, Conservation and Recycling,* 146**,** 280-290.

DEFRA 2012. *Observatory monitoring framework – indicator data sheet: Environmental Impact Water* [Online]. London: The Department for Environment, Food and Rural Affairs. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/162165/defra-stats-observatory-indicators-da4.-120224.pdf [Accessed 18/05 2020].

DEFRA 2013. Catchment Based Approach: Improving the Quality of Our Water Environment, Report May 2013. . London: Department for Environment, Food & Rural Affairs.

DEFRA 2018a. *A Green Future: Our 25 Year Plan to Improve the Environment.* [Online]. London: Department for Environment, Food & Rural Affairs. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf [Accessed].

DEFRA 2018b. *Rules for farmers and land managers to prevent water pollution* [Online]. Bristol: Department for Environment, Food & Rural Affairs. Available: https://www.gov.uk/guidance/rules-for-farmers-and-land-managers-to-prevent-water-pollution [Accessed 10/05 2020].

DOENI 2014. *Northern Ireland Water Management Facts and Figures* [Online]. Available: http://www.doeni.gov.uk/niea/water-facts-and-figures-booklet-2014-final-for-web.pdf. 2014. 12. [Accessed].

DOLAN, T., HOWSAM, P. & PARSONS, D. 2012. Diffuse pesticide pollution of drinking water sources: impact of legislation and UK responses. *Water Policy,* 14**,** 680-693.

DOLAN, T., HOWSAM, P., PARSONS, D. & WHELAN, M. 2014. Impact of European Water Framework Directive Article 7 on Drinking Water Directive compliance for pesticides: challenges of a prevention-led approach. *Water Policy,* 16**,** 280-297.

DPMAG 2015. Strategy to reduce diffuse pollution. Edinburgh: Scottish Environment Protection Agency.

DUCKETT, D., FELICIANO, D., MARTIN-ORTEGA, J. & MUNOZ-ROJAS, J. 2016. Tackling wicked environmental problems: The discourse and its influence on praxis in Scotland. *Landscape and Urban Planning,* 154**,** 44-56.

DWYER, J., MILLS, J., INGRAM, J., TAYLOR, J., BURTON, R., BLACKSTOCK, K., SLEE, B., BROWN, K., SCHWARZ, G. & MATTHEWS, K. 2007. Understanding and influencing positive behaviour change in farmers and land managers. *CCRI, Macaulay Institute*.

EC 1991. Council Directive 91/676/EEC Concerning the Protection of Waters Against Pollution by Nitrates from Agricultural Sources, OJ L375. Brussels: European Commission.

EC 1998. Council Directive 98/83/EC on the Quality of Water Intended for Human Consumption, L 330/32 ed. Official Journal of the European Communities. Brussels European Commission

EC 2000. Directive 2000/60/EC Establishing a Framework for Community Action in the Field of Water Policy, L 327. Official Journal of the European Communities. Brussels: European Commission.

EC 2005. Agri-environment Measures: Overview on General Principles, Types of Measures, and Application. Brussels: European Commission, Directorate General for Agriculture and Rural Development.

EC 2013. Regulation (EU) No 1305/2013 of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005. *Official Journal of the European Union,* 17**,** 487–548.

ENVIRONMENT AGENCY 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report. Bristol Environment Agency

ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. Bristol Environment Agency.

FLORESS, K., DE JALON, S. G., CHURCH, S. P., BABIN, N., ULRICH-SCHAD, J. D. & PROKOPY, L. S. 2017. Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality. *Journal of Environmental Psychology,* 53**,** 73-80.

FRANKS, J. R. 2016. Some implications of Brexit for UK agricultural environmental policy. Newcastle Centre for Rural Economy, Newcastle University.

FRY, G. L. A. 2001. Multifunctional landscapes—towards transdisciplinary research. *Landscape and Urban Planning,* 57**,** 159-168.

GIRI, S. & QIU, Z. 2016. Understanding the relationship of land uses and water quality in Twenty First Century: A review. *Journal of Environmental Management,* 173**,** 41-48.

GOVE, M. 2018. *Landmark Agriculture Bill to deliver a Green Brexit* [Online]. London: Department for Environment, Food & Rural Affairs. Available: https://www.gov.uk/government/news/landmark-agriculture-bill-to-deliver-a-green-brexit [Accessed 24/06 2020].

GRAVEY, V., BROWN, I., FARSTAD, F., HARTLEY, S. E., HEJNOWICZ, A. P., HICKS, K. & BURNS, C. 2017. *Post-Brexit Policy in the UK: A New Dawn? Agri-environment* [Online]. Available: https://www.brexitenvironment.co.uk/wp-content/uploads/dlm_uploads/2017/07/Brexit-Agri-Environment-Brief.pdf [Accessed 11/06 2020].

HAYES, A. F. 2013. *Introduction to mediation, moderation and conditional process analysis,* New York and London, The Guildford Press.

HOLDEN, J., HAYGARTH, P. M., DUNN, N., HARRIS, J. A., HARRIS, R. C., HUMBLE, A., JENKINS, A., MACDONALD, J., MCGONIGLE, D. F., MEACHAM, T. & ORR, H. G. 2017. Water quality and UK agriculture: challenges and opportunities. ortunities. WIREs Water, 4: n/a, e1201.

HOLLIS, J., BROWN, C., HUGHES, G. & RAMWELL, C. 2009. Review of data on pesticide concentrations in surface runoff relevant to UK agricultural conditions in Brown CD, Hughes G, Hollis JM, Ramwell CT (2009), Importance of surface runoff as a route of aquatic exposure. . York

HOSONUMA, N., HEROLD, M., DE SY, V., DE FRIES, R. S., BROCKHAUS, M., VERCHOT, L., ANGELSEN, A. & ROMIJN, E. 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters,* 7**,** 044009.

HUTCHINS, M. G. 2012. What impact might mitigation of diffuse nitrate pollution have on river water quality in a rural catchment? *Journal of Environmental Management,* 109**,** 19-26.

INMAN, A., WINTER, M., WHEELER, R., VRAIN, E., LOVETT, A., COLLINS, A., JONES, I., JOHNES, P. & CLEASBY, W. 2018. An exploration of individual, social and material factors influencing water pollution mitigation behaviours within the farming community. *Land Use Policy,* 70**,** 16-26.

KAY, P., EDWARDS, A. C. & FOULGER, M. 2009. A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. *Agricultural Systems,* 99**,** 67-75.

KAY, P., GRAYSON, R., PHILLIPS, M., STANLEY, K., DODSWORTH, A., HANSON, A., WALKER, A., FOULGER, M., MCDONNELL, I. & TAYLOR, S. 2012. The effectiveness of agricultural stewardship for improving water quality at the catchment scale: experiences from an NVZ and ECSFDI watershed. *Journal of hydrology,* 422**,** 10-16.

LINKOGLE, S., LEE-TREWEEK, G. & ESTERHUIZEN, L. 2001. Danger in the field: risk and ethics in social research. *In:* ESTERHUIZEN, L. (ed.).

MACGREGOR, C. J. & WARREN, C. R. 2006. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. *Agriculture, Ecosystems & Environment,* 113**,** 108-119.

MAGRATH, J. 2007. Water: A Shared Responsibility - The United Nations World Water Development Report 2. Routledge.

MARTIN-ORTEGA, J., PERNI, A., JACKSON-BLAKE, L., BALANA, B. B., MCKEE, A., DUNN, S., HELLIWELL, R., PSALTOPOULOS, D., SKURAS, D. & COOKSLEY, S. 2015. A transdisciplinary approach to the economic analysis of the European Water Framework Directive. *Ecological Economics,* 116**,** 34-45.

MCDONALD, M. 2004. Danger in the field: Risk and ethics in social research. Hoboken: Wiley Subscription Services, Inc., A Wiley Company.

MERRILEES, D. & DUNCAN, A. 2005. Review of attitudes and awareness in the agricultural industry to diffuse pollution issues. *Water Science and Technology,* 51**,** 373-381.

MORGAN, D. L. 2014. Pragmatism as a Paradigm for Social Research. *Qualitative Inquiry,* 20**,** 1045-1053.

NOVOTNY, V. 1999. Diffuse pollution from agriculture—A worldwide outlook. *Water Science and Technology,* 39**,** 1–13.

OECD 2012. Water quality and agriculture: meeting the policy challenge. OECD Studies on Water. . Paris: Organisation for Economic Co-operation and Development.

OECD 2017. Diffuse Pollution, Degraded Waters: Emerging Policy Solutions. Paris OECD Publishing.

OFWAT 2006. The Development of the Water Industry in England and Wales. Report by Ofwat. .

OFWAT 2014. *From catchment to customer – can upstream catchment management deliver a better deal for water customers and the environment?* [Online]. Ofwat. Available: https://www.ofwat.gov.uk/publications/from-catchment-to-customer-can-upstream-catchment-management-deliver-a-better-deal-for-water-customers-and-the-environment/ [Accessed 17/06 2020].

OKUMAH, M., CHAPMAN, P., MARTIN-ORTEGA, J. & NOVO, P. 2019. Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway. *Water,* 11**,** 29.

ONWUEGBUZIE, A. J. & LEECH, N. L. 2005. On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies. *International Journal of Social Research Methodology,* 8**,** 375-387.

PANSIRI, J. 2005. Pragmatism: A methodological approach to researching strategic alliances in tourism. *Tourism and Hospitality Planning & Development,* 2**,** 191-206.

PATTERSON, J. J., SMITH, C. & BELLAMY, J. 2013. Understanding enabling capacities for managing the 'wicked problem' of nonpoint source water pollution in catchments: A conceptual framework. *Journal of environmental management,* 128**,** 441-452.

RAGIN, C. C. 2014. *The comparative method: Moving beyond qualitative and quantitative strategies*, Univ of California Press.

RAYMOND, C. M., FAZEY, I., REED, M. S., STRINGER, L. C., ROBINSON, G. M. & EVELY, A. C. 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management,* 91**,** 1766-1777.

REED, M. S. 2008. Stakeholder participation for environmental management: A literature review. *Biological Conservation,* 141**,** 2417-2431.

SAUNDERS, B., KITZINGER, J. & KITZINGER, C. 2015. Anonymising interview data: challenges and compromise in practice. *Qualitative Research,* 15**,** 616-632.

SCHNEIDER, C. Q. & WAGEMANN, C. 2012. *Set-theoretic methods for the social sciences: A guide to qualitative comparative analysis*, Cambridge University Press.

SCOTTISH EXECUTIVE 2005. Prevention of Environmental Pollution From Agricultural Activity: A code of good practice. Edinburgh: Scottish Executive.

SCOTTISH GOVERNMENT. 2019. *Scottish Rural Development Programme: Rural Payments and Services* [Online]. Edinburgh Scottish Government Available: https://www.ruralpayments.org/publicsite/futures/topics/all-schemes/agri-environment-climate-scheme/ [Accessed 10/05 2020].

SEPA 2015. *Diffuse Pollution* [Online]. Scottish Environment Protection Agency. Available: http://www.sepa.org.uk/water/diffuse_pollution.aspx [Accessed].

SIEBER, S. D. 1973. The integration of fieldwork and survey methods. . *American Journal of Sociology,* 73**,** 1335-1359.

SMITH, L., PORTER, K., HISCOCK, K., PORTER, M. J. & BENSON, D. 2015. *Catchment and River Basin Management: Integrating Science and Governance. ,* London, Earthscan.

STOATE, C., JONES, S., CROTTY, F., MORRIS, C. & SEYMOUR, S. 2019. Participatory research approaches to integrating scientific and farmer knowledge of soil to meet multiple objectives in the English East Midlands. *Soil Use and Management,* 35**,** 150-159.

STRAUSS, A. & CORBIN, J. 1998. Basics of qualitative research: techniques and procedures for developing grounded theory. Sage Publications. *Thousand Oaks, CA*.

TERMEER, C. J. & DEWULF, A. 2019. A small wins framework to overcome the evaluation paradox of governing wicked problems. *Policy and Society,* 38**,** 298-314.

THE SCOTTISH GOVERNMENT. 2016. *Scotland's Place in Europe* [Online]. Available: http://www.gov.scot/Resource/0051/00512073.pdf [Accessed].

TRESS, G., TRESS, B. & FRY, G. 2005. Clarifying Integrative Research Concepts in Landscape Ecology. *Landscape Ecology,* 20**,** 479-493.

UNITED NATIONS 2016. Global Sustainable Development Report 2016. New York, US: Department of Economic and Social Affairs.

UNITED NATIONS ENVIRONMENT PROGRAMME 2017. Towards a pollution free planet background report. . Nairobi, Kenya: United Nations Environment Programme.

UNITED NATIONS WORLD WATER ASSESSMENT PROGRAMME 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris United Nations Educational, Scientific and Cultural Organization.

UNITED UTILITIES 2015. Boil water notice now lifted for all of Lancashire. . Warrington.: United Utilities

VRAIN, E. 2015. *'Factors Influencing Farmer Uptake of Water Pollution Mitigation Measures: The Role of Farm Advice'.* PhD, University of East Anglia

VRAIN, E. & LOVETT, A. 2016. The roles of farm advisors in the uptake of measures for the mitigation of diffuse water pollution. *Land Use Policy,* 54**,** 413-422.

VRAIN, E., LOVETT, A., NOBLE, L., GRANT, F., BLUNDELL, P. & CLEASBY, W. 2014. FARMER ATTITUDES TOWARDS DIFFUSE POLLUTION MITIGATION MEASURES IN ENGLAND. Department for Environment, Food & Rural Affairs.

WELSH GOVERNMENT. 2017a. *Securing Wales' Future: Transition from the European Union to a new relationship with Europe* [Online]. Available: https://beta.gov.wales/sites/default/files/201701/30683 Securing Wales1 Future_ENGLISH_WEB.pdf [Accessed].

WELSH GOVERNMENT 2017b. The Welsh Government Rural Communities – Rural Development Programme for Wales 2014-2020: Glastir Advanced 2019 Rules Booklet 1. . Westminster Welsh Government

WHEELER, C. 2018. *Farmers and conservation in Post-Brexit Britain; perceptions among the farming community on a changing subsidy regime and implications for on- farm conservation.* University of Oxford.

WHITE, P. J. & HAMMOND, J. P. 2009. The sources of phosphorus in the waters of Great Britain. *Journal of Environmental Quality* 13–26.

WINFIELD, M. S. & BENEVIDES, H. 2003. A Review of US Approaches to Integrated Watershed Management and Their Applicability in the Ontario Region. Calgary, AB, Canada: Pembina Institute for Appropriate Development, Environment Canada Contract.

ZEWELD, W., VAN HUYLENBROECK, G., TESFAY, G. & SPEELMAN, S. 2017. Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *Journal of Environmental Management,* 187**,** 71-81.

Chapter 2

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.

2.1 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 from agriculture (DWPA) 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 DWPA, 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, 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.

2.2 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[2] 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

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

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.

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).

2.3. Materials and methods

2.3.1 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 2.1). 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 2.1). 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 2.1: 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.

2.3.1.1 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. This raises concerns about the extent to which the data represents the true situation on the ground and may be reflected in estimation errors (Kormos and Gifford, 2014). However, high estimation errors were not observed in the present study as model evaluations indicated a satisfactory or good fit. Moreover, chapters 5 and 6 address these data gaps by providing further qualitative data on depth of awareness, experiential learning, and contextual factors that influence farmers' decisions and adoption of best management practices (BMPs).

2.3.1.2 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[3] (Burton and Schwarz, 2013, Scott Wilson Scotland Ltd, 2009). Information on participation in agri-environmental schemes was

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

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.

2.3.1.3 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 identify where on the farm nutrients are building up or being depleted which can allow management decisions to be made to reduce the surplus and thus potential for loss to water courses and/or the atmosphere (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 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. Such information is important as this could help us explore the potential role of experiential learning in farmers' adoption of best management practices (Science for Environment Policy, 2017, Kolb and Kolb, 2012)". Chapter 5 addresses this gap by providing further

quantitative and qualitative data on these variables and how they influence farmers'
decisions and practices.

2.3.1.4 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 like the other variables as indicated above.

2.3.1.5 Compliance with GBRs

The database contained compliance data for the 22 specific GBRs that apply to
agricultural activities (see Appendix A1). 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 A1, 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 contextual information is lacking. 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 out land management practices by themselves, have been shown 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. Therefore, analysing the awareness-behaviour link without including these contextual

factors in our model limits our ability to fully understand how such complex factors interact to influence farmers' decisions and adoption of best management practices.

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 an 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 policy responses to improve uptake of such mitigation measures at the catchment, regional or national scale.

Baseline Priority catchments

RBMP cycle

2015 **14 catchments**

2021 **32 catchments**

Surface waterbody catchments impacted by diffuse pollution

2015 **108 WB catchments**

2021 **166 catchments**

1:2,811,955

0 12.5 25   50 Kilometres

0   15   30   60 Miles

©2006 Scottish Environment Protection Agency. Some features of this map are based on digital spatial data licenced from the Centre for Ecology and Hydrology, ©CEH. Includes material based upon Ordnance Survey mapping with permission of H.M. Stationery Office, ©Crown Copyright. Licence number 100020538.

Helpdesk ref: N/A. Produced: 16/06/2009

Priority baseline catchments as of August 25. 2009

SEPA
Scottish Environment
Protection Agency

Figure 2.1: Priority Catchments in Scotland for the First cycle and proposed catchments
Source: SEPA (DPMAG, 2015)

2.3.2. 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 in 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 A2i). 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 A2i). 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.

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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 A3 for the details on each of the specific catchments included in each of the clusters).

2.4. Results

2.4.1. Overview of farmers' responses

Table 2.2 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 A2ii for responses by farm type and location.

Table 2.2: 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.

2.4.2 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 2.2) 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 (χ2 (n = 1564, df = 1) = 1, p>0.05; CFI = 1.000; RMSEA=0.000; SRMR = 0.000). The results in Table 2.3 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 , 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 2., Model 3, see also Figure 2.4). Specifically, we found that this mediated relationship between awareness and compliance exists in mixed-farms (p<0.01; p<0.05, for awareness -agri-environment schemes and agri-environment 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).
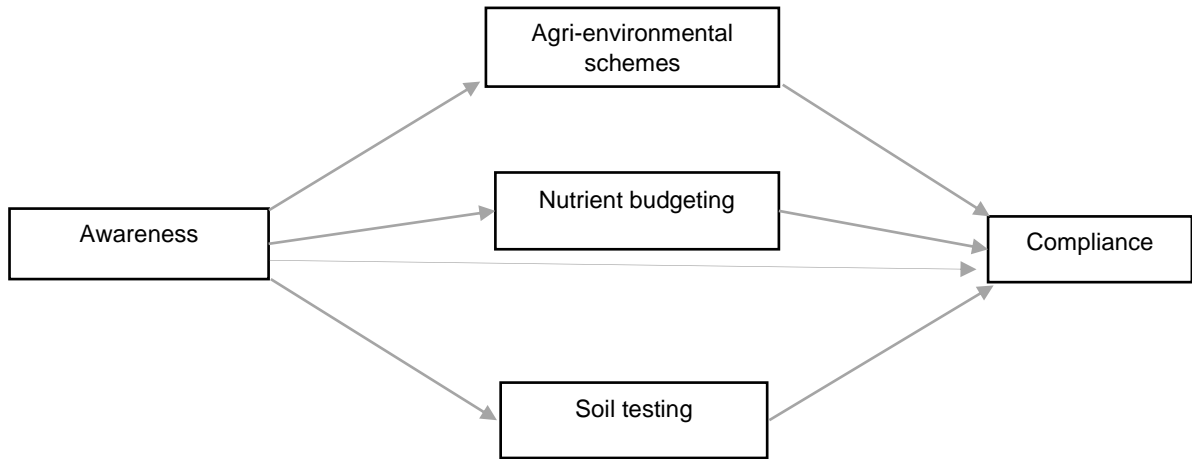
Note: All paths indicate a hypothesized positive relationship

Figure 2.2: Initial proposed model testing multiple mediation (Model 1)
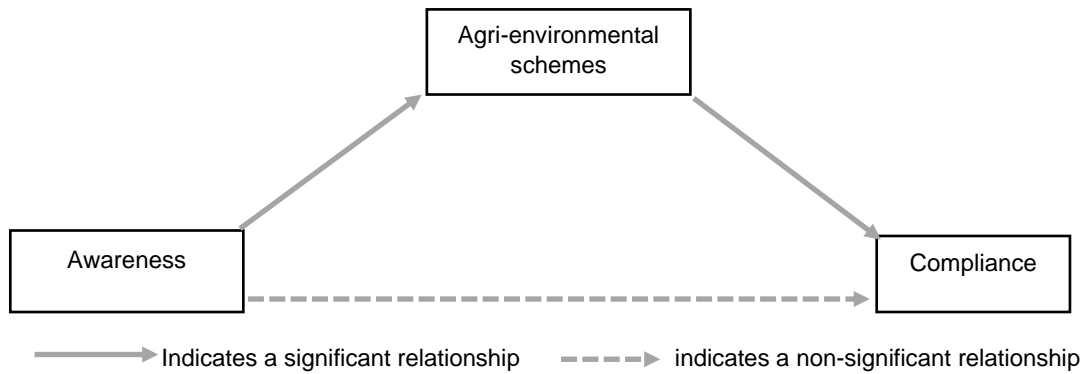
Note: All significant paths are positive relationships

Figure 2.3: Model after testing for mediation (Model 2)

Note: All significant paths are positive relationships

Indicates a non-significant relationship   indicates a significant relationship

Figure 2.4: Final model after testing for moderation (Model 3)

Table 2.3: 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 2.4: 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

2.5. 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 A2ii) 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 2.3). 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.

2.6. 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.

References

ADAS, 2008. Initial evaluation of effectiveness of measures to mitigate diffuse rural pollution. Report produced for Scottish Government under project ADA/011/07.
http://www.scotland.gov.uk/Resource/Doc/256611/0076192.pdf
[Accessed 21/03/2017].

BAEK, T.H., & YOON, S. 2017. Guilt and Shame: Environmental Message Framing Effects. J Advertising, 46(3), 440–453.

BAMBERG, S., & MOSER, G. 2007. Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. J Environ Psychol. 27, 14–25.

BANDURA, A., 1977. Social Learning Theory. Englewood Cliffs, New Jersey.

BARNES, A.P., WILLOCK, J., HALL, C., & TOMA, L., 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. Agr. Water. Manage. 96(1), 1715–1722.

BARREIRO-HURLÉ, J., ESPINOSA-GODED, M., & DUPRAZ, P. 2010. Does intensity of change matter? Factors affecting adoption of agri-environmental schemes in Spain. J. Environ. Plan. Manag. 53(7), 891-905.

BARRETT, P., 2007. Structural equation modelling: adjudging model fit. Pers. Indiv. Differ. 42, 815-824.

BIERHOFF, H.W. 2002. Pro-social behaviour. Psychology Press, Hove.

BLACKSTOCK, K.L., INGRAM, J., BURTON, R., BROWN, K.M., & SLEE, B., 2010. Understanding and influencing behaviour change by farmers to improve water quality. Sci. Total Environ. 408(1), 5631–8.

BOESCH, D.F., BRINSFIELD, R.B., & MAGNIEN, R.E., 2001. Chesapeake phosphorus, soluble phosphorus and phosphorus saturation in Del- Bay eutrophication: Scientific understanding, ecosystem restoration, and challenges for agriculture. J. Environ. Qual. 30, 303–320.

BOIRAL, O. 2002. Tacit Knowledge and Environmental Management. Long Range Plan. 35, 291-317.

BROUWER, F., 1998. Nitrogen balances at farm level as a tool to monitor effects of agri-environmental policy. Nutrient Cycling Agroecosyst. 52, 303–308.

BROWN, T.A., 2006. Confirmatory Factor Analysis for Applied Research, The Guildford Press, New York and London.

BURTON, R.J.F., & SCHWARZ, G. 2013. Result-oriented agri-environmental schemes in Europe and their potential for promoting behavioural change. Land Use Policy, 30, 628–641.

CAPITANIO, F., ADINOLFI, F., & MALORGIO, G. 2011. What explains farmers' participation in Rural Development Policy in Italian southern region? An empirical analysis. New Medit. 10(4), 19-24.

CHRISTEN, B., KJELDSEN, C., DALGAARD, T., & MARTIN-ORTEGA, J. 2015. Can fuzzy cognitive mapping help in agricultural policy design and communication? Land Use Policy. 45(42), 64–75.

DEASY, C., QUINTON, J.N., SILGRAM, M., BAILEY, A.P., JACKSON, B., & STEVENS, C.J., 2010. Contributing understanding of mitigation options for phosphorus and sediment to a review of the efficacy of contemporary agricultural stewardship measures. Agr. Syst. 103(1), 105–109.

DEFRANCESCO, E., GATTO, P., RUNGE, F., & TRESTINI, S. 2008. Factors affecting farmers' participation in agri-environmental measures: A northern Italian perspective. J. Agric. Econ. 59(1), 114-131.

DPMAG. 2015. Strategy to reduce diffuse pollution. http://www.sepa.org.uk/environment/water/river-basin-management-planning/who-is-involved-with-rbmp/dpmag/ [Accessed 22/05/2016].

DUCKETT. D., FELICIANO, D., MARTIN-ORTEGA, J., & MUNOZ-ROJAS, J., 2016. Tackling wicked environmental problems: The discourse and its influence on practice in Scotland. Landscape Urban Plan. 154, 44-56.

DUPRAZ, P., VERMERSCH, D., HENRY DE FRAHAN, B. & DELVAUX, L. 2003. The Environmental Supply of Farm Households. Environ Resour Econ. 25, 171-189

DWYER, J., MILLS, J., INGRAM, J., TAYLOR, J., BURTON, R., BLACKSTOCK, K.L., SLEE, B., BROWN, K.M., SCHWARZ, G., MATTHEWS, K.B., & DILLEY, R.., 2007. Understanding and influencing positive behaviour change in farmers and land managers. Project for DEFRA, CCRI and Macaulay Institute.

ENVIRONMENT AGENCY, 2014. Catchment Sensitive Farming: A clear solution for farmers. Phase 3 Delivery Report (April 2011 - March 2014). http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwiNocOl5dvNAhXrB8AKHY0SDJwQFggvMAI&url=http%3A%2F%2Fpublications.naturalengland.org.uk%2Ffile%2F5712596156022784&usg=AFQjCNG8IAIsXpRRduNjPLjSU73PcdT6JA&bvm=bv.126130881,d.ZGg

ENVIRONMENT AGENCY, 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report, TCM6-27149. [Accessed 21/05/2016] . http://publications.naturalengland.org.uk/publication/5329340644458496

ESPINOSA-GODED, M., BARREIRO-HURLE´, J., & RUTO, E. 2010. What Do Farmers Want From Agri-Environmental Scheme Design? A Choice Experiment Approach. . J Agr Econ. 61(2), 259–273.

FLORESS, K., S. GARCÍA DE JALÓN, S. P. CHURCH, N. BABIN, J. D. ULRICH-SCHAD, PROKOPY L. S., 2017. Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality. J Environ Psychol. 53, pp.73-80.

GARSON, G.D., 2015. Structural Equation Modelling, Statistical Associates Publishers, Asheboro, NC.

GOBSTER, P. H., FLORESS, K., WESTPHAL, L. M., WATKINS, C. A., VINING, J., & WALI, A., 2016. Resident and user support for urban natural areas restoration practices. Biol Conserv. 203, 216-225.

GUAGNANO, G. A. 2001. Altruism and market-like behavior: An analysis of willingness to pay for recycled products. Popul Environ. 22, 425-438

HAYES, A.F., 2012. PROCESS: A versatile computational tool for observed variable mediation, moderation, and conditional process modelling [White paper].

HAYES, A.F., 2013. Introduction to mediation, moderation and conditional process analysis, The Guildford Press, New York and London.

HINES, J.M., HUNGERFORD, H.R., & TOMERA, A.N., 1986. Analysis and synthesis of research on responsible environmental behaviour: a meta-analysis. J. Environ. Educ. 18(2), 1–8.

HOOPER, D., COUGHLAN, J., & MULLEN, M.R., 2008. Structural Equation Modelling: Guidelines for Determining Model Fit. J. Bus. Res. 6(1), 53-60.

HOVLAND, C., JANIS, I., & KELLEY, H., 1953. Communication and Persuasion: Psychological Studies of Opinion Change, Yale University Press, New Haven, CT.

HU, L., & BENTLER, P.M., 1999. Cutoff Criteria for Fit Indexes in Covariance Structure Analysis: Conventional Criteria versus New Alternatives. Struct. Equ. Modeling, 6(1), 1-55.

JACKMAN, M., 1973. Education and Prejudice or Education and Response-Set? Am. Sociol. Rev. 38(3), 327-339.

JACKSON, T., 2005. Motivating Sustainable Consumption. A review of evidence on consumer behaviour and behavioural change. A report to the Sustainable Development Research Network. Centre for Environmental Strategy, University of Surrey, Guildford. http://www.sustainablelifestyles.ac.uk/sites/default/files/motivating_sc_final.pdf [Accessed 20/05/2016].

JAVELINE, D., 1999. Response effects in polite cultures: A test of acquiescence in Kazakhstan. Public Opin. Quart. 63, 1–28.

KAY, P., EDWARDS, A.C., & FOULGER, M., 2009. A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. Agr Syst. 99(2), 67–75.

KAY, P., GRAYSON, R., PHILLIPS, M., STANLEY, K., DODSWORTH, A., HANSON, A., WALKER, A., FOULGER, M., MCDONNELL, I., & TAYLOR, S., 2012. The effectiveness of agricultural stewardship for improving water quality at the catchment scale: experiences from an NVZ and ECSFDI watershed. J. Hydrol. 422, 10-16.

KLINE, R.B., 2011. Principles and Practice of Structural Equation Modelling, third ed. The Guilford Press, New York.

KOLB, A.Y., & KOLB D.A. 2012. Experiential Learning Theory. In: Seel N.M. (eds) Encyclopedia of the Sciences of Learning. Springer, Boston, MA

KOLLMUSS, A., & AGYEMAN, J., 2002. Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behaviour? Environ. Educ. Res. 8(3), 239-260.

LASTRA-BRAVO, X.B., HUBBARD, C., GARROD, G., & TOLON-BECERRA, A., 2015. What drives farmers' participation in EU agri-environmental schemes? Results from a qualitative meta-analysis. Environ. Sci. Policy. 54, 1-9.

LOBLEY, M., SARATSI, E., WINTER, M., & BULLOCK, J., 2013. Training farmers in agri-environmental management: the case of Environmental Stewardship in lowland England. International Journal of Agricultural Management, 3(1), 12-20.

MACGREGOR, C.J., & WARREN, C.R., 2006. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. Agr. Ecosyst. Environ. 113, 108-119.

MAGUIRE, R. O., & SIMS, J. T., 2002. Soil Testing to Predict Phosphorus Leaching Published as Paper no. 1710 in the journal series of the Delaware Agricultural Experiment Station. J. Environ. Qual. 31, 1601-1609.

MILLS, J., GASKELL, P., INGRAM, J., DWYER, J., REED, M., & SHORT, C., 2017. Engaging farmers in environmental management through a better understanding of behaviour. Agric Hum Values, 34 (2), 283–299.

MARTIN-ORTEGA, J., & HOLSTEAD, K.L., 2013. Improving Implementation and Increasing Uptake of Measures to Improve Water Quality in Scotland. The

James Hutton Institute, Aberdeen. http://www.hutton.ac.uk/research/themes/managing-catchments-and-coasts/guidance-to-improve-water-quality [Accessed 11/04/2016].

MORRIS, J., MILLS, J. & CRAWFORD, I. 2000. Promoting farmer uptake of agri-environment schemes: the Countryside Stewardship Arable Options Scheme. *Land Use Policy* 17**,** 241-254.

NOVO, P., MARTIN-ORTEGA, J., & HOLSTEAD, K., 2015. Making mitigation of rural diffuse pollution work: facts and gaps regarding stakeholder's views and perceptions*.* XVth IWRA World Water Congress. Edinburgh, 25 – 29 of May 2015.

NOVOTNY, V., 1999. Diffuse pollution from agriculture — A worldwide outlook. *Water Sci. Technol.* 39(3), 1-13.

NOVOTNY, V., 2003. Water Quality: Diffuse pollution and watershed management. Second ed. John Wiley and Sons Inc., New York.

OECD. 2012. Water quality and agriculture: meeting the policy challenge*.* OECD Studies on Water. Organisation for Economic Co-operation and Development, Paris. https://www.oecd.org/tad/sustainable-agriculture/49849932.pdf [Accessed 20/06/2016].

OECD 2017. Diffuse Pollution, Degraded Waters: Emerging Policy Solutions. Organisation for Economic Co-operation and Development, Paris.

OENEMA, O., KROS, H., & DE VRIES, W., 2003. Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. Eur. J. Agron. 20, 3–16.

PATTERSON, J. J., SMITH, C., & BELLAMY, J., 2013. Understanding enabling capacities for managing the 'wicked problem' of nonpoint source water pollution in catchments: A conceptual framework. J. Environ. Manage. 128(1), 441-452.

PIKE, T. 2008. Understanding behaviours in a farming context: Bringing theoretical and applied evidence together from across Defra and highlighting policy relevance and implications for future research*.* Defra Agricultural Change and Environment Observatory Discussion Paper, November 2008. http://webarchive.nationalarchives.gov.uk/20130123162956/http:/www.defra.gov.uk/statistics/files/defra-stats-foodfarm-environ-obs-research-behavious-aceopaper-nov08.pdf [Accessed 20/05/2016].

SATTLER, C., & NAGEL, U. J. 2010. Factors affecting farmers' acceptance of conservation measures-A case study from north-eastern Germany. Land Use Policy, 27(1), 70-77

SCHUMAN, H., & PRESSER, S., 1981. Questions and Answers in Attitude Surveys, Academic Press, New York.

SCIENCE FOR ENVIRONMENT POLICY, 2017. Agri-environmental schemes: how to enhance the agriculture-environment relationship. Thematic Issue 57. Issue produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol. http://ec.europa.eu/science-environmentpolicy [Accessed 12,12/2017].

SCOTT WILSON SCOTLAND LTD, 2009. Monitoring & Evaluation of Agri-environment Schemes. Report produced for Scottish Government under project ADA/011/07. http://www.scotland.gov.uk/Resource/Doc/256611/0076192.pdf [Accessed 21/05/2017].

SEPA, 2014. Diffuse Pollution Management Advisory Group. Scottish Environmental Protection Agency (SEPA) http://www.sepa.org.uk/water/riverbasinplanning/diffusepollutionmag.aspx [Accessed 28/04/2016].

SEPA, 2013. Water Regulation Regimes: Diffuse Pollution. Scottish Environment Protection Agency (SEPA) http://www.sepa.org.uk/water/waterregulation/regimes/pollutioncontrol/diffuse pollution.aspx [Accessed 26/04/2016].

SKINNER, J.A., LEWIS, K.A., BARDON, K.S., TUCKER, P., CATT, J.A., & CHAMBERS, B.J., 1997. An overview of the environmental impact of agriculture in the UK. J. Environ. Manage. 50(2), 111–128.

SMALLSHIRE, D., ROBERTSON, P. & THOMPSON, P. 2004. Policy into practice: the development and delivery of agri-environment schemes and supporting advice in England. Ibis, 146, 250–25.

TSOUVALIS, J., SEYMOUR, S. & WATKINS, C. 2000. Exploring knowledge-cultures: precision farming, yield mapping, and the expert - farmer interface. Environ Plann A. 32, 909–924.

UNEP. 2016. A snapshot of the world's water quality: towards a global assessment, United Nations Environment Programme (UNEP), Nairobi.

UNITED NATIONS, 2016. Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators. 47th Session of the United Nations Statistical Commission, UN, New York. https://unstats.un.org/unsd/statcom/47th-session/documents/2016-2-IAEG-SDGs-E.pdf [Accessed 20/03/2017].

VRAIN, E., LOVETT, A., NOBLE, L., GRANT, F., BLUNDELL, P., & CLESBY, W., 2014. Farmer attitudes towards diffuse pollution mitigation measures in England: A Demonstration Test Catchments Report. Report for Defra. http://www.wensumalliance.org.uk/research_reports/Farmer_Attitudes_December_14_%20Final.pdf [Accessed 20/03/2016].

VRAIN, E., & LOVETT, A.A., 2016. The roles of farm advisors in the uptake of measures for the mitigation of diffuse water pollution. Land Use Policy, 54, 413–422.

WILSON, G.A., 1997. Factors influencing farmer participation in the Environmentally Sensitive Areas Scheme. J. Environ. Manage. 50(1), 67-93.

WILSON, G. A. & HART, K. 2001. Farmer Participation in Agri-environmental Schemes: Towards Conservation-Oriented Thinking? Sociol Ruralis, 41, 254–274.

WWAP. 2013. The United Nations World Water Development Report 2013, United Nations World Water Assessment Programme (WWAP), United Nations Educational, Scientific and Cultural Organization, Paris.

WYNN, G., CRABTREE, B. & POTTS, J. 2001. Modelling farmer entry into the environmentally sensitive area schemes in Scotland. J Agr Econ. 52, 65-82.

WYNVEEN, C.J. & SUTTON, S. G. 2017. Engaging Great Barrier Reef Stakeholders: Mediation Analyses of Barriers among the Antecedents of Pro-Environmental Behaviour. Human Dimensions of Wildlife, 22(2), 126-141.

Chapter 3

Revisiting the determinants of pro-environmental behaviour to inform land management policy: A meta-analytic structural equation model application

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Abstract

Environmental policies in the realm of land management are increasingly focussing on inducing behavioural change to improve environmental management outcomes. This is based, implicitly or explicitly, on theories that suggest that pro-environmental behaviour can be understood, predicted and altered based on certain factors (referred to as determinants of pro-environmental behaviour). However, studies examining the determinants of pro-environmental behaviour have found mixed evidence. It is therefore important that we revisit these theories to assess if the evidence supports their postulations so that a more robust knowledge base can be established to inform land management policies. In this study, we do this using meta-analytic structural equation modelling (MASEM) to explore whether the evidence on determinants of pro-environmental behaviour supports the postulations of some predominantly applied theories of behaviour and/or behaviour change. The study analyses research in four environmental policy areas to identify implications for land management. Evidence from these related environmental areas is expected to provide insights relevant to the land management literature and to allow us to identify the extent to which lessons on pro-environmental behaviour from these other areas can be transferred to the land management context. Our findings suggest a strong evidence base for the Theories of Planned Behaviour and Reasoned Action, Attitude-Behaviour-Context Model, and

the Persuasion Theory, but a weak evidence base for the Value-Belief-Norm Theory and the Norm Activation Model. We also found that type of environmental policy area moderates the relationship between different variables. This has key policy implications since, while lessons can be learnt from other environmental policy areas, land management policies aimed at influencing behaviours will need to be tailored to the specific context rather than simply 'imported' from other fields. Such context-specific policies may encourage pro-environmental behaviours, and potentially contribute towards improving environmental management outcomes.

3.1. Introduction

Policies across the environmental sector are increasingly focussing their attention on behavioural change as a means to improve environmental performance (Chen et al., 2016, Jakovcevic and Steg, 2013). Behaviour focussed approaches are particularly prominent in the realm of land management, where policies are increasingly aiming to influence uptake of best management practices by land managers to improve water quality, soil and human health and prevent further biodiversity loss (Kesternich et al., 2017, Blackstock et al., 2010, Prager, 2012, Vrain and Lovett, 2016, Vrain et al., 2014). Examples of these policies include the National Landcare Programme established in Australia in 1988 (Lockie and Higgins, 2007), the Water Quality Scheme and the Environmental Quality Incentive Programme in the United States of America in 1997, the Monitor Farms Programme established in 1991 in New Zealand (Dwyer et al., 2007), the Catchment Sensitive Farming Delivery Initiative started in 2005 in England (Environment Agency, 2011, Environment Agency, 2014) and the Diffuse Pollution

Management Strategy established in 2009 in Scotland (DPMAG, 2015). These policies acknowledge the role of a wide range of factors in understanding and influencing land managers' behaviours (Blackstock et al., 2010, Dwyer et al., 2007, Okumah et al., 2018, Okumah et al., 2019a, Okumah et al., 2019c). For instance, they place emphasis on land managers' awareness and attitudes under the expectation that this may encourage pro-environmental practices (Baumgart-Getz et al., 2012).

Despite the increasing popularization of such policies, studies examining the determinants of pro-environmental behaviour in land management have found mixed evidence on their impact (e.g., Macgregor and Warren, 2006, Barnes et al., 2009, Inman et al., 2018). Arguments have been made regarding the limitations of the behavioural theories that (implicitly or explicitly) underpin these policies. For instance, the assumption that awareness of best management practices (BMPs) results in pro-environmental behaviour has been criticised for being deterministic as this may not apply in every situation (Dwyer et al., 2007, Baumgart-Getz et al., 2012, Okumah and Ankomah-Hackman, 2020, Okumah et al., 2020a).

While these concerns are relevant and could help provide answers that may trigger new policy directions (Jackson, 2005), there have been very few studies establishing whether existing evidence supports the postulations of the behavioural theories underpinning land management policies (i.e., policies guiding land use and management). One known study that attempts to establish this is the work of Bamberg and Moser (Bamberg and Möser, 2007). However, while their study draws evidence from papers that rely on the Theory of Planned Behaviour and the Norm Activation Model, they do not test whether these theories were supported by the evidence or not; they tested a proposed integrative model of pro-environmental behaviour. While such

an integrative approach provides a comprehensive understanding of the determinants of pro-environmental behaviour and behavioural change, it does not provide evidence specific to the theories. Additionally, although they acknowledged the potential influence of moderating factors, their study did not explore such factors. This study aims to establish whether the existing empirical evidence supports the predictions of (five) key theories of pro-environmental behaviour, with the particular purpose to improve the information base for land management policy. To do this, we use meta-analytic structural equation modelling (MASEM). The study analyses research in four environmental policy areas to identify implications for land management. Evidence from these related environmental areas is expected to provide insights relevant to the land management literature and to allow us to identify the extent to which lessons on pro-environmental behaviour from these other areas can be transferred to the land management context. We use the term "land management policies" to refer to policies that guide land related activities such as farming, forestry and woodland management. "Environmental management policies" on the other hand refer to policies that regulate all activities (such as recycling, farming etc.) that could impact any aspects of the environment.

This work advances the literature in various ways. Firstly, unlike earlier meta-analytic reviews in the land management field that look only at the individual contributions of awareness, attitudes and situational factors (e.g. Baumgart-Getz et al., 2012), this study covers the joint contributions of a larger range of variables (e.g., subjective norms, ascription of responsibility). MASEM allows us to test the mechanisms through which these different variables affect each other (i.e. it considers their mediated relationships) via correlations and multiple regressions (Cheung and Hong, 2017). Moreover, the evidence base that we explore goes beyond that of land management

only, including other environmental sectors (e.g., recycling) as well as general ecological behaviours more broadly.

3.2. Theoretical basis

In this section, we provide an overview of the five main behaviour theories; Persuasion Theory (Hovland et al., 1953, Petty and Cacioppo, 1986), Theories of Reasoned Action and Planned Behaviour (Ajzen and Fishbein, 1980, Ajzen, 1991), The Norm-Activation Model (Schwartz, 1968, Schwartz, 1970), the Value-Belief Norm Theory (Stern et al., 1999, Stern and Dietz, 1994, Stern, 2000, Stern et al., 1985), and the Attitude-Behaviour-Context (ABC) Model (Stern, 2000)[4].

These theoretical frameworks cite environmental, personal, and behavioural characteristics as the major factors in behaviour determination and are frequently applied by researchers trying to understand and explain pro-environmental behavior (Bamberg and Möser, 2007, Michie et al., 2008, Okumah et al., 2019c, Daxini et al., 2019a). In Figure 3.1, we present a theoretical framework that joins the various paths (e.g. knowledge-awareness link, awareness-behaviour link, knowledge-behaviour link) postulated in these theories. We use letters to represent the different pathways (e.g. knowledge-awareness link, awareness-behaviour link, knowledge-behaviour link) hypothesized in each of the theories. Therefore, the link between variables also show which determinants are related to the different theories.

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[4] The Social learning theory has also been applied to understand individual and group pro-environmental behaviours related to networking and the development of tacit knowledge BOIRAL, O. 2002. Tacit knowledge and environmental management. *Long Range Planning,* 35**,** 291-317. This theory regards behavioural change as a learning process where the individual moulds his/her behaviour by observing and learning from their environment mainly through interactions and personal communication BANDURA, A. 1977. *Social Learning Theory,* Englewood Cliffs, New Jersey, Prentice H. This theory was not tested in the present study due to a lack of data for variables that explicitly measure experiential learning and how knowledge is acquired through networking.

3.2.1. Persuasion Theory

Persuasion Theory is one of the simplest models of behaviour, built on the idea of linear progression. Proponents of this model reasoned that behaviour change is realised through the provision of required information to the targeted actors (Hovland et al., 1953). It is argued that effective persuasion is contingent on three key elements, namely: the credibility or trustworthiness of the speaker (the source), power of the argument (the message) and the receptiveness of the audience (the recipient) (Hovland et al., 1953). In the context of environmental problems, the model assumes that the actors' current behaviour is due to some lack of awareness/knowledge regarding the right strategies to mitigate environmental problems, consequently, this model has more recently been termed 'information deficit model' (Kollmuss and Agyeman, 2002). It is also assumed that attitude and behavioural change can only happen when individuals access the required information and assimilate it. Based on these assumptions, the model prescribes information provision as the solution, contending that information provision results in awareness, which in turn leads to a change in attitude and behaviour.

The model has been criticized for being deterministic and simplistic as it assumes that information provision is a guarantee for realising the desired behavior (Kollmuss and Agyeman, 2002, Jackson, 2005). This deterministic view (if one becomes aware, one behaves desirably), overlooks the role of other multiple intervening factors (e.g. economic, cultural, social pressure) that determine outcomes of interventions, amidst information provision (Jackson, 2005, Steg and Vlek, 2009, Okumah and Yeboah, 2019, Okumah et al., 2020b). Behaviour and behaviour change are complex, therefore a strategy based only on 'information provision' will struggle to induce behavioural change. The linear perspective of the model is also problematic. Though the

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information-attitude-behaviour pathway appears reasonable, individuals can learn without necessarily assimilating the 'persuasive message', and behavioural change can occur without attitudinal influences (Petty and Cacioppo, 1986).

Despite its flaws, the model has made contributions in influencing pro-environmental behaviours since its key elements are still relevant in behaviour, particularly for land manager behaviour. For example, research shows that for farmers the source of information (e.g. the farm advisor) and the persuasiveness of the message are indeed crucial (albeit not necessarily sufficient) in influencing whether the farmer acts upon the advice, particularly where the message is consistent, well-placed and positive (Juntti and Potter, 2002, Vrain and Lovett, 2016). Using MASEM, Bamberg and Moser (Bamberg and Möser, 2007) showed that awareness affects attitudes towards pro-environmental behaviours, and this in turn affect behaviours (through intentions to act).

3.2.2. Theory of Reasoned Action (TRA) and the Theory of Planned Behaviour (TPB)
Proponents of the TRA reason that two factors directly affect people's intentions to act: attitude and subjective norms (referred to as an individual's perception regarding whether people who are important to him or her think if he should perform or not perform the behaviour at hand) and these in turn leads to the performance of the behaviour in question (Ajzen and Fishbein, 1980). Closely related to the TRA is the TPB, which integrates the actor's perceived control over the behaviour (Ajzen, 1991). TPB looks at 'intentions to behave', and not necessarily actual actions of individuals, and argues that attitudes, subjective norms and perceived behavioural control affect intentions to act and these in turn predict behaviour.

Proponents of these theories acknowledge that the link between belief and behaviour is not straightforward; there are other elements that influence the relationship between

the two. However, these models fail to provide clear understanding on the cognitive, normative and affective facets of human behaviour (Jackson, 2005). Additionally, even a positive intention does not necessarily result in pro-environmental behaviour as this depends on situational factors such as financial ability, time, and available resources, among others (Kollmuss and Agyeman, 2002). These complex factors make it difficult to predict behaviours relying solely on intentions. However, Bamberg and Moser (Bamberg and Möser, 2007) found strong evidence in support of this model, after their MASEM revealed that indeed attitudes, perceived behavioural control and subjective norms predicted intentions, and intentions in turn predicted behaviours.

3.2.3. Norm-Activation Model

This model was developed to help explain the determinants of moral behaviours: pro-social and altruistic behaviours among people. It is premised on the idea that awareness of the consequences of one's behaviour and ascription of responsibility to self are the main factors that determine personal norm, and this in turn determines whether individuals behave altruistically or not (Schwartz, 1977, Schwartz, 1970). Personal norms, i.e. feelings of moral obligations to carry out specific behaviours, are therefore viewed as direct antecedents of prosocial behaviours and Schwartz rejects the idea of intentions mediating the relationship between personal norm and behaviour. He argues that when people are aware of the consequences of (or not) engaging in specific prosocial behaviours and also ascribe such responsibilities to themselves, they are more likely to act positively. This is probably because personal norms serve as a benchmark for what an individual considers to be proper or improper and may in turn govern the person's behaviour. Subsequently, it is hypothesised that awareness of consequences and ascription of responsibility are not just viewed as fundamental independent variables, but also, moderators of the relationship between

personal norm and behavior (Jackson, 2005). This model however fails to provide insights into how personal norms are derived from the larger social fabric and how socially established measures could drive personal norms and behaviours.

3.2.4. Value-Belief-Norm Theory

The Value-Belief-Norm Theory was proposed as an attempt to modify the Norm Activation Model to reflect the complex connection between values, beliefs, attitudes and norms (Stern et al., 1999, Stern and Dietz, 1994, Stern, 2000). This theory suggests that values affect beliefs and this in turn affects personal norms, a direct antecedent of pro-environmental behaviour. In this model, Stern argues that endorsement of the new environmental paradigm (NEP) directly predicts awareness of consequences and the extent to which an individual accepts the NEP may reflect a high level of environmental value (Stern et al., 1999, Stern and Dietz, 1994, Stern, 2000, Stern et al., 1985). Subsequently, three major categories of pro-environmental behaviours are identified: environmental citizenship, support for policy and private sphere behaviours.

The Value-Belief-Norm Theory has made a substantial contribution in understanding environmental behaviour particularly in understanding the key role of values, beliefs and norms in environmentally significant behaviours. Nonetheless, this theory has a major limitation as it overlooks the role of situational factors in actual behaviours (Jackson, 2005). The influence of situational factors (e.g. institutional support or constraint, availability or lack of facilities) in behaviour is key and perhaps explains why values explained less than 35% of variance in general environmental behaviour (and less than 20% in private sphere behaviours) in Stern et al.'s study (Stern et al., 1999). Aside from situational factors, it is also possible that environmental values and

beliefs may perform better as moderators as opposed to mediators or direct independent variables in explaining behavior (Floress et al., 2017b, Okumah and Ankomah-Hackman, 2020, Okumah et al., 2018, Okumah et al., 2019a, Martin-Ortega et al., 2017).

3.2.5. Attitude-Behaviour-Context Theory

The Attitude-Behaviour-Context (ABC) models behaviour (B) as a complex interactive outcome of intrinsic or 'internal' attitudinal (A) variables and extrinsic or 'external' circumstantial elements (C) (Stern, 2000). The strength of this model lies in the acknowledgement of the complex structural interaction or dynamics concerning the influence of attitudes (labelled as internal factors) and situational factors (also known as external or contextual factors). It is argued that where situational factors (e.g. monetary incentives and costs, institutional and legal support or constrains, time), play a weak role, the attitude-behaviour link is strong, however, the link is non-existent or weak at best, when situational factors exert a strong influence. This suggests that situational factors moderate the relationship between attitude and behaviour hence, pro-environmental behaviour will be dynamic as situational factors change overtime and in different locations i.e., pro-environmental behaviour may be predisposed to temporal and spatial dynamics.
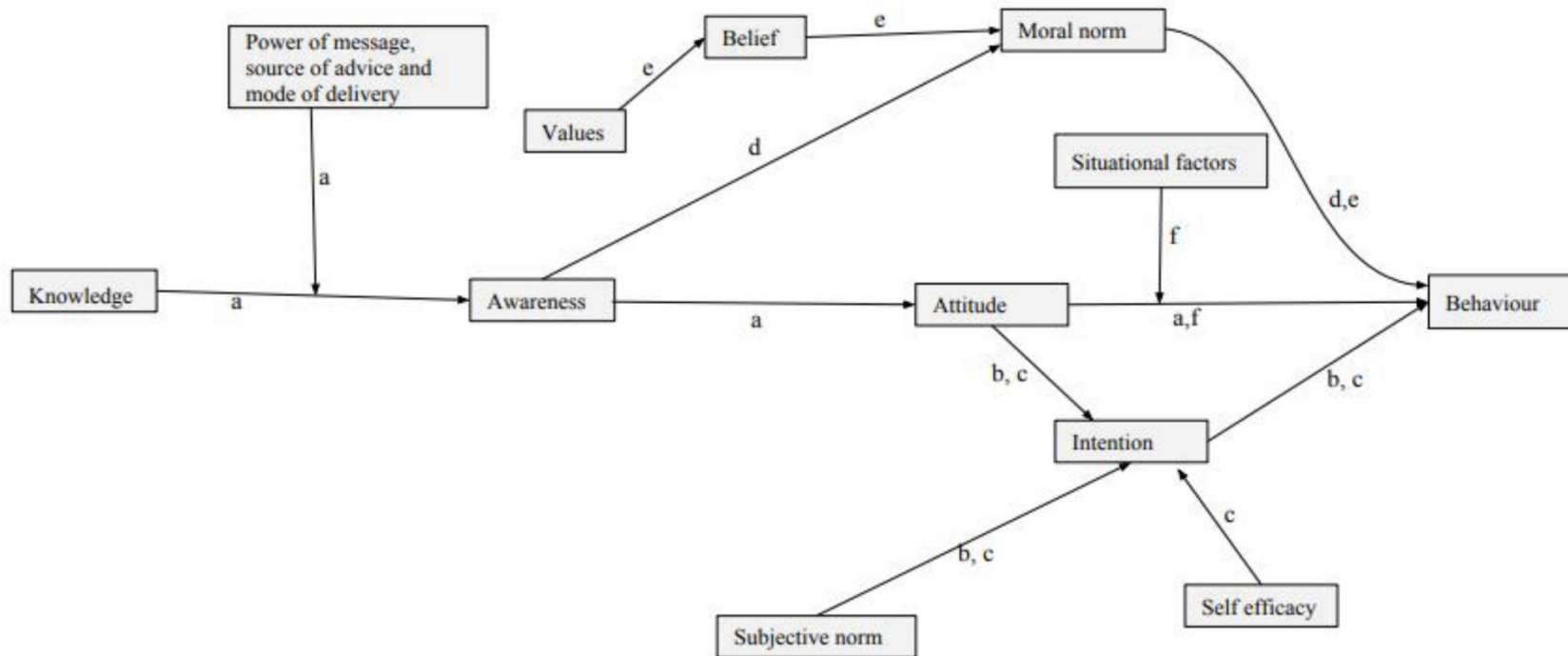
Figure 3.1. Integrated Framework of the behavioural theories to aid understanding of pro-environmental behaviour.
Note: We use letters to represent the different pathways (e.g. knowledge-awareness link, awareness-behaviour link, knowledge-behaviour link) hypothesised in each of the theories.

3.3. Materials and methods

3.3.1. Research design and data collection

The aim of the present study is to assess the empirical evidence base of the determinants of pro-environmental behaviour predicted by the theories described in section 3.2. For this purpose, we adopted a meta-analytic structural equation modelling (MASEM) technique. The first step involved an online search of the literature focusing on the determinants of pro-environmental behaviour (see Figure 3.2 for an overview of the research design used in this study). We restricted our search to papers written in English and published after 1994, when application of theories to understand pro-environmental behaviour gained considerable momentum (Bamberg and Möser, 2007). Keywords such as pro-environmental behaviour, pro-ecological behaviour, etc. were applied in multiple search queries to retrieve data from Google Scholar and other academic databases such as Web of Science, Scopus, Business Source Premier, PROQUEST's ABI/INFORM Collection, the Applied Social Sciences Index and Abstracts (ASSIA), and Sociological Abstracts (see Figure 3.3 for the document selection process and Appendix B1 for keyword groupings). After applying a follow-up snowball search and removing duplicates, we obtained 387 papers.

Next, we scanned the titles, abstracts and skimmed through the methods sections of the 387 papers with the aim of keeping only papers that contained outputs of "empirical research" as opposed to "reviews", "process-based modelling" or "conceptual papers". After this, there was an intensive reading of methods and result sections of these papers with the aim of retaining only papers that analysed at least one of the relationships of interest e.g., attitude-behaviour link, attitude-intention link, intention-behaviour link (see Figure 3.1 and Table 3.4, see also, Table 3.1 for definitions of the variables of interest) and also reported the correlation coefficients and sample sizes

as these were needed for the meta-analysis. After this step, 109 papers were retained and used for the meta-analysis (see Appendix B2 for references of these papers). From Appendix B2, it could be observed that the papers analysed cover a wide disciplinary spectrum and are published in a variety of journals. This wide disciplinary spectrum is a strength of the present study and a step towards advancing interdisciplinary approaches to understanding the complexity of pro-environmental behaviour.

As mentioned in section 3.1, this study covers a broader range of areas in which pro-environmental behaviour has been studied, beyond just land management. All 109 studies were then grouped under these (four) environmental policy areas based on the focus of the paper: recycling, land management, sustainable consumer behaviour and general ecological behaviour (see Table 3.2).

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┌─────────────────────────────────────────────────────────────────────────┐
│  Applying search criteria for literature (see Appendix B1 for the search  │
│                      terms and combinations)                              │
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                                    ▼
┌─────────────────────────────────────────────────────────────────────────┐
│  Applying inclusion and exclusion criteria to screen papers (see Figure   │
│                              3.3)                                         │
└─────────────────────────────────────────────────────────────────────────┘
                                    │
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┌─────────────────────────────────────────────────────────────────────────┐
│       Extracting correlations and sample sizes from the final papers      │
│                              included                                     │
└─────────────────────────────────────────────────────────────────────────┘
                                    │
                                    ▼
┌─────────────────────────────────────────────────────────────────────────┐
│         Generating the pooled mean correlations across all four sectors   │
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┌─────────────────────────────────────────────────────────────────────────┐
│  Generating the pooled mean correlations for the four different           │
│  environmental sectors (i.e., conducting sub-group analysis)              │
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┌─────────────────────────────────────────────────────────────────────────┐
│  Conducting the MASEM (using pooled mean correlations and sample sizes)   │
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│            Interpreting results and drawing conclusions                   │
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Figure 3.2: Research design used in this study
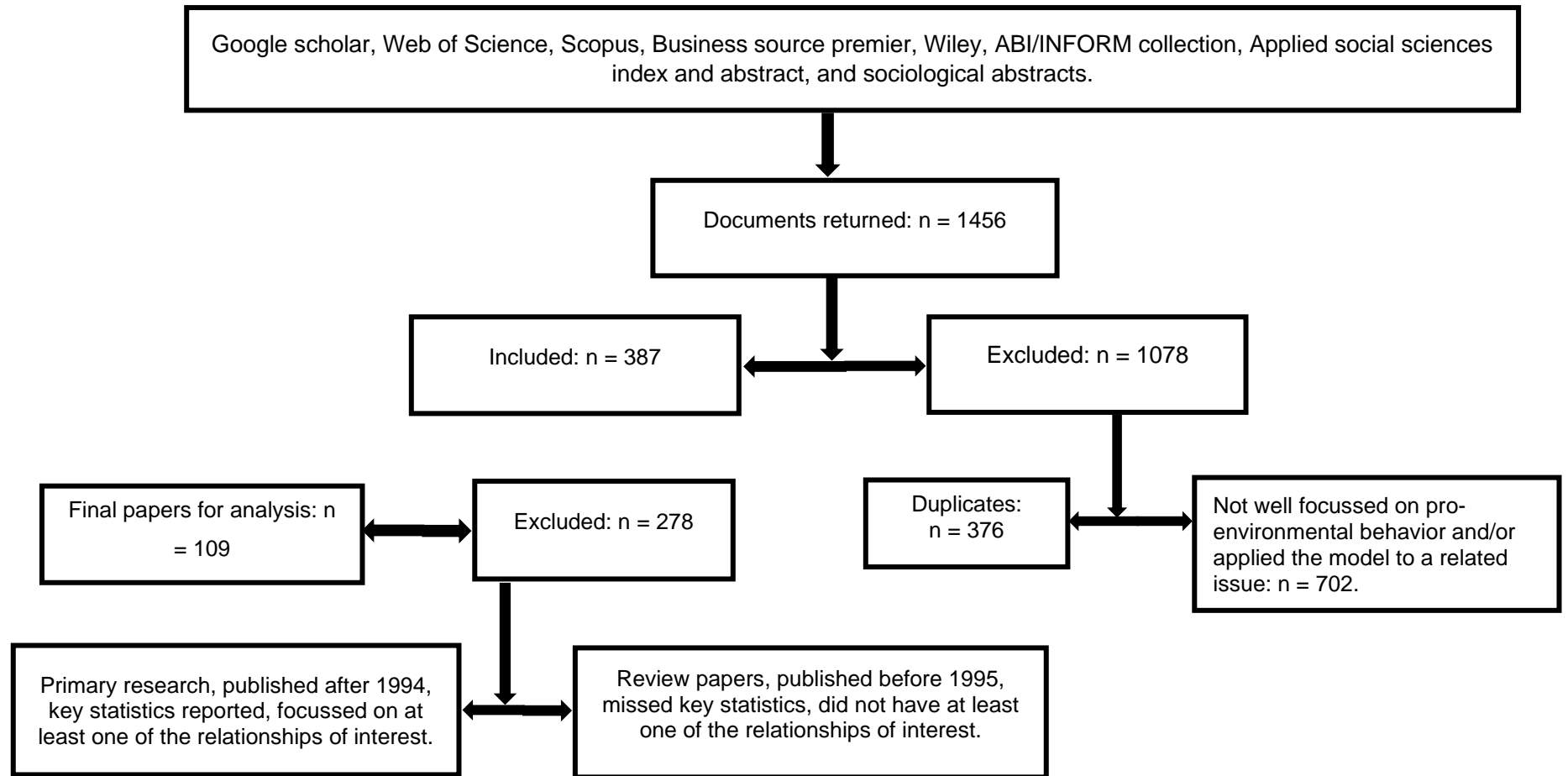
Figure 3.3. Document Selection Process.

Table 3.1. Definitions of study variables

Variable	Definition
Knowledge	Factual information regarding an environmental problem, action strategy or standard.
Beliefs	Perceived knowledge of an environmental problem or action strategy.
Awareness	A profound understanding or consciousness of an environmental problem or action strategy.
Attitude	A relatively stable feeling about the environment, a problem or an action strategy.
Habit	A way of behaving that has become a routine and a relatively stable behavioural pattern, often occurring without pronounced deliberate effort.
Intention	An intent or resolve (not) to effect environmentally significant behaviours.
Behavioural Willingness	"An openness to risk opportunity — what an individual would be willing to do under various circumstances" (Gibbons et al., 2003)
Behaviour	Actions, acts or measures that support or result in environmental management gains or at worst causes no harm to the environment.
Social Norm	Social or group understandings of what individuals ought to do.
Moral Norm	Feeling of moral obligation as opposed to what he perceives others think (Farrow et al., 2017).
Subjective Norm	Perception regarding what others think of him/her concerning a behaviour in question i.e. perceived social pressure.
Emotions	Emotions are reactions to an object or a process, and they include both sentimental and cognitive aspects.
Self-Efficacy	Self-efficacy is a personal judgement of how well an individual can perform courses of action necessary to deal with prospective situations.
Perceived Consequences	Views regarding the outcomes of certain actions or inactions, or an environmental issue.
Ascription of Responsibility	Claiming or apportioning responsibility for environmental problems and solutions to self, other individuals or institutions/society.
Situational Factors	Extrinsic factors that contingently facilitate or constrain pro-environmental behaviour. These may include institutional/regulatory support or constrain, time, farm size, farm type, land tenure system, income, cost of materials, etc.
Environmental Value	Refers to a desirable trans-situational goal regarding the environment, ecology, ecosystems or nature that serve as a guiding principle or influence individuals' environmental behaviours.
Environmental Concern	An assessment of one's own behaviour, or others' actions with consequences for ecological systems or nature.

Table 3.2. Classification of Papers based on Different Environmental Policy Areas.

Number	Issue area/broad focus	Items covered
1	Recycling	Psycho-social determinants of pro-environmental behaviours related to recycling, public support for recycling support, etc.
2	Land management	Main issues here include sustainable agriculture/conservation, biodiversity, diffuse pollution water quality issues.
3	Sustainable consumer behaviour	Green behaviour, sustainable transport modes, renewable and efficient energy use, etc.
4	General ecological behaviour	Cross-cutting issues e.g. climate change or paper discusses issues that cut across 2 or three of the specific areas above

3.3.2. Implementing the MASEM

Meta-analysis is a widely accepted technique for the synthesis of evidence (Koricheva and Gurevitch, 2013). It is appropriate for this study since our goal is to establish the quantitative empirical evidence base of the relationships of interest from studies sharing similar hypotheses (Koricheva and Gurevitch, 2013, Glass et al., 1981, Hunter and Schmidt, 2000, Hedges and Vevea, 1998). In this case, it involved pooling the correlation coefficients and samples from the primary studies. Using Hedges and Olkin (Hedges and Olkin, 1985) technique, we calculated the pooled mean correlations and associated p-values of the relationships of interest e.g., attitude-behaviour link, attitude-intention link, intention-behaviour link (Table 3.5). This was done through the application of the Comprehensive Meta-Analysis (Version 2) software. Publication bias was assessed using funnel plots (Jennions et al., 2013) which indicated a general absence of publication bias, except for the relationship between intention and environmental concern, which might be biased by not reporting small trials or studies that show non-significant results. We interpret our results under the random-effects assumption as heterogeneity test results indicated strong between-study heterogeneity of the pooled correlation matrix[5] (Jennions et al., 2013). The random-effect model is an extension of the fixed-effect model where variations in the mean effect across studies are attributed to factors such as differences in location, experimental conditions, and variable type, among others (Hedges and Olkin, 1985, Hunter and Schmidt, 2004, Hedges and Vevea, 1998, Rosenberg et al., 2013).

In an analysis such as this, where the evidence is pooled from multiple sources, it is important to assess the extent to which the statistical significance of the relationships

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[5] The p-value associated with the Q-statistic and I-squared statistic were significant (p<0.001) with the I² statistic mostly greater than 80 (Appendix B4, see also Appendix B3 for the 95% confidence intervals).

are affected by moderators, i.e. by an additional factor that might contingently impact the statistical significance, direction and/or magnitude of the relationship (Hayes, 2013). Because we are using a broad evidence base from different types of environmental behaviours, we tested for the moderating effects of type of environmental behaviour or focus of the primary research through sub-group analysis. Technically, applying sub-group analysis as a meta-regression has advantages as it focuses on differences between multiple groups as appropriate, as opposed to effects in each sub-group separately (Thompson and Higgins, 2002b). A detailed description of how sub-group analysis is applied is presented in (Jak and Cheung, 2018). The pooled mean correlation matrix was then fitted onto structural equation models (using AMOS 24) to test the behavioural theories. The structural equation models help to determine the regression weights and associated p-values of all the paths hypothesized in the respective theories (see Figure 3.1).

3.4. Results

3.4.1. Overview of the evidence

Of the 109 papers, only seven focused on environmentally responsible behaviours related to land management while the most, 52, focussed on sustainable consumer behaviour (Table 3.3). Table 3.4 presents the number of retrieved independent primary bivariate correlation coefficients and the respective combined total sample size on which these coefficients are based. This information shows that while some relationships have been commonly studied empirically (e.g. attitude–intention, self-efficacy–intention), others have received little attention (e.g. knowledge–emotion, social norm–ascription of responsibility) and some not studied at all (e.g. habit–behavioural willingness). Table 3.4 also shows that the awareness–habit link had the

smallest (pooled) total sample size (N=319) while the attitude–self-efficacy link had the largest sample size (N=22390).

Table 3.3. Summary of papers based on different environmental policy areas.

Number	Environmental policy area	Number of papers	% of total
1	Recycling	16	14.7
2	Land management	7	6.4
3	Sustainable consumer behaviour	52	47.7
4	General ecological behaviour	34	31.2
Total		109	100.0

3.4.2. Pooled mean correlation analysis

Pooled mean correlations of the relationships analysed are presented in Table 3.5. The strongest association was found between awareness of problem and/or action strategies and perceived consequences of individual's actions/inactions (r =0.67; p<0.01; N=1479; 6 studies). This indicates that people who are aware of an environmental problem (e.g. diffuse pollution) and action strategies (e.g. best land management practices) are more likely to perceive associated consequences of (not) engaging in that practice. The second strongest relationship was found between moral norm and environmental attitude (r = 0.62; p<0.01; N=5415; 9 studies), indicating that individuals who feel a moral obligation to behave in an environmentally responsible manner are more likely to report a positive environmental attitude. On the contrary, the weakest (but still statistically significant) relationships were found between habit and environmental awareness (r =0.02; p<0.01; N=319; 1 study) and between habit and attitude (r =0.03; p<0.01; N=1597; 4 studies). There were a few associations (e.g. emotions-attitude) for which results indicated no significant relationship.

Results also indicate a strong between-study heterogeneity (Appendix B4), which is partly attributable to the different environmental policy areas that the studies address (Table 3.6). For instance, while an overall correlation of r=0.21 was recorded for the

relationship between environmental awareness and behaviour, results varied between different environmental policy areas: it was slightly stronger (r=0.23; p<0.05) in sustainable consumer behaviour, slightly weaker (r=0.20; p<0.05) in general ecological behaviour, but it was non-significant (p>0.05) in recycling and land management behaviours.

Table 3.4. Number of independent primary bivariate correlation coefficients and pooled total sample size.

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Knowledge	-																	
2	Beliefs	K(4) N(2739)	-																
3	Awareness or consciousness	K(2) N(523)	K(3) N(2244	-															
4	Attitude	k(10) N(5462)	K(7) N(4455)	K(10) N(3080)	-														
5	Habit	K(1) N(352)		K(1) N(319)	K(4) N(1597)	-													
6	Intention	K(8) N(4401	K(4) N(2889)	K(13) N(4746	K(46) N(21886	K(5) N(1563	-												
7	Behavioural willingness	K(5) N(1222	K(1) N(1467)	K(6) N(2353	K(4) N(1060)	0	K(4) N(911)	-											
8	Behaviour	K(9) N(4106	K(7) N(12828	K(17) N(7694	K(30) N(18078	K(4) N(1493	K(29) N(10805	K(5) N(1498	-										
9	Social norm	K(2) N(627)		K(2) N(751)	K(6) N(4621)		K(9) N(6557)		K(9) N(2658	-									
10	Moral norm	K(1) N(352)		K(1) N(316)	K(9) N(5415)		K(7) N(3132)		K(3) N(1462		-								
11	Subjective norm	K(2)* N(2202		K(6) N(1944	K(42) N(22242		K(33) N(15355		K(20) N(8676			-							
12	Emotions	K(1) N(321)		K(10) N(3653	K(6) N(2286		K(13) N(5323			K(5) N(1777	K(6) N(2420		-						
13	Self-efficacy	K(4)* N(3377		K(6) N(2158	K(37) N(22390	K(2) N(1079	K(39) N(19528	K(6) N(1809	K23) N(9822	K(4) N(1733	K(5) N(3472	K(9) N(8757		-					
14	Perceived consequences	K(3) N(971)		K(6) N(1479	K(10) N(3346		K(19) N(6402		K(12) N(4324	K(3)* N(1181	K(12) N(6684				-				
15	Ascription of responsibility			K(3) N(493)	K(5) N(1314)		K(8) N(2907)		K(6) N(2006	K(2) N(676)		K(3) N(974)				-			

1 6	Situational factors e.g. time, institutional support			K(9) N(3097)	K(11) N(5194)	-
1 7	Environmenta l value	K(2) N(762)	K(2) N(590)	K(7) N(2494)		-
1 8	Environmenta l concern	K(4) N(1103)	K(7) N(2743)	K(11) N(4404)		-

K= Number of independent correlation coefficients obtained from reviewed papers and N = total sample size from respective K

Table 3.5. Pooled correlations for all environmental policy areas.

SN	Construct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	knowledge	-																	
2	beliefs	0.51	-																
3	Awareness	0.25	0.16	-															
4	Attitude	0.36	0.52	0.31	-														
5	Habit	0.22a		0.02a	0.03	-													
6	Intention	0.40	0.42	0.41	0.53	0.12	-												
7	Behavioural willingness	0.27	0.23a	0.39	0.20	0	0.43	-											
8	Behaviour	0.28	0.24	0.22	0.37	0.28	0.44	0.34	-										
9	Social norm	0.22		0.29	0.37		0.42		0.42	-									
10	Moral norm	0.23		0.41	0.62		0.48		0.36		-								
11	Subjective norm	0.57		0.40	0.45		0.43		0.25			-							
12	Emotions	0.45a		0.24	0.28NS		0.38			0.11NS	0.18NS		-						
13	Self-efficacy	0.18		0.32	0.39	0.28	0.49	0.39	0.27	0.31	0.47	0.31		-					
14	Perceived consequences	0.22	0.67	0.42			0.38		0.15	0.18	0.49				-				
15	Ascription of responsibility			0.41	0.37		0.51		0.23	0.35		0.47				-			
16	Situational factors						-0.02NS		-0.07NS								-		
17	Environmental value	0.40			0.42		0.39											-	
18	Environmental concern	0.30			0.24		0.30												-

Note: Correlations under random-effects assumption; a = no pooled correlation (i.e. only one correlation was retrieved); NS = non-significant relationship (all other r values are significant at the p≤0.05). We combined locus of control and perceived behavioural control as self-efficacy due to limited data on the two see (Ajzen, 2002 for a discussion on how they are related).

Table 3.6. Pooled correlations across different environmental policy areas.

Group	Correlation	Lower limit	Upper limit
Awareness-behaviour relationship			
Recycling	0.12	-0.35	0.55
Land management	0.25	-0.22	0.62
Sustainable consumer behaviour	0.23**	0.07	0.37
General ecological behaviour	0.20*	0.00	0.38
Overall	0.21**	0.10	0.32
Attitude-behaviour relationship			
Recycling	0.12	-0.35	0.55
Land management	0.25	-0.22	0.62
Sustainable consumer behaviour	0.23**	0.07	0.37
General ecological behaviour	0.20*	0.00	0.38
Overall	0.21**	0.10	0.32
Intention-behaviour relationship			
Recycling	0.61**	0.41	0.76
Land management	0.07a	-0.01	0.15
Sustainable consumer behaviour	0.47**	0.31	0.60
General ecological behaviour	0.40**	0.30	0.49
Overall	0.23**	0.18	0.29
Self-efficacy-behaviour relationship			
Recycling	0.44**	0.27	0.59
Land management	0.23*	0.01	0.42
Sustainable consumer behaviour	0.32**	0.18	0.45
General ecological behaviour	0.18**	0.04	0.32
Overall	0.28**	0.20	0.36
Subjective norm-behaviour relationship			
Recycling	0.18**	0.05	0.30
Land management	0.33	-0.26	0.74
Sustainable consumer behaviour	0.33**	0.18	0.46
General ecological behaviour	0.07	-0.12	0.26
Overall	0.21**	0.12	0.29

Notes: **$p \le 0.01$; *$p \le 0.05$; a = just 1 correlation retrieved

3.4.3. Meta-analytic structural equation modelling

Results of the MASEM that were used to test the predicted paths of the theories under consideration (see Figure 3.4) are presented in Table 3.7. First, we evaluated the fit of the models using a combination of recommended fit indices. When model fit indices such as the Normed Fit Index and the Comparative Fit Index[6] are greater than 0.95 it shows that the model fits the data very well (Hu and Bentler, 1999, Hooper et al.,

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[6] Although the chi square appears to be a traditional measure for assessing overall model fit HOOPER, D., COUGHLAN, J. & MULLEN, M. R. 2008. Structural Equation Modelling: Guidelines for Determining Model Fit. *J. Bus. Res. 6(1), 53-60.,* J. Bus. Res. **,** 53-60., we do not rely on it. This is because it is susceptible to sample size, thus, unlikely to accurately differentiate between an acceptable fitting model and a poor one (Kenny and McCoach, 2003). We therefore rely on the Normed Fit Index (NFI) and the Comparative Fit Index (CFI). This combination helps us to overcome problems of sample size susceptibility as the CFI is least affected by sample size (Hooper et al., 2008).

2008). Based on this criterion, all theories fitted the data with the exception of the Value-Belief-Norm Theory and Norm Activation Model. Results of the paths hypothesized by the behavioural theories for which we obtained acceptable fits (Table 3.7) are presented in Table 3.8. They indicate that almost all predictions of the theories are statistically significant with the exception of the knowledge-awareness pathway for Persuasion Theory and the subjective norm-intention link for Theories of Reasoned Action and Planned Behaviour.

Results in Table 3.8 further indicate that, the evidence supports the postulation that, awareness affects attitude (56% of the variance explained) and attitude in turn affects pro-environmental behaviour (49% of the variance explained) in line with the Persuasion Theory. Also the results support the hypotheses of the Theory of Reasoned Action: we found that, attitude predicts intention (78% of variance explained) and intentions in turn predict behaviour (74% of variance explained). Furthermore, our results confirm the postulations of the Theory of Planned Behaviour as intentions mediate the relationship between factors such as attitude, subjective norms and perceived behaviour control (referred to as self-efficacy in the present study) and pro-environmental behaviour (76% of variance explained). Overall, there is strong evidence from the MASEM supporting the majority of the theoretical frameworks under consideration.

Table 3.7. Model fit indices.

Theories	DF	NFI	CFI	Judgement
Persuasion Theory	3	1.0	1.0	Good fit
Theory of Reasoned Action	3	1.0	1.0	Good fit
Theory of Planned Behaviour	5	1.0	1.0	Good fit
Norm Activation Model	2	-	-	Poor fit
Value-Belief-Norm Model	2	-	0.0	Poor fit
Attitude-Behaviour-Context (ABC) Model	0	1.0	1.0	Good fit

DF= Degrees of freedom; NFI = Normed Fit Index; CFI = Comparative Fit Index

Table 3.8. Results of regression paths.

Independent variable	Dependent variable	Estimate	Standard Error	Total explained variance
Persuasion Theory				
Knowledge	Awareness	-0.1	0.4	-
Awareness	Attitude	0.8***	0.2	0.56
Attitude	Behaviour	0.7***	0.1	0.49
Theory of Reasoned Action				
Attitude	Intention	0.9***	0.1	0.78
Subjective norm	Intention	-0.2	0.3	-
Intention	Behaviour	0.9***	0.1	0.74
Theory of Planned Behaviour				
Attitude	Intention	0.7***	0.1	0.77a
Subjective norm	Intention	0.3	0.2	-
Self-efficacy	Intention	0.5***	0.1	0.77a
Self-efficacy	Behaviour	-0.4***	0.1	0.76a
Intention	Behaviour	1.0***	0.1	0.76a
Attitude-Behaviour-Context (ABC) Theory				
Attitude	Behaviour	0.7***	0.1	0.49

Notes: *** p<0.001; **p<0.01; *p<0.05; a = cumulative effect of two or more variables

Path results for Value-Belief-Norm and Norm Activation Models were excluded as data did not fit models.
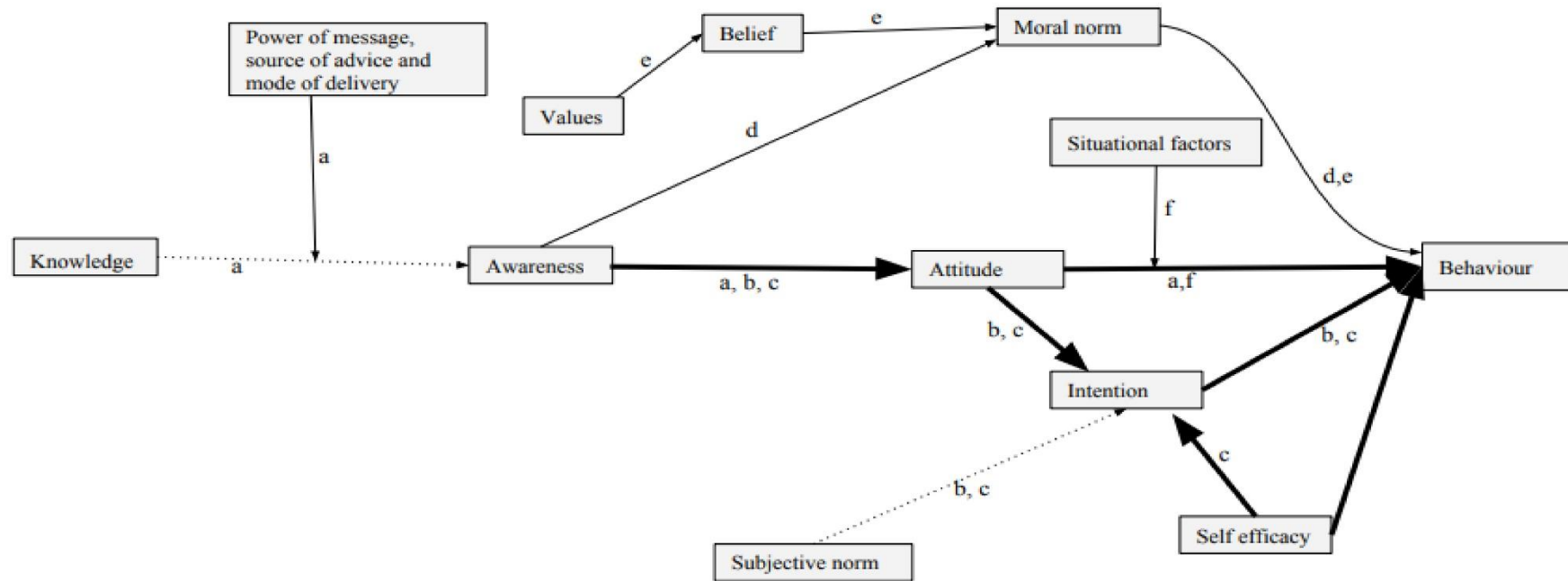
Figure 3.4. Integrated Framework of paths tested under the different theories.

Note: We use letters to represent the different pathways (e.g. knowledge-awareness link, awareness-behaviour link, knowledge-behaviour link) hypothesized in each of the theories.

3.5. Discussion

The results of our meta-analysis indicate that almost all the pooled correlations between variables were significant but the strength of the relationships are mainly weak to moderate. The strongest association was found between awareness (of problem and/or action strategies) and perceived consequences of individual's actions. This finding is unsurprising as people who are conscious of an environmental problem (e.g. diffuse water pollution from agriculture) and best management practices are more likely to be concerned with the consequences of engaging in practices that could cause or induce such environmental problems (Okumah et al., 2019a, Okumah and Ankomah-Hackman, 2020, Dwyer et al., 2007). Results from the MASEM show that most of the paths hypothesised in the Theories of Planned Behaviour and Reasoned Action, Attitude-Behaviour-Context Model, and the Persuasion Theory are supported by evidence from the literature. For instance, the link between attitudes and intentions, and intentions and behaviours (in the Theory of Planned Behaviour) are supported. This suggests that people with strong pro-environmental attitudes are more likely to have positive intentions to engage in pro-environmental behaviour, and this in turn can result in uptake of best management practices.

Although generally the evidence supports the theoretical frameworks, there were a few cases where results indicated non-significant relationships. For instance, the knowledge-awareness link predicted in the Persuasion Theory was non-significant. This implies that having access to knowledge or environmental management information does not automatically guarantee environmental awareness as this may depend on factors such as environmental concern, emotions, experience, information source, message framing and delivery (Kollmuss and Agyeman, 2002, Vrain and Lovett, 2016, Vrain et al., 2014). Indeed proponents of the Persuasion Theory

acknowledge that the link between knowledge and awareness depends on some of these factors, however, in the present study, we were unable to confirm this due to a lack of quantitative data or limited data on these variables in the literature. Nonetheless, qualitative evidence from land management studies (e.g., Blackstock, 2007, Blackstock et al., 2010, Dwyer et al., 2007, Vrain and Lovett, 2016) has indicated that indeed experience, knowledge networks, advice source and nature plays a key role in land managers' awareness and uptake of best management practices (specifically diffuse pollution mitigation measures).

The MASEM suggests that, the Value-Belief-Norm Theory and the Norm Activation Model were not supported by the data. The lack of evidence supporting their framing may be due to the neglect of situational factors (which this study was unable to confirm due to data limitation) in these two theories and their reductionist approach (i.e. the emphasis placed on altruistic factors). Pro-environmental behaviour is complex as many decisions and actions are influenced by self-interest and situational factors. For instance, in land management, while a farmer may be willing to engage in an environmentally sustainable practice, cost of compliance, income forgone and 'goodness of fit' of agri-environment schemes are key players of the ultimate decision and action (Morris et al., 2000c, Barnes et al., 2009, Daxini et al., 2019a, Vrain et al., 2014, Okumah et al., 2020b). Evidence suggests that for those policies that achieved significant successes (e.g., National Landcare Programme, Monitor Farms Programme, Diffuse Pollution Management Strategy), success depended greatly on contextual factors such as the financial incentives given to farmers, identifying trusted sources which exert the greatest social pressure on farmers (e.g., friends, advisors, family), presenting optimistic messages and highlighting benefits to farmers (Dwyer et al., 2007, Okumah et al., 2019a). Perhaps this could explain why policies (e.g.,

Vietnamese Government Forest Conservation Policy) that place little emphasis on such situational factors are less likely to succeed in triggering positive behaviours (Phuc, 2009) and also, why in the present study we did not find statistical evidence to support some of these models. Additionally, situational factors are predisposed to temporal and spatial dynamics (Stern, 2000), hence, future research in land management could examine these models considering the peculiarities of different spatial and temporal factors (such as how much time is needed for farmers to adopt different best land management practices and how does one's location influence such decisions?) Further, future research could focus on unpacking the complex interaction between the variables explored in this study and other potential factors such as land managers' demographic characteristics, and how that influence their behaviours. A deeper understanding of these interactions could further contribute to designing effective policies to encourage positive behavioural change amongst farmers.

Another important finding is that there is a strong between-study heterogeneity which is partly attributable to the type of environmental behaviour which the different studies address (Thompson and Higgins, 2002, Bamberg and Möser, 2007, Hines et al., 1986, Kormos and Gifford, 2014). That is, results for the same model varied in terms of statistical significance and strength of association for different environmental behaviours. For instance, results for the relationship between environmental awareness and behaviour indicated that this relationship was slightly stronger in sustainable consumer behaviour, slightly weaker in general ecological behaviour, but it was non-significant in recycling and land management behaviours. This is an important finding because it would preclude the validity of directly transferring recommendations across sectors (i.e. what is valid for recycling in terms of promoting behaviours might not be successful in trying to promote uptake of best land

management practices). Therefore, policy recommendations should be tailored to the specific environmental issues. This is because models of pro-environmental behaviour will yield varying levels of predictive capacity or effectiveness for different environmental behaviours hence, a critical evaluation should be undertaken in order to select which models are more suitable for understanding a particular environmental behaviour (e.g. best land management practices) while paying attention to the different conditions in which a particular model is the most useful (Steg and Vlek, 2009).

We now turn to discuss the potential limitations of our study. It must also be noted that most of the primary studies used a self-reported approach in measuring the variables under study (e.g., attitudes and behaviour). Self-reported studies are usually impacted by social desirability bias, limited memory of survey participants, and variation in participants' environmental knowledge and beliefs (Warriner et al., 1984, Kormos and Gifford, 2014). This can potentially introduce estimation errors in the results of the primary studies, and by extension, the results of this meta-analysis. Additionally, we are aware of the fact that meta-analysis of relationships involves some form of data aggregation (e.g. lots of different actions which may be affected by other variables are being pooled together and generically referred to as 'behaviour') which could be faced with issues of ecological confounding (Thompson and Higgins, 2002a, Jak and Cheung, 2018). As a result, we treat non-significant relationships as tentative cases requiring further investigation in primary research rather than as an absence of true relationships.

Another limitation lies in the fact that the MASEM used a correlation matrix instead of a covariance matrix as input. This could potentially result in unreliable/incorrect Chi square statistics and standard errors (Bamberg and Möser, 2007, Jak and Cheung,

2018). Furthermore, the MASEM was based on correlations, not covariance, this could result in overestimation of some parameters due to problems of multicollinearity (as can be observed from the results for the intention-behaviour link of the TPB model). Finally, the subgroup analysis relied on correlation coefficients and not regression coefficients, and also used a dichotomous method. This may result in the loss of valuable information, as it fails to take account of the complex nature of data from the different primary studies (Jak and Cheung, 2018). We entreat readers to consider these limitations when interpreting our results, while encouraging future studies to take account of study-level variables as continuous covariates in the application of MASEM.

The final limitation stems from the variation in the number of papers (from the different environmental policy areas) and the unequal sample sizes. For instance, only seven papers were drawn from the land management sector (probably due to the restriction to only papers that reported correlations and sample sizes). This could have impacted the statistical analysis. Also, removing qualitative studies and papers that do not report correlations and sample sizes could limit our understanding of the 'true' relationships between variables reported across the different environmental sectors. It is also important to note that although we attempted to reduce the possibility of missing relevant papers by using the snowball technique, it is possible that we still missed a few key papers. Nonetheless, the results provide insights into the significant variation in relationships studied across the different environmental policy areas.

3.6. Concluding Remarks

Land management policies are increasingly emphasizing behavioural change as a means to improve environmental management outcomes. This is based, implicitly or explicitly, on theories that suggest that pro-environmental behaviour can be predicted

and altered based on certain factors (referred to as determinants of pro-environmental behaviour), and that behavioural changes, in turn, can be expected to lead to improved environmental outcomes (such as water quality, soil health, biodiversity loss) through the adoption of mitigation measures or reduction of impactful activities. This assumes the existence of a straightforward pathway linking the determinants of behaviour to pro-environmental behaviour and then to environmental outcomes. However, studies examining the determinants of pro-environmental behaviour have found mixed evidence. Establishing whether existing evidence supports the postulations of such theories (in aggregate terms) could help provide answers that may trigger new policy directions. It is therefore important that these theories are revisited to assess if the evidence supports their postulations so that a more robust knowledge base can be established to inform land management policies. In this study we conducted such analysis. By using meta-analytic structural equation modelling (MASEM), we expand over previous reviews as the method allows us to test the mechanisms through which these different variables affect one another, which previous studies relying on correlations and multiple regressions were unable to reveal. Moreover, although we focus on land management, the evidence base that we explore goes beyond that of land management only, including related areas and general ecological behaviours more broadly.

Our findings suggest a strong evidence base for the Persuasion Theory, Theory of Reasoned Action, Theory of Planned Behaviour and the Attitude-Behaviour-Context (ABC) Model. In contrast, evidence supporting the Value-Belief-Norm Theory and the Norm Activation Model is less established. The lack of evidence supporting the Value-Belief-Norm Theory and the Norm Activation Model suggests the need to include situational factors in models of pro-environmental behaviour (and by extension,

environmental policies that are implicitly or explicitly based on such models. Including such variables could improve our understanding of the complex determinants of pro-environmental behaviour, and this may in turn, help adjust policies to address various motivations, capabilities and circumstances of stakeholders (e.g., farmers). From a research perspective, qualitative methods could be used to gather rich data that provides a deeper understanding of the determinants of pro-environmental behaviour and how best to influence stakeholders' behaviour.

The results also indicate that type of environmental policy area (e.g., recycling, land management) moderates the relationships between the different constructs and therefore the underlying assumptions might not be shared across fields. This has key policy implications as while lessons can be learnt from other environmental areas, land management policies aimed at influencing behaviours will need to be tailored to the specific context rather than simply 'imported' from other areas. Therefore, models upon which policies may (implicitly/explicitly) be based need to consider context-specific nuances. Such context-specific policies may encourage uptake of pro-environmental behaviours. This does not pre-empt, however, the need for the assessment of the full pathway, i.e. including also the assessment of the effectiveness of changes in behaviour on environmental outcomes (Okumah *et al.*, 2019). This study has attempted to investigate the first component of the pathway: the path linking psycho-social factors to pro-environmental behaviour, which is a contribution towards understanding the effects of policies on uptake of pro-environmental behaviours. We encourage future research to explore the full pathway drawing both on psychosocial and biophysical data.

Acknowledgments

References

ABDUL-MUHMIN, A. G. 2007. Explaining consumers? willingness to be environmentally friendly. *International Journal of Consumer Studies,* 31**,** 237-247.

ADNAN, N., NORDIN, S. M. & BIN ABU BAKAR, Z. 2017. Understanding and facilitating sustainable agricultural practice: A comprehensive analysis of adoption behaviour among Malaysian paddy farmers. *Land Use Policy,* 68**,** 372-382.

AJZEN, I. 1991. The theory of planned behavior. *Organizational Behavior and Human Decision Processes,* 50**,** 179-211.

AJZEN, I. & FISHBEIN, M. 1980. *Understanding Attitudes and Predicting Social Behaviour,* Englewood Cliffs, New Jersey Prentice-Hall Inc.

ALLEN, J. B. & FERRAND, J. L. 1999. Environmental Locus of Control, Sympathy, And Pro-environmental Behavior: A Test of Geller's Actively Caring Hypothesis. *Environment and Behavior,* 31**,** 338-353.

ANDERSSON, L., SHIVARAJAN, S. & BLAU, G. 2005. Enacting Ecological Sustainability in the MNC: A Test of an Adapted Value-Belief-Norm Framework. *Journal of Business Ethics,* 59**,** 295-305.

ANDERSSON, M. & VON BORGSTEDE, C. 2010. Differentiation of determinants of low-cost and high-cost recycling. *Journal of Environmental Psychology,* 30**,** 402-408.

ANDOW, D. A., RESENDE FILHO, M. A., CARNEIRO, R. G., LORENA, D. R., SUJII, E. R. & ALVES, R. T. 2017. Heterogeneity in Intention to Adopt Organic Strawberry Production Practices Among Producers in the Federal District, Brazil. *Ecological Economics,* 140**,** 177-189.

ARI, E. & YıLMAZ, V. 2016. A proposed structural model for housewives' recycling behavior: A case study from Turkey. *Ecological Economics,* 129**,** 132-142.

ARNOCKY, S., MILFONT, T. L. & NICOL, J. R. 2013. Time Perspective and Sustainable Behavior. *Environment and Behavior,* 46**,** 556-582.

BAMBERG, S., HUNECKE, M. & BLÖBAUM, A. 2007. Social context, personal norms and the use of public transportation: Two field studies. *Journal of Environmental Psychology,* 27**,** 190-203.

BAMBERG, S. & MÖSER, G. 2007. Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. *Journal of environmental psychology,* 27**,** 14-25.

BANDURA, A. 1977. *Social Learning Theory,* Englewood Cliffs, New Jersey, Prentice H.

BARNES, A. P., WILLOCK, J., HALL, C. & TOMA, L. 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management,* 96**,** 1715-1722.

BAUMGART-GETZ, A., PROKOPY, L. S. & FLORESS, K. 2012. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of environmental management,* 96**,** 17-25.

BISSONNETTE, M. M. & CONTENTO, I. R. 2001. Adolescents' Perspectives and Food Choice Behaviors in Terms of the Environmental Impacts of Food Production Practices: Application of a Psychosocial Model. *Journal of Nutrition Education,* 33**,** 72-82.

BLACKSTOCK, K. Negotiating Change: the importance of Knowledge networks in mitigating diffuse pollution. Paper presented at CAIWA 2007, International Conference on Adaptive and Integrated Water Management, 2007 Basel 12-15th, September 2007.

BLACKSTOCK, K. L., INGRAM, J., BURTON, R., BROWN, K. M. & SLEE, B. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the total environment,* 408**,** 5631-5638.

BLOK, V., WESSELINK, R., STUDYNKA, O. & KEMP, R. 2015. Encouraging sustainability in the workplace: a survey on the pro-environmental behaviour of university employees. *Journal of Cleaner Production,* 106**,** 55-67.

BOIRAL, O. 2002. Tacit knowledge and environmental management. *Long Range Planning,* 35**,** 291-317.

BOTETZAGIAS, I., DIMA, A.-F. & MALESIOS, C. 2015. Extending the Theory of Planned Behavior in the context of recycling: The role of moral norms and of demographic predictors. *Resources, Conservation and Recycling,* 95**,** 58-67.

BRATT, C. 1999. Do Norms and Assumed Consequences Influence Environmental Behavior? *Environment and Behavior,* 31**,** 630-656.

BUSSE, M. & MENZEL, S. 2014. The role of perceived socio-spatial distance in adolescents' willingness to engage in pro-environmental behavior. *Journal of Environmental Psychology,* 40**,** 412-420.

CARRICO, A. R. & RIEMER, M. 2011. Motivating energy conservation in the workplace: An evaluation of the use of group-level feedback and peer education. *Journal of Environmental Psychology,* 31**,** 1-13.

CASTANEDA, M. G., MARTINEZ, C. P., MARTE, R. & ROXAS, B. 2015. Explaining the environmentally-sustainable consumer behavior: a social capital perspective. *Social Responsibility Journal,* 11**,** 658-676.

CASTRO, P., GARRIDO, M., REIS, E. & MENEZES, J. 2009. Ambivalence and conservation behaviour: An exploratory study on the recycling of metal cans. *Journal of Environmental Psychology,* 29**,** 24-33.

CHAKRABORTY, A., SINGH, M. P. & ROY, M. 2017. A study of goal frames shaping pro-environmental behaviour in university students. *International Journal of Sustainability in Higher Education,* 18**,** 1291-1310.

CHAO, Y.-L. & LAM, S.-P. 2011. Measuring Responsible Environmental Behavior: Self-Reported and Other-Reported Measures and Their Differences in Testing a Behavioral Model. *Environment and Behavior,* 43**,** 53-71.

CHATZIDAKIS, A., KASTANAKIS, M. & STATHOPOULOU, A. 2014. Socio-Cognitive Determinants of Consumers' Support for the Fair Trade Movement. *Journal of Business Ethics,* 133**,** 95-109.

CHEN, C.-F., XU, X. & FREY, S. 2016. Who wants solar water heaters and alternative fuel vehicles? Assessing social–psychological predictors of adoption intention and policy support in China. *Energy Research & Social Science,* 15**,** 1-11.

CHEN, M.-F. 2015a. An examination of the value-belief-norm theory model in predicting pro-environmental behaviour in Taiwan. *Asian Journal of Social Psychology,* 18**,** 145-151.

CHEN, M.-F. 2015b. Impact of fear appeals on pro-environmental behavior and crucial determinants. *International Journal of Advertising,* 35**,** 74-92.

CHEN, M.-F. 2016. Extending the theory of planned behavior model to explain people's energy savings and carbon reduction behavioral intentions to mitigate climate change in Taiwan–moral obligation matters. *Journal of Cleaner Production,* 112**,** 1746-1753.

CHEN, M.-F. & TUNG, P.-J. 2009. The Moderating Effect of Perceived Lack of Facilities on Consumers' Recycling Intentions. *Environment and Behavior,* 42**,** 824-844.

CHEN, M.-F. & TUNG, P.-J. 2014. Developing an extended Theory of Planned Behavior model to predict consumers' intention to visit green hotels. *International Journal of Hospitality Management,* 36**,** 221-230.

CHEUNG, M. W.-L. & HONG, R. Y. 2017. Applications of meta-analytic structural equation modelling in health psychology: examples, issues, and recommendations. *Health psychology review,* 11**,** 265-279.

CHOI, A. S., RITCHIE, B. W. & FIELDING, K. S. 2015. A Mediation Model of Air Travelers' Voluntary Climate Action. *Journal of Travel Research,* 55**,** 709-723.

CLARK, W. A. & FINLEY, J. C. 2007. Determinants of water conservation intention in Blagoevgrad, Bulgaria. *Society & Natural Resources,* 20**,** 613-627.

CORBETT, J. B. 2002. Motivations to Participate in Riparian Improvement Programs: Applying the Theory of Planned Behavior. *Science Communication,* 23**,** 243-263.

COTTRELL, S. P. 2003. Influence of Sociodemographic and Environmental Attitudes on General Responsible Environmental Behavior among Recreational Boaters. *Environment and Behavior,* 35**,** 347-375.

DAGHER, G. K. & ITANI, O. 2014. Factors influencing green purchasing behaviour: Empirical evidence from the Lebanese consumers. *Journal of Consumer Behaviour,* 13**,** 188-195.

DAVIES, J., FOXALL, G. R. & PALLISTER, J. 2002. Beyond the intention–behaviour mythology: An integrated model of recycling. *Marketing Theory,* 2**,** 29–113.

DAVIS, G., O'CALLAGHAN, F. & KNOX, K. 2009. Sustainable attitudes and behaviours amongst a sample of non-academic staff. *International Journal of Sustainability in Higher Education,* 10**,** 136-151.

DAXINI, A., RYAN, M., O'DONOGHUE, C. & BARNES, A. P. 2019. Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour. *Land Use Policy,* 85**,** 428-437.

DENG, J., SUN, P., ZHAO, F., HAN, X., YANG, G. & FENG, Y. 2016. Analysis of the ecological conservation behavior of farmers in payment for ecosystem service programs in eco-environmentally fragile areas using social psychology models. *Sci Total Environ,* 550**,** 382-90.

DONALD, I. J., COOPER, S. R. & CONCHIE, S. M. 2014. An extended theory of planned behaviour model of the psychological factors affecting commuters' transport mode use. *Journal of Environmental Psychology,* 40**,** 39-48.

DORAN, R., HANSS, D. & LARSEN, S. 2015. Attitudes, efficacy beliefs, and willingness to pay for environmental protection when travelling. *Tourism and Hospitality Research,* 15**,** 281-292.

DORAN, R. & LARSEN, S. 2016. The Relative Importance of Social and Personal Norms in Explaining Intentions to Choose Eco-Friendly Travel Options. *International Journal of Tourism Research,* 18**,** 159-166.

DPMAG 2015. Strategy to reduce diffuse pollution. Edinburgh: Scottish Environment Protection Agency.

DUERDEN, M. D. & WITT, P. A. 2010. The impact of direct and indirect experiences on the development of environmental knowledge, attitudes, and behavior. *Journal of Environmental Psychology,* 30**,** 379-392.

DWYER, J., MILLS, J., INGRAM, J., TAYLOR, J., BURTON, R., BLACKSTOCK, K., SLEE, B., BROWN, K., SCHWARZ, G. & MATTHEWS, K. 2007. Understanding and influencing positive behaviour change in farmers and land managers. *CCRI, Macaulay Institute*.

ECHEGARAY, F. & HANSSTEIN, F. V. 2017. Assessing the intention-behavior gap in electronic waste recycling: the case of Brazil. *Journal of Cleaner Production,* 142**,** 180-190.

ENVIRONMENT AGENCY 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report. Bristol: Environment Agency

ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. . Bristol: Environment Agency.

ERIKSSON, L. & FORWARD, S. E. 2011. Is the intention to travel in a pro-environmental manner and the intention to use the car determined by different factors? *Transportation Research Part D: Transport and Environment,* 16**,** 372-376.

ERIKSSON, L., GARVILL, J. & NORDLUND, A. M. 2006. Acceptability of travel demand management measures: The importance of problem awareness, personal norm, freedom, and fairness. *Journal of Environmental Psychology,* 26**,** 15-26.

ERNST, J., BLOOD, N. & BEERY, T. 2015. Environmental action and student environmental leaders: exploring the influence of environmental attitudes, locus of control, and sense of personal responsibility. *Environmental Education Research,* 23**,** 149-175.

FANG, W. T., NG, E. & CHANG, M. C. 2017. Physical Outdoor Activity versus Indoor Activity: Their Influence on Environmental Behaviors. *Int J Environ Res Public Health,* 14.

FARROW, K., GROLLEAU, G. & IBANEZ, L. 2017. Social Norms and Pro-environmental Behavior: A Review of the Evidence. *Ecological Economics,* 140**,** 1-13.

FLORESS, K., GARCÍA DE JALÓN, S., CHURCH, S. P., BABIN, N., ULRICH-SCHAD, J. D. & PROKOPY, L. S. 2017. Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality. *Journal of Environmental Psychology,* 53**,** 73-80.

FORWARD, S. E. 2014. Exploring people's willingness to bike using a combination of the theory of planned behavioural and the transtheoretical model. *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology,* 64**,** 151-159.

GÄRLING, T., FUJII, S., GÄRLING, A. & JAKOBSSON, C. 2003. Moderating effects of social value orientation on determinants of proenvironmental behavior intention. *Journal of Environmental Psychology,* 23**,** 1-9.

GIBBONS, F. X., GERRARD, M. & LANE, D. J. 2003. A social reaction model of adolescent health risk. *Social psychological foundations of health and illness***,** 107-136.

GLASS, V. G., MCGRAW, B. & SMITH, M. L. 1981. *Meta-analysis in Social Research,* California and London, SAGE.

GOH, S. K. & BALAJI, M. S. 2016. Linking green skepticism to green purchase behavior. *Journal of Cleaner Production,* 131**,** 629-638.

GREGORY, G. D. & DI LEO, M. 2003. Repeated behaviour and environmental psychology: the role of personal involvement and habit formation in

explaining water consumption. *Journal of Applied Social Psychology, 33*, 1261-1296.

GRØNHØJ, A. & THØGERSEN, J. 2012. Action speaks louder than words: The effect of personal attitudes and family norms on adolescents' pro-environmental behaviour. *Journal of Economic Psychology, 33*, 292-302.

GUAGNANO, G. A., STERN, P. C. & DIETZ, T. 1995. Influences on Attitude-Behavior Relationships: A Natural Experiment with Curbside Recycling. *Environment and Behavior, 27*, 699-718.

HA, H. Y. & JANDA, S. 2012. Predicting consumer intentions to purchase energy-efficient products. *Journal of Consumer Marketing, 29*, 461-469.

HAMID, P. N. & CHENG, S. 1995. Predicting antipollution behavior: the role of molar behavior intentions, past behavior and locus of control. *Environment & Behavior, 27*, 679-698.

HAN, H. 2014. The norm activation model and theory-broadening: Individuals' decision-making on environmentally-responsible convention attendance. *Journal of Environmental Psychology, 40*, 462-471.

HAN, H. 2015. Travelers' pro-environmental behavior in a green lodging context: Converging value-belief-norm theory and the theory of planned behavior. *Tourism Management, 47*, 164-177.

HAN, H., HWANG, J., KIM, J. & JUNG, H. 2015. Guests' pro-environmental decision-making process: Broadening the norm activation framework in a lodging context. *International Journal of Hospitality Management, 47*, 96-107.

HAN, H., HWANG, J. & LEE, S. 2017. Cognitive, affective, normative, and moral triggers of sustainable intentions among convention-goers. *Journal of Environmental Psychology, 51*, 1-13.

HAN, H. & HYUN, S. S. 2016. Fostering customers' pro-environmental behavior at a museum. *Journal of Sustainable Tourism, 25*, 1240-1256.

HAN, H. & HYUN, S. S. 2018. What influences water conservation and towel reuse practices of hotel guests? *Tourism Management, 64*, 87-97.

HAN, H., JAE, M. & HWANG, J. 2016. Cruise travelers' environmentally responsible decision-making: An integrative framework of goal-directed behavior and norm activation process. *International Journal of Hospitality Management, 53*, 94-105.

HASNAH HASSAN, S. 2014. The role of Islamic values on green purchase intention. *Journal of Islamic Marketing, 5*, 379-395.

HAYES, A. F. 2013. *Introduction to mediation, moderation and conditional process analysis,* New York and London, The Guildford Press.

HEDGES, L. V. & OLKIN, I. 1985. *Statistical Methods for Meta-analysis.*

HEDGES, L. V. & VEVEA, J. L. 1998. Fixed- and Random-Effects Models in Meta-Analysis. *Psychological Methods, 3*, 486-504.

HINES, J. M., HUNGERFORD, H. R. & TOMERA, A. N. 1986. Analysis & Synthesis of Research on Responsible Environmental Responsible Behavior: A Meta-Analysis *Journal of Environmental Education, 18*, 1-8.

HOOPER, D., COUGHLAN, J. & MULLEN, M. R. 2008. Structural Equation Modelling: Guidelines for Determining Model Fit. *J. Bus. Res. 6(1), 53-60.,* J. Bus. Res. *,* 53-60.

HOVLAND, C. I., JANIS, I. L. & KELLEY, H. H. 1953. Communication and persuasion; psychological studies of opinion change.

HU, L. & BENTLER, P. M. 1999. Cutoff Criteria for Fit Indexes in Covariance Structure Analysis: Conventional Criteria versus New Alternatives. *Struct. Equ. Modeling, ,* 6**,** 1-55.

HUFFMAN, A. H., VAN DER WERFF, B. R., HENNING, J. B. & WATROUS-RODRIGUEZ, K. 2014. When do recycling attitudes predict recycling? An investigation of self-reported versus observed behavior. *Journal of Environmental Psychology,* 38**,** 262-270.

HUNECKE, M., BLÖBAUM, A., MATTHIES, E. & HÖGER, R. 2001. Responsibility and Environment: Ecological Norm Orientation and External Factors in the Domain of Travel Mode Choice Behavior. *Environment and Behavior,* 33**,** 830-852.

HUNTER, J. E. & SCHMIDT, F. L. 2000. Fixed Effects vs. Random Effects Meta-Analysis Models: Implications for Cumulative Research Knowledge. *International Journal of Selection and Assessment,* 8**,** 275-292.

HUNTER, J. E. & SCHMIDT, F. L. 2004. *Methods of meta-analysis: Correcting error and bias in research findings,* London, Sage.

INMAN, A., WINTER, M., WHEELER, R., VRAIN, E., LOVETT, A., COLLINS, A., JONES, I., JOHNES, P. & CLEASBY, W. 2018. An exploration of individual, social and material factors influencing water pollution mitigation behaviours within the farming community. *Land Use Policy,* 70**,** 16-26.

JACKSON, T. 2005. Motivating Sustainable Consumption: a review of evidence on consumer behaviour and behavioural change. Sustainable Development Research Network.

JAK, S. & CHEUNG, M. W.-L. 2018. Testing moderator hypotheses in meta-analytic structural equation modeling using subgroup analysis. *Behavior Research Methods,* 50**,** 1359-1373.

JAKOVCEVIC, A. & STEG, L. 2013. Sustainable transportation in Argentina: Values, beliefs, norms and car use reduction. *Transportation Research Part F: Traffic Psychology and Behaviour,* 20**,** 70-79.

JENNIONS, M. D., LORTIE, C. J., ROSENBERG, M. S. & ROTHSTEIN, H. R. 2013. Publication and Related Biases. . *In:* KORICHEVA, J., GUREVITCH, J. & MENGERSEN, K. (eds.) *Handbook of Meta-analysis in Ecology and Evolution.* Princeton and Oxford: Princeton University Press.

JOIREMAN, J. A., LASANE, T. P., BENNETT, J., RICHARDS, D. & SOLAIMANI, S. 2001. Integrating social value orientation and the consideration of future consequences within the extended norm activation model of pro-environmental behaviour. *British Journal of Social Psychology,* 40**,** 133–155.

JORGEN, G., AGNETA, M. & ANNIKA, N. 2003. Effects of increased awareness on choice of travel mode. *Transportation,* 30**,** 63-79.

JUNTTI, M. & POTTER, C. 2002. Interpreting and Reinterpreting Agri-Environmental Policy:Communication, Trust and Knowledge in the Implementation Process. *Sociologia Ruralis,* 42**,** 216-232.

KAISER, F. G. 2006. A moral extension of the theory of planned behavior: Norms and anticipated feelings of regret in conservationism. *Personality and Individual Differences,* 41**,** 71-81.

KAISER, F. G. & GUTSCHER, H. 2003. The Proposition of a General Version of the Theory of Planned Behavior: Predicting Ecological Behavior. *Journal of Applied Social Psychology,* 33**,** 586-60.

KAISER, F. G. & SCHEUTHLE, H. 2003. Two challenges to a moral extension of the theory of planned behavior: moral norms and just world beliefs in conservationism. *Personality and Individual Differences,* 35**,** 1033-1048.

KAISER, F. G. & SHIMODA, T. A. 1999. Responsibility as a Predictor of Ecological Behaviour. *Journal of Environmental Psychology,* 19**,** 243-253.

KAISER, F. G., WO¨LFING, S. & FUHRER, U. 1999. Environmental Attitude and ecological Behaviour. *Journal of Environmental Psychology,* 19**,** 1-19.

KESTERNICH, M., REIF, C. & RÜBBELKE, D. 2017. Recent trends in behavioral environmental economics. *Environmental and Resource Economics,* 67**,** 403-411.

KIM, S.-Y., YOON, J. & CHOI, I. 2016. What matters to promote consumers' intention to patronize sustainable business-and-industry (B&I) food services? *British Food Journal,* 118**,** 2710-2731.

KIM, S., JEONG, S.-H. & HWANG, Y. 2012. Predictors of Pro-Environmental Behaviors of American and Korean Students. *Science Communication,* 35**,** 168-188.

KLÖCKNER, C. A. & BLÖBAUM, A. 2010. A comprehensive action determination model: Toward a broader understanding of ecological behaviour using the example of travel mode choice. *Journal of Environmental Psychology,* 30**,** 574-586.

KNUSSEN, C., YULE, F., MACKENZIE, J. & WELLS, M. 2004. An analysis of intentions to recycle household waste: The roles of past behaviour, perceived habit, and perceived lack of facilities. *Journal of Environmental Psychology,* 24**,** 237-246.

KOLLMUSS, A. & AGYEMAN, J. 2002. Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research,* 8**,** 239-260.

KORICHEVA, J. & GUREVITCH, J. 2013. Place of Meta-analysis among other methods of research synthesis. *In:* KORICHEVA, J., GUREVITCH, J. & MENGERSEN, K. (eds.) *Handbook of meta-analysis in ecology and evolution.* Princeton and Oxford: Princeton University Press.

KORMOS, C. & GIFFORD, R. 2014. The validity of self-report measures of proenvironmental behavior: A meta-analytic review. *Journal of Environmental Psychology,* 40**,** 359-371.

LALANI, B., DORWARD, P., HOLLOWAY, G. & WAUTERS, E. 2016. Smallholder farmers' motivations for using Conservation Agriculture and the roles of yield, labour and soil fertility in decision making. *Agricultural Systems,* 146**,** 80-90.

LAUDENSLAGER, M. S. & HOLT, D. T. 2004. Understanding Air Force Members' Intentions to Participate In Pro-Environmental Behaviors: An Application of the Theory of Planned Behavior. *Perceptual and Motor Skills,* 98**,** 1162-1 170.

LIN, C.-Y. & SYRGABAYEVA, D. 2016. Mechanism of environmental concern on intention to pay more for renewable energy: Application to a developing country. *Asia Pacific Management Review,* 21**,** 125-134.

LIN, J.-C., WU, C.-S., LIU, W.-Y. & LEE, C.-C. 2012. Behavioral intentions toward afforestation and carbon reduction by the Taiwanese public. *Forest Policy and Economics,* 14**,** 119-126.

LIOBIKIENĖ, G., GRINCEVIČIENĖ, Š. & BERNATONIENĖ, J. 2017. Environmentally friendly behaviour and green purchase in Austria and Lithuania. *Journal of Cleaner Production,* 142**,** 3789-3797.

LOCKIE, S. & HIGGINS, V. 2007. Roll-out neoliberalism and hybrid practices of regulation in Australian agri-environmental governance. *Journal of Rural Studies,* 23**,** 1-11.

LYNNE, G. D., CASEY, C. F., HODGES, A. & RAHMANI, M. 1995. Conservation technology adoption decisions and the theory of planned behavior. *Journal of Economic Psychology,* 16**,** 581-598.

MACGREGOR, C. J. & WARREN, C. R. 2006. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. *Agriculture, Ecosystems & Environment,* 113**,** 108-119.

MANNETTI, L., PIERRO, A. & LIVI, S. 2004. Recycling: Planned and self-expressive behaviour. *Journal of Environmental Psychology,* 24**,** 227-236.

MARTIN-ORTEGA, J., GLENK, K., BYG, A. & OKUMAH, M. 2017. Public's views and values on peatland restoration in Scotland: Results from a quantitative study. . Leeds and Aberdeen The James Hutton Institute, Scotland's Rural College and the University of Leeds joint report.

MARTINS GONÇALVES, H. & VIEGAS, A. 2015. Explaining consumer use of renewable energy: determinants and gender and age moderator effects. *Journal of Global Scholars of Marketing Science,* 25**,** 198-215.

MEINHOLD, J. L. & MALKUS, A. J. 2016. Adolescent Environmental Behaviors. *Environment and Behavior,* 37**,** 511-532.

MICHIE, S., JOHNSTON, M., FRANCIS, J., HARDEMAN, W. & ECCLES, M. 2008. From Theory to Intervention: Mapping Theoretically Derived Behavioural Determinants to Behaviour Change Techniques. . *Applied Psychology* 57**,** 660-680. .

MINTON, A. P. & ROSE, R. L. 1997. The Effects of Environmental Concern on Environmentally Friendly Consumer Behavior: An Exploratory Study. *Journal of Business Research,* 40**,** 37–48.

MOBLEY, C., VAGIAS, W. M. & DEWARD, S. L. 2009. Exploring Additional Determinants of Environmentally Responsible Behavior: The Influence of Environmental Literature and Environmental Attitudes. *Environment and Behavior,* 42**,** 420-447.

MORRIS, J., MILLS, J. & CRAWFORD, I. M. 2000. Promoting farmer uptake of agri-environment schemes: the Countryside Stewardship Arable Options Scheme. *Land Use Policy,* 17**,** 241-254.

NILSSON, M. & K• ULLER, R. 2000. Travel behaviour and environmental concern. *Transportation Research Part D,* 5**,** 211-234.

NORDLUND, A. M. & GARVILL, J. 2003. Effects of values, problem awareness, and personal norm on willingness to reduce personal car use. *Journal of Environmental Psychology,* 23**,** 339-347.

OKUMAH, M. & ANKOMAH-HACKMAN, P. 2020. Applying conditional process modelling to investigate factors influencing the adoption of water pollution mitigation behaviours. *Sustainable Water Resources Management,* 6**,** 17.

OKUMAH, M., ANKOMAH-HACKMAN, P. & YEBOAH, A. S. 2020a. Do socio-demographic groups report different attitudes towards water resource management? Evidence from a Ghanaian case study. *GeoJournal.*

OKUMAH, M., CHAPMAN, P., MARTIN-ORTEGA, J. & NOVO, P. 2019a. Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway. *Water,* 11**,** 29.

OKUMAH, M., MARTIN-ORTEGA, J. & NOVO, P. 2018. Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: A conditional process modelling. *Land Use Policy,* 76**,** 36-45.

OKUMAH, M. & YEBOAH, A. S. 2019. Exploring stakeholders' perceptions of the quality and governance of water resources in the Wenchi municipality. *Journal of Environmental Planning and Management***,** 1-29.

OKUMAH, M., YEBOAH, A. S. & AMPONSAH, O. 2020b. Stakeholders' willingness and motivations to support sustainable water resources management: Insights from a Ghanaian study. *Conservation Science and Practice,* 2**,** e170.

OKUMAH, M., YEBOAH, A. S., NKIAKA, E. & AZERIGYIK, R. A. 2019b. What Determines Behaviours Towards Water Resources Management in a Rural Context? Results of a Quantitative Study. . *Resources,* 8.

PETTY, R. & CACIOPPO, J. 1986. *Communication and Persuasion: central and peripheral routes to attitude change,* New York, pringer-Verlag.

PHUC, X. 2009. Why did the forest conservation policy fail in the Vietnamese uplands? Forest conflicts in Ba Vi National Park in Northern Region. *International Journal of Environmental Studies,* 66**,** 59-68.

POŠKUS, M. S. 2016. Investigating pro-Environmental Behaviors of Lithuanian University Students. *Current Psychology*.

PRAGER, K. 2012. Understanding Behaviour Change: How to apply theories of behaviour change to SEWeb and related public engagement activities. Aberdeen/Edinburg: Scottish Government/Scottish Environment Protection Agency (SEPA).

PRAKASH, G. & PATHAK, P. 2017. Intention to buy eco-friendly packaged products among young consumers of India: A study on developing nation. *Journal of Cleaner Production,* 141**,** 385-393.

PRETE, M. I., PIPER, L., RIZZO, C., PINO, G., CAPESTRO, M., MILETI, A., PICHIERRI, M., AMATULLI, C., PELUSO, A. M. & GUIDO, G. 2017. Determinants of Southern Italian households' intention to adopt energy efficiency measures in residential buildings. *Journal of Cleaner Production,* 153**,** 83-91.

PRICE, J. C. & LEVISTON, Z. 2014. Predicting pro-environmental agricultural practices: The social, psychological and contextual influences on land management. *Journal of Rural Studies,* 34**,** 65-78.

RAYMOND, C. M. & KENTER, J. O. 2016. Transcendental values and the valuation and management of ecosystem services. *Ecosystem Services,* 21**,** 241-257.

RISE, J., THOMPSON, M. & VERPLANKEN, B. 2003. Measuring implementation intentions in the context of the theory of planned behavior. *Scandinavian Journal of Psychology,* 44**,** 87–95.

ROBINSON, R. & SMITH, C. 2002. Psychosocial and Demographic Variables Associated with Consumer Intention to Purchase Sustainably Produced Foods as Defined by the Midwest Food Alliance. *Journal of Nutrition Education and Behavior,* 34**,** 316-325.

ROSENBERG, M. S., ROTHSTEIN, H. R. & GUREVITCH, J. 2013. Effect sizes: conventional choices and calculations. *Handbook of Meta-analysis in ecology and evolution.* Princeton and Oxford: Princeton University Press.

SCHWARTZ, S. 1970. Elicitation of moral obligation and self-sacrificing behavior. *Journal of Personality and Social Psychology,* 15.

SCHWARTZ, S. H. 1968. Awareness of Consequences and the Influence of Moral Norms on Interpersonal Behavior. *Sociometry,* 31**,** 355-369.

SCHWARTZ, S. H. 1977. Normative influences on altruism. *Advances in Experimental Social Psychology.*

STAATS, H., HARLAND, P. & WILKE, H. A. M. 2016. Effecting Durable Change. *Environment and Behavior,* 36**,** 341-367.

STEG, L. & VLEK, C. 2009. Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of environmental psychology,* 29**,** 309-317.

STERN, P. C. 2000. Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues,* 56**,** 407–424.

STERN, P. C. & DIETZ, T. 1994. The value basis of environmental concern. *Journal of social issues,* 50**,** 65-84.

STERN, P. C., DIETZ, T., ABEL, T., GUAGNANO, G. A. & KALOF, L. 1999. A value-belief-norm theory of support for social movements: The case of environmentalism. *Human ecology review***,** 81-97.

STERN, P. C., DIETZ, T. & BLACK, J. S. 1985. Support for environmental protection: The role of moral norms. *Population and Environment,* 8**,** 204-222.

SWAIM, J. A., MALONI, M. J., NAPSHIN, S. A. & HENLEY, A. B. 2013. Influences on Student Intention and Behavior Toward Environmental Sustainability. *Journal of Business Ethics,* 124**,** 465-484.

TANNER, C. 1999. Constraints on Environmental Behaviour. *Journal of Environmental Psychology,* 19**,** 145^157.

TANNER, C. & KAST, S. W. 2003. Promoting Sustainable Consumption: Determinants of Green Purchases by Swiss Consumers. *Psychology & Marketing,* 20**,** 883–902.

TERRY, D. J., HOGG, M. A. & WHITE, K. M. 1999. The theory of planned behaviour : Selfidentity, social identity and group norms. *British Journal of Social Psychology,* 38**,** 225-244.

THOMPSON, S. G. & HIGGINS, J. P. T. 2002. How should meta-regression analyses be undertaken and interpreted? *STATISTICS IN MEDICINE,* 21**,** 1559–1573.

TONGLET, M., PHILLIPS, P. S. & READ, A. D. 2004. Using the Theory of Planned Behaviour to investigate the determinants of recycling behaviour: a case study from Brixworth, UK. *Resources, Conservation and Recycling,* 41**,** 191-214.

TRUELOVE, H. B. & JOIREMAN, J. 2009. Understanding the Relationship Between Christian Orthodoxy and Environmentalism: The Mediating Role of Perceived Environmental Consequences. *Environment and Behavior,* 41**,** 806-820.

UNTARU, E.-N., ISPAS, A., CANDREA, A. N., LUCA, M. & EPURAN, G. 2016. Predictors of individuals' intention to conserve water in a lodging context: the application of an extended Theory of Reasoned Action. *International Journal of Hospitality Management,* 59**,** 50-59.

VAN BIRGELEN, M., SEMEIJN, J. & BEHRENS, P. 2011. Explaining pro-environment consumer behavior in air travel. *Journal of Air Transport Management,* 17**,** 125-128.

VELUDO-DE-OLIVEIRA, T., PALLISTER, J. G. & FOXALL, G. R. 2012. Accounting for Sustained Volunteering by Young People: An Expanded TPB. *International Journal of Voluntary and Nonprofit Organizations,* 24**,** 1180-1198.

VRAIN, E. & LOVETT, A. 2016. The roles of farm advisors in the uptake of measures for the mitigation of diffuse water pollution. *Land Use Policy,* 54**,** 413-422.

VRAIN, E., LOVETT, A., NOBLE, L., GRANT, F., BLUNDELL, P. & CLEASBY, W. 2014. FARMER ATTITUDES TOWARDS DIFFUSE POLLUTION MITIGATION MEASURES IN ENGLAND. Department for Environment, Food & Rural Affairs.

WARRINER, G., MCDOUGALL, G. & CLAXTON, J. 1984. Any data or none at all? Living with inaccuracies in self-reports of residential energy consumption. . *Environ Behav* 503–526.

WERNER, C. M. & MAKELA, E. 1998. Motivations and behaviors that Support Recycling. *Journal of Environmental Psychology,* 18**,** 373]386.

WESSELINK, R., BLOK, V. & RINGERSMA, J. 2017. Pro-environmental behaviour in the workplace and the role of managers and organisation. *Journal of Cleaner Production,* 168**,** 1679-1687.

WYNVEEN, C. J. & SUTTON, S. G. 2016. Engaging Great Barrier Reef Stakeholders: Mediation Analyses of Barriers Among the Antecedents of Pro-Environmental Behavior. *Human Dimensions of Wildlife,* 22**,** 126-141.

XU, X., MAKI, A., CHEN, C.-F., DONG, B. & DAY, J. K. 2017. Investigating willingness to save energy and communication about energy use in the American workplace with the attitude-behavior-context model. *Energy Research & Social Science,* 32**,** 13-22.

ZHANG, Y., ZHANG, H.-L., ZHANG, J. & CHENG, S. 2014. Predicting residents' pro-environmental behaviors at tourist sites: The role of awareness of disaster's consequences, values, and place attachment. *Journal of Environmental Psychology,* 40**,** 131-146.

Chapter 4

Mitigating agricultural diffuse pollution: Uncovering the evidence base of the awareness–behaviour–water quality pathway

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Abstract

Diffuse water pollution from agriculture (DWPA) is a major environmental issue worldwide causing eutrophication, human health problems, increased water treatment costs and reducing the recreational potential of water bodies. In addition to penalties and provision of incentives, policy efforts are increasingly focussing on raising land managers' awareness regarding diffuse pollution under the expectation that this would influence behaviours and thus increase uptake of best management practices that would, in turn, improve water quality. Given the multimillion financial investments in these awareness-focused approaches, a good understanding of the awareness–behavioural change–water quality pathway is critical to set the basis for assessing the real potential of these policy interventions. We systematically review the evidence across the full pathway drawing on published peer-reviewed papers from both the social and natural sciences, with a focus on Europe and North America. Results indicate that there is no one study that looks at the pathway in full, evidencing the paucity of research on the topic. For the limited studies that focus on the different components of the pathway, we find mixed evidence for the relationship between awareness and behaviour, and behavioural change and water quality. Furthermore, complexity within the pathway (e.g., through the study of factors mediating and moderating such relationships) has hardly been addressed by the literature. An in-depth understanding and analysis of this complexity—through an integrative model

covering the entire pathway—could help in the design and implementation of effective policy strategies to encourage best land management practices and ultimately improve water quality.

Keywords: Environmental Knowledge; Land Management; Pro-Environmental Behaviour; Best Management Practice; Water Resource Management; Diffuse Water Pollution from Agriculture

4.1. Introduction

Diffuse water pollution from agriculture (DWPA) is a major environmental issue worldwide, causing eutrophication, human health problems, increased water treatment costs and reducing the recreational potential of water bodies (Hutchins, 2012, OECD, 2012, United Nations World Water Assessment Programme, 2015, Novotny, 1999). In Europe for instance, diffuse agricultural pollution poses significant pressure on 38% of the region's water bodies (United Nations World Water Assessment Programme, 2015). As the pressure to increase food production globally augments, DWPA is likely to increase (United Nations World Water Assessment Programme, 2015). In their search for new strategies to tackle this problem, academics and policymakers have increasingly drawn their attention to understanding and influencing the behaviour of land managers over the past decade (Blackstock et al., 2010, Gehring et al., 2016, Vrain et al., 2014). By addressing farmers' behaviours with respect to the adoption of best management practices (BMPs), it is expected that diffuse pollution at the catchment scale can be reduced (Blackstock et al., 2010, Kay et al., 2009, Kay et al., 2012).

Among other mechanisms (e.g., penalties, provision of incentives), one of the strategies towards changing land managers' behaviour has been the provision of

advice and increasing awareness (Blackstock et al., 2010, Merrilees and Duncan, 2005, Okumah et al., 2018). This has resulted in the development of novel awareness-focused approaches that represent a transition from top-down, punitive and narrow strategies to bottom-up, voluntary, collaborative and integrative ones (Blackstock et al., 2010, Vrain et al., 2014, Environment Agency, 2011, Environment Agency, 2014, Macleod et al., 2007, OECD, 2017, DPMAG, 2015). This shift is as a result of the failure of earlier approaches to significantly tackle DPWA due to its complexities (e.g., DPWA has an emergent character, several causal factors with multiple stakeholders). These novel approaches are expected to enable policy-makers and catchment managers to tap into land managers' (and other stakeholders') knowledge regarding their farm environments and socio-ecological systems to understand the "why" and "how" to achieve better outcomes (DPMAG, 2015, Environment Agency, 2011, Environment Agency, 2014, Falkenmark, 2004). Notably, catchment-based approaches (CaBA)—also referred to as integrated catchment and watershed management programmes—are being used in Europe and North America to provide advice to farmers through various participatory means (Environment Agency, 2011, Environment Agency, 2014, DPMAG, 2015, Winfield and Benevides, 2003, Iital et al., 2014, Iital et al., 2008, Hadrich and Van Winkle, 2013, Drangert et al., 2017). It is expected that such dialogical approaches increase land managers' awareness of diffuse pollution and mitigation measures, leading to changes in behaviour that would reflect in the adoption of best land management practices and ultimately in water quality improvement (Environment Agency, 2011, Environment Agency, 2014, DPMAG, 2015, Falkenmark, 2004). Awareness refers to land mangers' consciousness of DWPA, mitigation measures, and/or associated consequences of (not) taking up such measures.

The cornerstone of these expectations is the assumption that a relatively straightforward link between awareness, behaviour and improvement in water quality can be established, but there is not yet a comprehensive review of the evidence to support this. The few existing reviews on this topic (e.g., Kay et al., 2009, Baumgart-Getz et al., 2012) have only covered individual links between awareness and behaviour and behavioural change and water quality, but not the pathway in full. For example, Baumgart-Getz et al. focused on factors that affect adoption of BMPs without looking at their impact on water quality (Baumgart-Getz et al., 2012). On the other hand, Kay et al. focused on whether the implementation of BMPs led to an improvement in water quality, without consideration of whether and how awareness affect land managers' adoption of those practices (Kay et al., 2009). Given that land managers' attitudes and behaviours are fundamental antecedents of environmental quality and change (Steg and Vlek, 2009), we would argue that partial understanding of this pathway is going to fall short of providing the comprehensive understanding that is needed for effective policy designs. Considering the multimillion financial investments in these awareness-focused approaches (Environment Agency, 2014), a good understanding of the awareness–behavioural change–water quality pathway is thus critical to set the basis for assessing the real potential of these policy interventions.

This improved understanding of the awareness–behavioural change–water quality pathway could help assess the effects of awareness-focused interventions as well as allow stakeholders to adjust policy strategies to help reverse increasing pollution of water bodies within local contexts (Giri and Qiu, 2016). We contribute to addressing this knowledge gap by systematically reviewing the evidence base of

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awareness–behavioural change–water quality pathway in full, with a regional focus (Europe and North America). The added value of this study therefore lies in its ability to uncover the full pathway and, unlike earlier reviews, cutting across the natural and social sciences. Specifically, the study seeks to answer the following questions: (1) What is the evidence base of the awareness–behaviour–water quality pathway? (2) Based on this evidence, can we establish which factors (referred to as mediators and moderators) affect or could affect the complex relationships within this pathway? and (3) Which aspects of the full pathway and which variables have received little or no attention and what does it say of our current ability to develop strategies to mitigate diffuse pollution from agriculture?

4.2. Methodology

We employed a systematic review method to evaluate and synthesize the evidence linking awareness, behavioural change and improvement in water quality (Bilotta et al., 2014, Collaboration for Environmental Evidence, 2013). This was done as a structured and iterative process in four phases. In Phase 1, data search and extraction included an online search for papers. This involved the application of clearly defined search terms to access publications from the following academic sources: Google Scholar, Web of Science, Scopus, the Applied Social Sciences Index and Abstracts and Sociological Abstracts. Search terms covered the areas of environmental knowledge and awareness, behaviour, and water quality change as indicated in Table 4.1 (see Appendix C1 for an explanation on how the search items were applied). We restricted our search to documents published in English and within the last three decades (from 1987) because many contemporary diffuse pollution management policies and monitoring networks either commenced, became more consolidated or gained prominence around that time (Iital et al., 2008, EC,

1991, EC, 2000, EC, 2005). The final process in the literature search involved a snowball technique of manually tracing references from recent papers (e.g., Kay et al., 2009, Kay et al., 2012a, Iital et al., 2008, Giri and Qiu, 2016). This process yielded a total of 609 papers.

In Phase 2, references were filtered to remove duplicates, resulting in a total of 492 papers. In Phase 3 papers were screened to select those relevant to this study. To do this we read the titles, abstracts and the methodology section and applied the following inclusion criteria: reported the results of an empirical research, focused on the role of information or advice on uptake of diffuse pollution mitigation measures and/or water quality. After this stage, a substantial number of papers were excluded (n = 456), resulting in 36 published papers. The 456 papers were excluded for either being a review paper (e.g., Blackstock et al., 2010, Kay et al., 2009, Merrilees and Duncan, 2005, Winfield and Benevides, 2003, Baumgart-Getz et al., 2012), providing conceptual overview of integrated catchment management approaches (e.g., Macleod et al., 2007, Falkenmark, 2004) or not focused on any of the components of the pathway. Here, empirical research refers to evidence from scientific testing or observation as opposed to speculation, hypothetical modelling or anecdotal information. We selected empirical papers because the study aimed at providing the evidence base of the awareness–behaviour–water quality pathway thus, the need for 'reliable information' as opposed to speculations, anecdotal data, or papers providing conceptual overview.

Next, we retained only papers that were based on observation and from North America or Europe. Our reason for retaining only papers from these regions was to analyse papers from similar farming and policy settings, and which covered a region

in which catchment-based approaches and awareness-oriented strategies are being clearly articulated and promoted (Environment Agency, 2011, Environment Agency, 2014, DPMAG, 2015, Winfield and Benevides, 2003, Iital et al., 2008). Only 19 papers met all of the criteria outlined above and form the basis of this review (see Appendix C2 for an overview of these papers).

The fourth and final phase involved reading all of the 19 papers and extracting data relevant to the three research questions. A deductive approach was employed to analyse the evidence in relation to the three research questions: (1) what is the evidence base of the awareness–behaviour–water quality pathway? (2) Which factors affect or could affect this pathway? (3) Which aspects of the full pathway and which variables have received little or no attention? The approach offers the possibility to expound underlying connections between models and variables and the opportunity to take a broad view of research findings. The papers were evaluated critically for key results, with the aim of identifying the presence of an observed relationship between variables (which could be direct or indirect and/or positive, negative or mixed) or whether there was no evidence of a relationship.

Next, we checked whether authors reported psychosocial and biophysical variables (referred to as mediators[7] and moderators) that affect or could affect the relationships under study. This is because the literature on environmental psychology, land management and environmental biogeochemistry have highlighted that some variables could affect the relationship between awareness and behaviour and behaviour and water quality. For instance, even when a farmer is aware of

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[7] Mediators are variables through which an independent variable (e.g., awareness) transmits its effects onto a dependent variable (e.g., water quality) while moderators are those elements that contingently influence the statistical significance, direction and/or strength of the relationship between two or more other variables (e.g., awareness, behaviour and water quality).

diffuse pollution mitigation measures, uptake of such measures is not guaranteed as this depends on e.g., farm type, scheme design, financial cost and time required to implement such mitigation measures (Lobley and Potter, 1998, Barnes et al., 2009, Macgregor and Warren, 2006). Similarly, even when farmers implement the required mitigation measures, improvement in water quality is not guaranteed as this depends on e.g., land use type and intensity, pollutant type, crop uptake of nutrients, and for groundwater, this depends very much on the depth of the aquifer (Iital et al., 2008, Giri and Qiu, 2016, Chen et al., 2017, Carling et al., 2001). Investigating the interaction between these factors and the awareness–behaviour–water quality pathway is expected to enhance our understanding.

Table 4.1. Compilation of search terms.

| Group	Search Terms
1. Environmental knowledge and awareness	Advice; Agricultural Stewardship; Agrienvironmental Scheme; Appreciation; Consciousness; Awareness Campaign; Awareness; Environmental Concern; Environmental Education, Environmental Stewardship; Information; Intervention Programme; Knowledge; Recognition; Understanding
2. Behaviour	Act; Adoption; Apply; Carry Out; Compliance; Conform; Effect; Engage; Execute; Implementation; Perform; Practise; Uptake
3. Land management	Agricultural Change; Best Management Practice; Catchment Management; Catchment Sensitive Farming; Conservation; Diffuse Pollution Management; Diffuse Pollution Mitigation; Farm Management Practices; Farm Practices; Hydrologically Sensitive Area Measures; Land Quality Sustenance; Land Resource Management; Land Resource Use; Land Use Control; Land Use Pattern; River Basin Management; River Management; Soil Conservation; Soil Management; Sustainable Agriculture; Sustainable Farming Activities; Water Resource Management; Watershed Management
4.Water quality and agricultural pollutants	Agricultural River; Agricultural Runoff; Aquatic Ecosystem; Contamination Potential Index; Deposition Flux; Ecological Condition of Water; Ecological Status of Water; Groundwater Quality; Marine Eutrophication; Nitrate; Soil Water Retention; Nitrate; Nitrogen Deposition; Nitrogen Deposits; Nutrient Leakage; Nutrient Pollution; Pesticide concentration; Phosphate; Phosphorus Deposition; Phosphorus Exportation; Pollutant Concentration; Pollutant Load; Reduced Nutrient; River Water Chemistry; Riverine Loads; Stream Health; Stream Integrity; Stream Purification; Stream Water Quality; Surface Water Quality; Water Quality Assessment; Water Quality Improvement; Water Quality Index; Water Regulation Capacity; Watershed Hydrology; Sediment

4.3. Results and discussion

4.3.1. Overview of the evidence

The 19 papers selected for the purpose of this study span both the social and natural sciences (Appendix C2). Nine papers covered the behavioural change–water quality link, nine covered the awareness–behaviour link, and one paper covered the awareness–water quality link. None of the papers explored the full awareness–behavioural change–water quality pathway.

Figure 3.1 and Appendix C3 provide information on potential mediators and moderators of the awareness–behavioural change–water quality pathway. From Figure 4.1, it is clear that some variables (e.g., situational factors) have received substantial attention in the academic literature, while others (e.g., moral norms) have received much less attention. Situational factors are extrinsic factors that facilitate or constrain farmers' environmental behaviour and water quality responses. These may include institutional support (or lack of), farm size, farm type, farm tenure, income, cost of materials/compliance, 'goodness of fit' of schemes, flexibility of schemes, and variant of pollutant, among others. Of the 26 potential mediators and moderators, 14 of them are psychosocial factors (e.g., social norm, attitude, habit) mainly associated with awareness and behaviour. Eleven of these variables are biophysical factors (e.g., pollutant type, critical source of pollution) with direct implications for water quality, while the last variable (situational factors) affects both awareness and behaviour, and water quality.
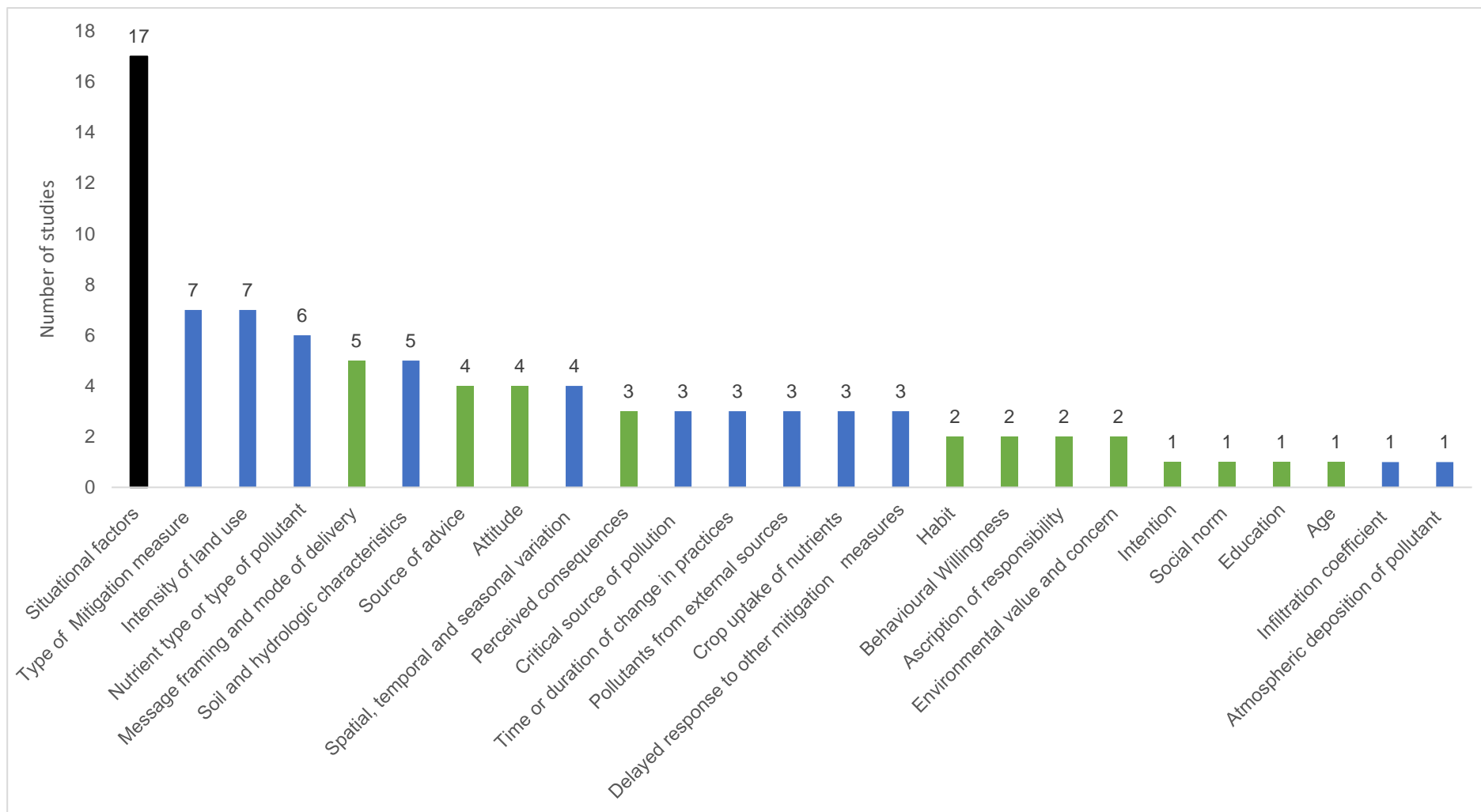
Figure 4.1. Summary of variables affecting the awareness–behavioural change–water quality pathway.

Note: Green = factors directly affecting awareness and behaviour; Blue = factors directly affecting water quality; Black = factor affecting awareness, behaviour and water quality.

4.3.2. Uncovering the evidence-base of the awareness–behaviour–water quality pathway

In this section, we classify the evidence under the following components of the pathway: (i) awareness–behaviour change link; (ii) awareness–water quality link; (iii) behavioural change–water quality link; and (iv) the full awareness–behaviour–water quality pathway.

4.3.2.1. Awareness–behavioural change link

Almost all studies that reported on a direct relationship between awareness and behavioural change (n = 7) indicate a positive effect with the exception of Barnes et al. and Macgregor and Warren who reported negative attitudes, lack of ascription of responsibility to self and unchanged behaviours despite the implementation of awareness campaigns and participation in schemes (Barnes et al., 2009, Macgregor and Warren, 2006). Two studies found a positive indirect effect through the mediating effect of agricultural stewardship (Floress et al., 2017, Okumah et al., 2018). That is, awareness affected participation in agricultural stewardship schemes and this in turn affected willingness and compliance with best land management practices.

Table 2 shows diffuse pollution mitigation measures and associated outcomes, as well as other variables that affect the awareness–behavioural change link. Results suggest that the relationship is influenced by a range of factors such as farm size, farm type, farm tenure, cost of materials/compliance, 'goodness of fit' of schemes, flexibility of schemes (see also Figure 4.1 and Appendix C3). Seven studies reported situational factors that affect this relationship (Okumah et al., 2018, Lobley and Potter, 1998), while social norm and intention were the least reported (only one study). Additionally, evidence shows that awareness itself may be dependent on

sociodemographic characteristics (e.g., age, education level and gender), environmental values, concern and beliefs, thus, better access to information does not guarantee an increase awareness for the DWPA (Kollmuss and Agyeman, 2002).

The idea that situational factors influence behaviours has been established in the literature, e.g., in Stern's Attitude–Behaviour–Context model which postulates that the link between attitude and behaviour is dependent on situational factors (Stern, 2000). Thus, where situational factors play a weak role, the direct link between attitude and behaviour is strong while this direct link weakens where the role of situational factors is strong. This is in line with the findings of some of the studies reviewed in this paper e.g., Macgregor and Warren, and Barnes et al. who found that attitudes and behaviours did not change despite awareness of the Nitrate Vulnerable Zones (NVZ) scheme (attributable to the inflexible nature of schemes, time and financial cost of compliance) (Barnes et al., 2009, Macgregor and Warren, 2006). The inflexible nature of schemes makes it often harder for farmers to respond to changes in markets thus even if advice is good, the scheme may not be flexible enough to allow uptake of BMPs—highlighting the crucial role of situational factors (e.g., scheme content and design). Overlooking these factors weakens the analysis and understanding of the awareness–behaviour link. This in turn limits our ability to design policies that can be adapted to various contexts or situations.

Although other potential moderators (e.g., source of advice, message framing and means of delivery) have not been widely studied and reported in the diffuse pollution management literature, they play a key role and need to be considered in policy designs. For instance, the limited research in this field has indicated that the source

of information (i.e., the institution that is sending the information and/or the farm advisor) is a crucial factor determining whether land managers take up best land management measures or not, especially where the message is well-placed, consistent and well framed (Prager, 2012, Juntti and Potter, 2002, Vrain and Lovett, 2016). Additionally, uptake across catchment might be influenced by social norms, that is, farmers are more likely to take up BMPs where their neighbours adopt such practices and the practices become embedded in their norms (Kuhfuss et al., 2016, Ayer, 1997).

Table 4.2. Effects of awareness on uptake of diffuse pollution mitigation measures.

Link	Diffuse Pollution Mitigation Measure(s)	Results	Other Influential Factors	Method	Number of Respondents	Reference
Direct relationship	Advice on general conservation/biodiversity management	59% adopted scheme measures.	Scheme design or package, farm system and income sources.	Survey and statistical test	144	(Lobley and Potter, 1998)
	General BMPs for farms and diffuse pollution advice	Awareness affects adoption ($p \leq 0.05$).	Belief, farm tenancy, access to equipment, farm size, and trust in source of advice.	Surveys, open interviews, focus groups and statistical analysis	145 1320 30 *	(Rehman et al., 2007) (Ulrich-Schad et al., 2017) (Drangert et al., 2017)
	Nutrient management, filter strips, and streambank fencing	Those who were aware of nutrient management regulations were 28% more likely to adopt nutrient management as a BMP, and was found to increase filter strip adoption by 24%.	Business ownership, years anticipated to remain in business, education, cost/benefit.	Survey and statistical test	150	(Hadrich and Van Winkle, 2013)
	NVZ-related advice	Despite awareness of the NVZ regulations, farmer attitudes indicate a somewhat negative view towards the perceived environmental benefits, water management and behaviours have not changed.	Ascription of responsibility, attitudes and inflexible nature of regulations	Survey, workshops, interviews and statistical analysis	184 30 *	(Barnes et al., 2009) (Macgregor and Warren, 2006)
Indirect relationship	Diffuse pollution measures to protect water quality	Awareness influenced willingness ($p \leq 0.05$) to adopt as well as adoption/compliance ($p \leq 0.1$) indirectly through the mediating effect of agricultural stewardship. 46.2% complied with regulations.	Farm type and location.	Survey and statistical test	647 1564	(Floress et al., 2017) (Okumah et al., 2018)

For number of respondents, * indicates number for qualitative interviews; all others are surveys. Number of respondents follow a respective order where there are two or more references.

4.3.2.2. Awareness and water quality link

This was the least studied link in the awareness–behaviour–water quality pathway, with only one study found in the literature. Kreuger and Nilsson found that Swedish aquatic ecosystems underwent remarkable (more than 90%) reductions in concentrations of pesticides in catchments where farmers received catchment specific information regarding best pesticide management practices (Kreuger and Nilsson, 2001). Based on expert judgement and qualitative reasoning, they attribute this to an improvement in land management owing to awareness of BMPs regarding handling of spraying equipment and application procedures. However a clear link between both awareness and water quality is still missing. Further research is thus required to exploring how awareness translates into water quality improvements, what's the role of other influential factors such as farmer attitude, behaviours, and biogeochemical changes and ultimately what's the effectiveness of awareness centred approaches.

4.3.2.3. Behavioural change and water quality nexus

The nine papers reviewed found contrasting evidence for a relationship between uptake of mitigation measures and improvements in water quality (Table 4.3). Four papers found a positive effect, and five reported mixed results i.e., positive effect in some (sub) catchments, negative results in others and no changes in some others. Eight papers reported variation in results for different pollutants while five (of those eight papers) reported variation across (sub) catchments. For instance, Kay et al. reported a decline in nitrate concentrations in 7 of the 10 sub-catchments studied and that there was no decrease in phosphorus in any of the sub-catchments (Kay et al., 2012). They attributed this variation to a number of potential factors such as time lag and the fact that these pollutants derive from other sources than just

agriculture. This means that even when farmers take up mitigation measures, the impact on pollutant concentration and/or loads (and by extension, water quality) depends very much on the type of pollutant. For example, in the case of phosphorus, research has shown that the impact on concentrations may take longer to be realised due to the build-up of phosphorus in soils and river sediments—raising concerns about time lags (Environment Agency, 2011b, Environment Agency, 2014, Stålnacke et al., 2003, Grimvall et al., 2000, Meals et al., 2010). In catchments dominated by groundwater, nitrate usually moves slowly through the aquifer. Thus it can take several decades to reach rivers and so the impacts of land management actions (e.g., reduced fertiliser application) may not be evident for many years (Grimvall et al., 2000). As Kay et al. noted, the decline in nitrate concentration observed in some sub catchments could be due to delayed impacts of the implementation of NVZs (Kay et al., 2012). Such temporal and spatial mismatches may affect a direct relationship being observed in the short-term between behavioural change and improvements in water quality.

We also found that the variation in results across (sub) catchments could also be attributed to different levels of uptake by land managers across catchments and the focus of mitigation measures (Kay et al., 2009, Kay et al., 2012, Price et al., 2008)) which may be difficult to determine at the broader catchment scale. That is, farmers in some (sub) catchments may not implement the recommended measures and the measures implemented may vary in terms of focus: some farmers may adopt mitigation measures that are more focused on reducing nitrate leaching to water bodies as opposed to mitigation measures that are more focused on phosphorus. For instance, if farmers implement manure focused mitigation measures, this could result in little or no reduction in other pollutants e.g., sediments (Price et al., 2008).

However, if the mitigation measure focuses on reducing soil erosion, it is more likely that significant reduction in sediments will be realised (Price et al., 2008). This complex interaction between type of mitigation measures and uptake of measures needs to be more critically considered at the catchment scale to assess effectiveness of mitigation measures.

Again, biophysical factors such as the geological and climatic characteristics of the land affect the impact of behavioural changes on water quality (Iital et al., 2008, Giri and Qiu, 2016, Kyllmar et al., 2014, Lord et al., 2007). For instance, if farmers in two different catchments take up the same mitigation measures on their farms, improvement in water quality is likely to be lower in a catchment with high runoff. Ryberg et al. use structural equation modelling to show how these factors including climate variability and anthropogenic factors interact in a complex manner to determine phosphorus loads—a key measure of water quality—in the Chesapeake Bay watershed (Ryberg et al., 2018). They found that while purposeful management practices help in decreasing phosphorus loading in the watershed, the effects are counterbalanced by increasing runoff attributed to natural climate variability.

Other factors that may play a role include differences in land use, crop uptake of nutrients, and for groundwater, this depends very much on the depth of the aquifer (Iital et al., 2008, Giri and Qiu, 2016, Chen et al., 2017, Carling et al., 2001). Additionally, the intensity of land use may affect pollutant loads in water resources although reduced production and/or productivity levels do not always result in significant reduction of agricultural pollutants in water bodies (Povilaitis, 2006). Moreover, some land units may be critical sources of diffuse pollution than others (Kay et al., 2012, Giri and Qiu, 2016). This is related to hydrologically sensitive areas

(i.e., the portion of land within the catchment which contributes actively to runoff) and critical source area (that is, the portion of land within the catchment where large amounts of pollutants are generated) that may serve as explanatory variables to water quality responses (Giri and Qiu, 2016). For instance, Thompson et al. found that arable soils produced more suspended sediment than grassland and woodland in some catchments (Thompson et al., 2013).

Table 4.3. Effects of uptake of mitigation measures on water quality.

Pollutant	Mitigation Measure(s)	Results	Other Influential Factors	Reference
Nitrate	Implementation of the Code of Good Agricultural Practice and measures in Nitrate Vulnerable Zones (NVZ).	Nitrate concentrations decreased significantly in 7 out of 10 sub catchments. The median nitrate concentration reduced from 3.7 mg N L^{-1} before implementation to 2.7 mg N L^{-1} after implementation (study conducted between 2006 and 2009).	Time lag i.e., delayed benefits of NVZ actions (as this started in 2002).	(Kay et al., 2012)
	Reduction in the percentages of arable crops, lower N fertiliser use in arable farming, greater extent of cover cropping, grassland with little or no N fertilisation.	Nitrate content reduced by 3.2 mg L^{-1}, with up to −4.4 mg L^{-1} observed in some areas. Mean reduction in N leaching of 29% (16 kg N ha^{-1} $year^{-1}$) for the arable land in the Fehraltorf catchment.	Soil and hydrological characteristics, type of mitigation measure and critical source, scale of analysis.	(Herzog et al., 2008)
	Implementation of the Code of Good Agricultural Practice, spatial and temporal restrictions for use of fertilisers, buffer strips along the water courses, protection zones around the wells, etc.	No significant changes in concentration was observed except for an increase in one river (the River Ra¨pu). For ground water, recent (since 2003) results indicate a slight increase in nitrate content in those areas with more intensive agriculture.	Land use intensity, soil and hydrological characteristics, and how long measure was implemented.	(Iital et al., 2008)
	Use of buffer strips (For a more detailed review of nutrient efficacies of buffer zones, see (Kay et al., 2009)).	No statistically significant differences were observed (at $P > 0.05$) between buffer strip (BS) and no buffer strip (no-BS). Nutrient removal efficiency: 9% decrease–217% increase	Spatial and seasonal variation, soil and hydrological characteristics.	(Borin et al., 2005)
	Buffer strips (BS) A fertilization rate reduction by 15% and 30% BS, fertilizer reduction, Pasture land increase and other BMPs.	A reduction of 3.9–9.3% in nitrate load depending on width of BS 15.1% and 25% reduction respectively in nitrate loads 4.7%–38.2% reduction in nitrate loads; results varied across seasons.	Land use intensity and how long measure was implemented.	(Haas et al., 2017)
	Reduce fertilizer application	Land with nitrate concentrations exceeding 50 mg L^{-1} observed 13%–33% reduction but results vary across different variants of N. Nitrate leaching decreased by 0.08 kg ha^{-1} $year^{-1}$ when the net N loading of the soil decreased by 1 kg ha^{-1} $year^{-1}$, but results differed across soil type, land use and hydrology. Land with nitrate concentrations exceeding 100 mg L^{-1}decreased from 1%–17% depending on the variant of N.	Pollutant type, type of mitigation measure, spatial and seasonal variation, land use intensity, how long measure was implemented, external sources, crop uptake of nutrients.	(Oenema et al., 2005)
	NVZ regulations	29% of NVZs showed a significant improvement but 31% showed a significant worsening. The average improvement relative to a control due to NVZ designation was 0.02 ± 0.08 mg N L^{-1} $year^{-1}$.	Type of mitigation measure, soil and hydrological characteristics, land use intensity.	(Worrall et al., 2009)

Total N	Implementation of the Code of Good Agricultural Practice, spatial and temporal restrictions for use of fertilisers, buffer strips along the water courses, protection zones around the wells, etc.	A statistically significant decreasing trend in TN was observed in the River Põltsamaa	Pollutant type, type of mitigation measure, critical source, spatial and seasonal variation, soil and hydrological characteristics and external sources.	(Iital et al., 2008)
	Reduced autumn ploughed area between 7% and 17%., introduction of catch crop and constructed wetlands.	Non-statistically significant downward trend observed (*p*-value ≥ 0.05), though some catchments show a decline or an increase in absolute values.	Differences in crop type, land use intensity, fertilizer application and delay in uptake of measures in some catchments. Intensity of advisory services and financial support varied.	(Bechmann et al., 2008)
	Use of buffer strips	Reducing total nitrogen losses from 17.3 to 4.5 kg ha^{-1} in terms of mass balance. Nutrient removal efficiency: 10% decrease–217% increase	Spatial and seasonal variation, soil and hydrological characteristics.	(Borin et al., 2005)
	Tramline management	74–98% reduction in what total N	Pollutant type, type of mitigation measure, spatial, temporal and seasonal variation.	(Deasy et al., 2010)
Total P	Placement of in-field manure heaps, soil and manure nutrient content analysis, leaving buffer zones next to water courses when spreading manure and reseeding grassland, installing stream fencing to exclude livestock.	Remained relatively static except for 1 monitoring site where a reduction was observed, even with that, the *p*-value of regression analysis was non-significant.	Probably due to some farmers not engaging and others implementing particular measures only.	(Kay et al., 2012)
	Reduction in the percentages of arable crops, Lower N fertiliser use in arable farming, greater extent of cover cropping, Grassland with little or no N fertilisation.	The P pollution of Swiss surface waters from farm systems reduced by between 10% and a maximum of 30%.	Soil and hydrological characteristics, type of mitigation measure and critical source.	(Herzog et al., 2008)
	Reduced autumn ploughed area between 7% and 17%., introduction of catch crop and constructed wetlands.	Nonstatistically significant downward trend observed (*p*-value ≥ 0.05) though some catchments show a decline in absolute values.	Differences in crop type, type of mitigation measure, intensity of land use, soil and hydrologic characteristics, how long measure was implemented, intensity of advisory services, level of financial support.	(Bechmann et al., 2008)
	Use of buffer strips	27% reduction–41% increase in total P	Spatial and seasonal variation, soil and hydrological characteristics.	(Borin et al., 2005)

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	Tramline management	72–99% reduction in total P	Type of mitigation measure, spatial, temporal and seasonal variation.	(Deasy et al., 2010)
	Reduce fertilizer application	Reduction in P leaching to surface waters was much less than 0.1 kg ha^{-1} when the net P loading of the soil diminished by 1 kg ha^{-1} (mainly because P is strongly retained by the soil).	Type of mitigation measure, spatial and seasonal variation, land use intensity, how long measure was implemented, external sources, crop uptake of nutrients.	(Oenema et al., 2005)
Dissolved P	Placement of in-field manure heaps, soil and manure nutrient content analysis, leaving buffer zones next to water courses when spreading manure and reseeding grassland, installing stream fencing to exclude livestock	Remained relatively static except for 1 monitoring site where a reduction was observed, with the *p*-value of regression analysis being significant.	Possibility of external sources of pollutants e.g., Boron.	(Kay et al., 2012)
	Implementation of the Code of Good Agricultural Practice, spatial and temporal restrictions for use of fertilisers, buffer strips along the water courses, protection zones around the wells, etc.	No significant trends in P concentrations in agricultural rivers since the 1990s except for an increase in the River Ra¨pu.	Farm type, land use intensity and external sources of pollutants.	(Iital et al., 2008)
	Use of buffer strips	No significant differences in total P concentrations between BS and no-BS but the median reduction (almost 22%) became significant (P < 0.05). Nutrient removal efficiency: 17% decrease–475% increase	Spatial and seasonal variation, soil and hydrological characteristics.	(Borin et al., 2005)
Sediment	Reduced autumn ploughed area between 7% and 17%., introduction of catch crop and constructed wetlands.	Non-statistically significant downward trend for some catchments, but one catchment shows a statistically significant upward trend (*p*-value ≤ 0.05)	Differences in crop type, land use intensity, fertilizer application and delay in uptake of measures in some catchments. Variation in intensity of advisory services and financial support.	(Bechmann et al., 2008)
	Use of buffer strips	78% reduction in sediment losses	Spatial and seasonal variation, soil and hydrological characteristics.	(Borin et al., 2005)
	Tramline management	75–99% reduction in sediment losses	Type of mitigation measure, spatial, temporal and seasonal variation.	(Deasy et al., 2010)

4.3.2.4. Awareness–behaviour–water quality pathway

We did not find any primary study in the academic literature that investigates the full awareness–behaviour–water quality pathway, although researchers often tried to link these variables using correlation analysis, qualitative inferences and/or expert judgement (e.g., Kay et al., 2012). As such, there is currently a lack of evidence on the hypothesis that land managers who are aware of diffuse pollution and mitigation measures are more likely to take up these measures and this, in turn, may result in improvements in water quality.

Additionally, none of the studies reviewed in this study considered the joint effect of psychosocial and biophysical factors on land management and water quality. While existing studies examined the factors that can potentially affect awareness and adoption of diffuse pollution mitigation measures, the mechanisms and the conditions under which this happens (i.e., the relevant mediators and moderators) and whether some of these factors are confounding variables remain understudied. However, when these variables are considered in first generation statistical techniques (e.g., correlations, multiple regressions), they are found to have an influence on awareness and/or adoption of mitigation measures (e.g., Amponsah et al., 2016, Kagoya et al., 2018, Mango et al., 2017). These findings point to the need for developing more sophisticated analysis that takes into account the complex nature of catchments, pro-environmental behaviour and diffuse agricultural water pollution (Macleod et al., 2007). Knowledge of the mechanisms and interactions between awareness and these variables can help to design more targeted and effective land use policies (Merrilees and Duncan, 2005, Ryberg et al., 2018).

We now turn to discuss potential limitations of our study. For instance, although the strategy adopted in the data gathering process, a multi-pronged method enhances

precision and recall rates (Jaffe and Cowell, 2014), there is a danger that a few studies are missed if they do not contain the search terms in their titles, keywords and abstracts. That is, there could be work on the impact of specific measures (e.g., cover cropping) on specific pollutants other than the ones selected but they will not be reported as 'water quality'. We attempt to mitigate this limitation by using the snowball technique where key references are traced as well as randomly reading additional papers. Nonetheless, we admit there is the possibility that we missed a few key papers.

Like all narrative and vote counting reviews, this research was unable to determine the overall magnitude (and statistical significance) of the relationship between the variables as well as the cause of discrepancy in results of the different primary studies (Koricheva and Gurevitch, 2013). The method allows for the identification of potential factors (e.g., methods) responsible for the discrepancy in results of the various primary studies, however it does not enable the determination or confirmation of statistical significance. Therefore, while we encourage more primary research on the topic, it is important that future reviews employ meta-analytic techniques to determine overall magnitude of the relationship between awareness, behavioural change and water quality as well as the bases of variation in outcomes reported across studies (Koricheva and Gurevitch, 2013).

4.4. Concluding remarks

Diffuse water pollution from agriculture (DWPA) is a major and persistent environmental issue worldwide causing multiple problems. Recent policies introduced to improve water quality have focused on raising land managers' awareness regarding diffuse pollution, under the expectation that this would influence behaviours and thus increase uptake of best management practices. As stakeholders commit financial resources to awareness-focused approaches, it is important that a good understanding of the awareness–

behavioural change–water quality pathway is developed to assess the effects of these policy interventions. In this study, we systematically review, for the first time, the evidence across the full pathway drawing on published peer-reviewed papers from both the social and natural sciences.

Results indicate that there is no study that looks at the pathway in full, showing the paucity of research on the topic. For the existing studies that focused on the different components of the pathway, we find mixed evidence for the relationship between awareness and behaviour, and behavioural change and water quality; some studies reported negative relationships, others found positive relationships, yet other studies reported that no impact on behaviour and water quality was found despite the implementation of awareness-focused interventions. Furthermore, complexity within the pathway has hardly been addressed by the literature. Complexity and variability of diffuse water pollution, catchments and pro-environmental behaviour challenge our ability to design 'tailored' diffuse water pollution reduction measures. However, from a research perspective, a better understanding of the factors that mediate or moderate the relationships between the various components of the pathway might enable us to disentangle the mechanisms through which these relationships operate as well as the conditions under which they occur. Such a more profound understanding would offer an opportunity to design and implement more context-specific, and possibly more effective policies to influence uptake of BMPs and ultimately improve water quality. This could be facilitated through the development of an integrative model, in which researchers treat behavioural change as a key mediator in the relationship between awareness and water quality, with other situational, biophysical and psychosocial factors acting as moderators of these relationships across the awareness–behaviour–water quality pathway.

From a policy perspective, policymakers need to incorporate the relevant factors outlined in the full pathway in their strategies to influence uptake of mitigation measures. The outcomes and impacts of such strategies on behaviour and water quality could then be evaluated using the integrative models developed from research. While the implementation of such integrative models could be challenging, their application could offer very useful understandings of the role of DWPA policies.

References

AMPONSAH, O., HÅKAN, V., SCHOU, T. W., BRAIMAH, I., ABAIDOO, R. C. J. E., DEVELOPMENT & SUSTAINABILITY 2016. The impact of farmers' participation in field trials in creating awareness and stimulating compliance with the World Health Organization's farm-based multiple-barrier approach. 18**,** 1059-1079.

AYER, H. W. 1997. Grass roots collective action: agricultural opportunities. *Journal of agricultural and resource economics***,** 1-11.

BARNES, A. P., WILLOCK, J., HALL, C. & TOMA, L. 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management,* 96**,** 1715-1722.

BAUMGART-GETZ, A., PROKOPY, L. S. & FLORESS, K. 2012. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of Environmental Management,* 96**,** 17-25.

BECHMANN, M., DEELSTRA, J., STÅLNACKE, P., EGGESTAD, H., ØYGARDEN, L., PENGERUD, A. J. E. S. & POLICY 2008. Monitoring catchment scale agricultural pollution in Norway: policy instruments, implementation of mitigation methods and trends in nutrient and sediment losses. 11**,** 102-114.

BILOTTA, G. S., MILNER, A. M. & BOYD, I. 2014. On the use of systematic reviews to inform environmental policies. *Environmental Science and Policy,* 42**,** 67-77.

BLACKSTOCK, K. L., INGRAM, J., BURTON, R., BROWN, K. M. & SLEE, B. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the total environment,* 408**,** 5631-5638.

BORIN, M., VIANELLO, M., MORARI, F., ZANIN, G. J. A., ECOSYSTEMS & ENVIRONMENT 2005. Effectiveness of buffer strips in removing pollutants in runoff from a cultivated field in North-East Italy. 105**,** 101-114.

CARLING, P. A., IRVINE, B. J., HILL, A. & WOOD, M. 2001. Reducing sediment inputs to Scottish streams: a review of the efficacy of soil conservation practices in upland forestry. *The Science of the total environment,* 265**,** 209-227.

CHEN, B., CHANG, S. X., LAM, S. K., ERISMAN, J. W. & GU, B. 2017. Land use mediates riverine nitrogen export under the dominant influence of human activities. *Environmental Research Letters,* 12**,** urn:issn:1748-9318.

COLLABORATION FOR ENVIRONMENTAL EVIDENCE 2013. Guidelines for Systematic Review and Evidence Synthesis in Environmental Management. Version 4.2. Bangor: Centre for Evidence-Based Conservation.

DEASY, C., QUINTON, J. N., SILGRAM, M., BAILEY, A. P., JACKSON, B. & STEVENS, C. J. 2010. Contributing understanding of mitigation options for phosphorus and sediment to a review of the efficacy of contemporary agricultural stewardship measures. *Agricultural Systems,* 103**,** 105-109.

DPMAG 2015. Strategy to reduce diffuse pollution. Edinburgh: Scottish Environment Protection Agency.

DRANGERT, J.-O., KIEŁBASA, B., ULEN, B., TONDERSKI, K. S. & TONDERSKI, A. 2017. Generating applicable environmental knowledge among farmers: experiences from two regions in Poland. *Agroecology and Sustainable Food Systems,* 41**,** 671-690.

EC 1991. Council Directive 91/676/EEC Concerning the Protection of Waters Against Pollution by Nitrates from Agricultural Sources, OJ L375. Brussels: European Commission.

EC 2000. Directive 2000/60/EC Establishing a Framework for Community Action in the Field of Water Policy, L 327. Official Journal of the European Communities. Brussels: European Commission.

EC 2005. Agri-environment Measures: Overview on General Principles, Types of Measures, and Application. Brussels: European Commission, Directorate General for Agriculture and Rural Development.

ENVIRONMENT AGENCY 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report. Bristol: Environment Agency

ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. . Bristol: Environment Agency.

FALKENMARK, M. 2004. Towards integrated catchment management: opening the paradigm locks between hydrology, ecology and policy-making. *International Journal of Water Resources Development,* 20**,** 275-281.

FLORESS, K., GARCÍA DE JALÓN, S., CHURCH, S. P., BABIN, N., ULRICH-SCHAD, J. D. & PROKOPY, L. S. 2017. Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality. *Journal of Environmental Psychology,* 53**,** 73-80.

GEHRING, C., BRAUN, H., DE SOUZA LIMA, A., JUNIOR, F. & DE OLIVEIRA REIS, F. 2016. Improving Farming Practices for Sustainable Soil Use in the Humid Tropics and Rainforest Ecosystem Health. *Sustainability,* 8**,** 841-841.

GIRI, S. & QIU, Z. 2016. Understanding the relationship of land uses and water quality in Twenty First Century: A review. *Journal of Environmental Management,* 173**,** 41-48.

GRIMVALL, A., STÅLNACKE, P. & TONDERSKI, A. J. E. E. 2000. Time scales of nutrient losses from land to sea—a European perspective. 14**,** 363-371.

HAAS, M. B., GUSE, B. & FOHRER, N. J. J. O. E. M. 2017. Assessing the impacts of Best Management Practices on nitrate pollution in an agricultural dominated lowland catchment considering environmental protection versus economic development. 196**,** 347-364.

HADRICH, J. & VAN WINKLE, A. 2013. Awareness and pro-active adoption of surface water BMPs. *Journal of Environmental Management,* 127**,** 221.

HERZOG, F., PRASUHN, V., SPIESS, E., RICHNER, W. J. E. S. & POLICY 2008. Environmental cross-compliance mitigates nitrogen and phosphorus pollution from Swiss agriculture. 11**,** 655-668.

HUTCHINS, M. G. 2012. What impact might mitigation of diffuse nitrate pollution have on river water quality in a rural catchment? *Journal of Environmental Management,* 109**,** 19-26.

IITAL, A., KLÕGA, M., PIHLAK, M., PACHEL, K., ZAHHAROV, A. & LOIGU, E. 2014. Nitrogen content and trends in agricultural catchments in Estonia. *Agriculture, Ecosystems and Environment,* 198**,** 44-53.

IITAL, A., PACHEL, K. & DEELSTRA, J. 2008. Monitoring of diffuse pollution from agriculture to support implementation of the WFD and the Nitrate Directive in Estonia. *Environmental Science and Policy,* 11**,** 185-193.

JAFFE, R. & COWELL, J. M. 2014. Approaches for improving literature review methods. Sage Publications Sage CA: Los Angeles, CA.

JUNTTI, M. & POTTER, C. 2002. Interpreting and Reinterpreting Agri-Environmental Policy:Communication, Trust and Knowledge in the Implementation Process. *Sociologia Ruralis,* 42**,** 216-232.

KAGOYA, S., PAUDEL, K. P. & DANIEL, N. L. J. E. M. 2018. Awareness and Adoption of Soil and Water Conservation Technologies in a Developing Country: A Case of Nabajuzi Watershed in Central Uganda. 61**,** 188-196.

KAY, P., EDWARDS, A. C. & FOULGER, M. 2009. A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. *Agricultural Systems,* 99**,** 67-75.

KAY, P., GRAYSON, R., PHILLIPS, M., STANLEY, K., DODSWORTH, A., HANSON, A., WALKER, A., FOULGER, M., MCDONNELL, I. & TAYLOR, S. 2012. The effectiveness of agricultural stewardship for improving water quality at the catchment scale: Experiences from an NVZ and ECSFDI watershed. *Journal of Hydrology,* 422-423**,** 10-16.

KOLLMUSS, A. & AGYEMAN, J. 2002. Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research,* 8**,** 239-260.

KORICHEVA, J. & GUREVITCH, J. 2013. Place of Meta-analysis among other methods of research synthesis. *In:* KORICHEVA, J., GUREVITCH, J. & MENGERSEN, K. (eds.) *Handbook of Meta-Analysis in Ecology and Evolution.* Princeton, NJ, USA; Oxford, MS, USA: Princeton University Press.

KREUGER, J. & NILSSON, E. Catchment scale risk-mitigation experiences- key issues for reducing pesticide transport to surface waters. British Crop Protection Council Symposium Proceedings, 2001. 319-324.

KUHFUSS, L., PRÉGET, R., THOYER, S., HANLEY, N., LECOENT, P. & DÉSOLÉ, M. 2016. Nudges, Social Norms, and Permanence in Agri-environmental Schemes. *Land Economics,* 92**,** 641.

KYLLMAR, K., BECHMANN, M., DEELSTRA, J., IITAL, A., BLICHER-MATHIESEN, G., JANSONS, V., KOSKIAHO, J., POVILAITIS, A. J. A., ECOSYSTEMS & ENVIRONMENT 2014. Long-term monitoring of nutrient losses from agricultural catchments in the Nordic–Baltic region–A discussion of methods, uncertainties and future needs. 198**,** 4-12.

LOBLEY, M. & POTTER, C. 1998. Environmental Stewardship in UK agriculture: A comparison of the environmentally sensitive area programme and the Countryside Stewardship Scheme in South East England. *Geoforum,* 29**,** 413-432.

LORD, E., SHEPHERD, M., SILGRAM, M., GOODLASS, G., GOODAY, R., ANTHONY, S. G., DAVISON, P. S. & HODGKINSON, R. 2007. Investigating the Effectiveness of NVZ Action Programme Measures: Development of a Strategy for England. Bristol: Department for Environment, Food and Rural Affairs.

MACGREGOR, C. J. & WARREN, C. R. 2006. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. *Agriculture, Ecosystems & Environment,* 113**,** 108-119.

MACLEOD, C. J. A., SCHOLEFIELD, D. & HAYGARTH, P. M. 2007. Integration for sustainable catchment management. *Science of the Total Environment,* 373**,** 591-602.

MANGO, N., MAKATE, C., TAMENE, L., MPONELA, P., NDENGU, G. J. I. S. & RESEARCH, W. C. 2017. Awareness and adoption of land, soil and water conservation practices in the Chinyanja Triangle, Southern Africa. 5**,** 122-129.

MEALS, D. W., DRESSING, S. A. & DAVENPORT, T. E. 2010. Lag Time in Water Quality Response to Best Management Practices: A Review. *Journal of environmental quality,* 39**,** 85-96.

MERRILEES, D. & DUNCAN, A. 2005. Review of attitudes and awareness in the agricultural industry to diffuse pollution issues. 51**,** 373-381.

NOVOTNY, V. 1999. Diffuse pollution from agriculture - A worldwide outlook. *Water Science and Technology*.

OECD 2012. Water Quality and Agriculture: Meeting the Policy Challenge. OECD Studies on Water. Paris: Organisation for Economic Co-Operation and Development.

OECD 2017. Diffuse Pollution, Degraded Waters: Emerging Policy Solutions. Paris: OECD

OENEMA, O., VAN LIERE, L. & SCHOUMANS, O. J. J. O. H. 2005. Effects of lowering nitrogen and phosphorus surpluses in agriculture on the quality of groundwater and surface water in the Netherlands. 304**,** 289-301.

OKUMAH, M., MARTIN-ORTEGA, J. & NOVO, P. 2018. Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: A conditional process modelling. *Land Use Policy,* 76**,** 36-45.

POVILAITIS, A. J. E. 2006. Impact of agriculture decline on nitrogen and phosphorus loads in Lithuanian rivers. 1**,** 32-39.

PRAGER, K. 2012. Understanding Behaviour Change: How to apply theories of behaviour change to SEWeb and related public engagement activities. Aberdeen/Edinburg: Scottish Government/Scottish Environment Protection Agency (SEPA).

PRICE, P. N., SHEPHERD, M., WHITEHEAD, J., GOODLASS, G. & ANTHONY, S. 2008. Initial Evaluation of Effectiveness of Measures to Mitigate Diffuse Rural Pollution. Edinburgh: Scottish Government.

REHMAN, T., MCKEMEY, K., YATES, C. M., COOKE, R. J., GARFORTH, C. J., TRANTER, R. B., PARK, J. R. & DORWARD, P. T. 2007. Identifying and understanding factors influencing the uptake of new technologies on dairy farms in SW England using the theory of reasoned action. *Agricultural systems,* 94**,** 281-293.

RYBERG, K. R., BLOMQUIST, J. D., SPRAGUE, L. A., SEKELLICK, A. J. & KEISMAN, J. J. S. O. T. T. E. 2018. Modeling drivers of phosphorus loads in Chesapeake Bay tributaries and inferences about long-term change. 616**,** 1423-1430.

STÅLNACKE, P., GRIMVALL, A., LIBISELLER, C., LAZNIK, M. & KOKORITE, I. J. J. O. H. 2003. Trends in nutrient concentrations in Latvian rivers and the response to the dramatic change in agriculture. 283**,** 184-205.

STEG, L. & VLEK, C. 2009. Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of environmental psychology,* 29**,** 309-317.

STERN, P. C. 2000. Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues,* 56**,** 407–424.

THOMPSON, J., CASSIDY, R., DOODY, D. G., FLYNN, R. J. A., ECOSYSTEMS & ENVIRONMENT 2013. Predicting critical source areas of sediment in headwater catchments. 179**,** 41-52.

ULRICH-SCHAD, J. D., DE JALÓN, S. G., BABIN, N., PAPE, A., PROKOPY, L. S. J. J. O. S. & CONSERVATION, W. 2017. Measuring and understanding agricultural producers' adoption of nutrient best management practices. 72**,** 506-518.

UNITED NATIONS WORLD WATER ASSESSMENT PROGRAMME 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris: United Nations Educational, Scientific and Cultural Organization.

VRAIN, E. & LOVETT, A. 2016. The roles of farm advisors in the uptake of measures for the mitigation of diffuse water pollution. *Land Use Policy,* 54**,** 413-422.

VRAIN, E., LOVETT, A., NOBLE, L., GRANT, F., BLUNDELL, P. & CLEASBY, W. 2014. FARMER ATTITUDES TOWARDS DIFFUSE POLLUTION MITIGATION MEASURES IN ENGLAND. Department for Environment, Food & Rural Affairs.

WINFIELD, M. S. & BENEVIDES, H. 2003. A Review of US Approaches to Integrated Watershed Management and Their Applicability in the Ontario Region. Calgary: Pembina Institute for Appropriate Development.

WORRALL, F., SPENCER, E. & BURT, T. J. J. O. H. 2009. The effectiveness of nitrate vulnerable zones for limiting surface water nitrate concentrations. 370**,** 21-28.

Chapter 5

The role of experiential learning in the adoption of best land management practices

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Abstract

Agriculture is both the cornerstone of global food security and one of the main drivers of environmental degradation. To address existing and potential environmental impacts of agriculture, policymakers are increasingly focussing on influencing farmers' behaviour to adopt best management practices (BMPs). One of the strategies adopted is the provision of advice aimed at raising awareness of environmental pollution and mitigation measures. By improving farmers' awareness, it is expected that changes in behaviour would be reflected in the adoption of BMPs. This expectation is based on the assumption of a direct link between awareness and uptake of BMPs. So far, however, the limited empirical research has shown that, while there is a link between awareness and adoption, this link is indirect and is mediated and moderated by other factors. One of the potential intervening factors that remains poorly understood is the enabling capacity that experiential learning brings. Through a mixed-methods approach, we explored farmers' awareness and the role of experiential learning in the adoption of BMPs. The study focusses on the experiential learning process associated with the use of nutrient management plans to reduce diffuse water pollution from agriculture in the context of a soil sampling scheme in Northern Ireland (UK). Overall, we found that while advice seems to have contributed to increased uptake of BMPs, likelihood of adoption increased if the farmers had prepared the nutrient management

plans themselves. This shows the critical role that experiential learning plays in deepening farmers' understanding and increasing the likelihood of their adopting BMPs. This provides support for the conceptual premise that while information provision is important, farmers need to actively engage in and be able to reflect on the practice for it to lead to behavioural changes. The role of experiential learning also suggests the need to move from the predominant model of a unidirectional relationship (the notion that the relationship always starts from awareness to behaviour), to a bidirectional one (i.e. from behaviour to awareness) and such interactions need to be understood through analysing the feedback loops over time. More research on this could offer insights into effective ways to help farmers adopt BMPs and ultimately contribute to reducing the environmental impacts of agricultural land management.

Keywords: Awareness; Behaviour change; Farm advice; Nutrient Management; Soil Testing; Northern Ireland

5.1 Introduction

Agriculture is both the cornerstone of global food security and one of the main drivers of environmental degradation (Hosonuma et al., 2012, United Nations, 2016, United Nations Environment Programme, 2017). Conventional agricultural systems which currently dominate global food production contribute to biodiversity loss, soil degradation, water pollution and climate change (Hutchins, 2012, OECD, 2012, United Nations World Water Assessment Programme, 2015, Novotny, 2013, UNCCD, 2015). Sustainable (global) food production can only be achieved by safeguarding environmental systems and natural resources such as soil health, biodiversity and water quality, which underpin agricultural production (United Nations, 2015). Therefore, the integration of agricultural and environmental policies is recognised as

a priority for sustainability transitions (UNCCD, 2015, United Nations, 2015, Environment Agency, 2014). Farmers are key decision makers in addressing environmental problems (Stringer et al., 2020, Macgregor and Warren, 2006a, Blackstock et al., 2010). In their search for new measures to tackle environmental degradation, researchers and policymakers are thus increasingly focussed on finding effective ways to help farmers adopt best management practices (BMPs) (Evans et al., 2019).

One such BMP challenge is farm-sourced diffuse pollution (e.g. phosphate, nitrogen, pesticides, herbicides, desiccants, etc.) in waterbodies. The increasing consideration of behavioural change as a means to address this problem is evident in the emergence of many behaviour focussed policies such as the Water Quality Scheme and the Environmental Quality Incentive Programme in the United States of America (Dwyer et al., 2007), the Catchment Sensitive Farming Delivery Initiative started in England (Environment Agency, 2011, Environment Agency, 2014) and the Diffuse Pollution Management Strategy established in Scotland (DPMAG, 2015, SEPA, 2015). One of the strategies adopted by policymakers has been to provide advice in order to raise awareness of environmental pollution and BMPs amongst farmers (Merrilees and Duncan, 2005, Blackstock et al., 2010), under the expectation that this will lead to increased adoption of BMPs (Okumah et al., 2019). This is based on the assumption of a direct link between awareness and behavioural changes.

To date, however, the limited empirical research examining behavioural aspects of awareness-focussed strategies suggests that the link between awareness and adoption of BMPs is not a direct one (Okumah et al., 2019). A number of factors influence the awareness-behaviour link. For instance, Inman et al. (2018) have

demonstrated that while awareness might be useful in fostering behavioural changes, sources of advice and social norms also play key roles in whether farmers adopt BMPs (see also, Vrain and Lovett, 2016). Other studies have indicated that beyond awareness, farmers' decision to take up BMPs depends very much on the context; for example, the flexibility of arrangements (e.g. agri-environmental schemes (AES)) in the framework in which they are delivered (Barnes et al., 2009, Macgregor and Warren, 2006b) or the receptiveness of farmers (Houser et al., 2020). Some important issues regarding the flexibility of AES include terms of ease of application, choice of options, or how easy it is to leave or change those options (Barnes et al., 2009).

Some of these (indirect) influencing factors have to do with the enabling capacity that experiential learning brings. For instance, Okumah et al. (2018) found that although farmers' awareness influenced compliance with Diffuse Pollution General Binding Rules (GBRs)[8] in Scotland (UK) (DPMAG, 2015), this link was found to be mediated by farmers participation in AES. The study revealed that awareness of diffuse pollution was not sufficient to yield farmers' compliance with GBRs and that significantly more farmers complied if they also participated in (voluntary) AES. The study suggests that awareness could lead to farmers' involvement in some practices, which in turn, deepens their understanding of their environmental impacts and mitigation strategies, leading to a wider uptake of BMPs. As put forward in Kolb's experiential learning theory, individuals' reflections on new experiences provide the impetus for learning which leads to further active engagement or experimentation (Kolb, 1984). Based on this, hands-on strategies that allow farmers to engage in such experiential learning appear to be essential in maximising the value of awareness strategies. Indeed the

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[8] General Binding Rules represent a set of mandatory rules which cover specific low risk activities.

role of experiential learning has been recognised in studies focussing on farmers' establishment of wildlife friendly habitats (Science for Environment Policy, 2017) and identification of pollution sources (Okumah and Yeboah, 2019, Okumah et al., 2019b, Boiral, 2002). Moreover, the experience of engaging in conservation practices also helps to shape individuals' understanding of the complex socio-ecological systems in which they operate (Whiteman et al., 2004) and this understanding has implications on their decisions and behaviours (Woodwell, 1989, Adams and Sandbrook, 2013, Sutherland et al., 2004).

Despite its potentially critical importance in the success awareness-based land management policies (Fazey et al., 2006, Pahl-Wostl and Hare, 2004, Whiteman et al., 2004, Suškevičs et al., 2019), the role of experiential learning still remains under studied with existing studies focussing on Latin America (D'Angelo and Brunstein, 2014, Kumler and Lemos, 2008). The current research aims to fill this knowledge gap by exploring, through a mixed methods approach, farmers' awareness and the role of experiential learning in the adoption of BMPs. The study focusses on the experiential learning process associated with the use of nutrient management plans to reduce diffuse water pollution from agriculture. It is set in the context of the European Union Exceptional Adjustment Aid Soil Sampling and Analysis Scheme (EU EAA SSAS) in its application to Northern Ireland (UK). The process of preparing a nutrient management plan involves a conscious assessment of a wide range of factors, an iterative and reflective process that allows the developer to make sound decisions (Adusumilli and Wang, 2018, Oenema et al., 2003, Maguire and Sims, 2002). This process can help farmers to learn over time, enhance ownership of the final product (i.e. the nutrient plan) and their confidence in it. It could therefore be argued that

farmers who go through the experience of preparing their own plans, enhance their experiential learning.

The Nutrient Action Programme Regulations (Northern Ireland) stipulates that farmers must comply with all land and water related regulations, to avoid prosecution and penalties such as possible fines, but also to help them meet the requirements of Cross-compliance. These regulations require farmers to keep records of fertiliser application to all fields. Therefore, although these regulations and financial incentives tied to the EU's Common Agricultural Policy are expected to trigger the preparation of nutrient management plans and adoption of BMPs, Posthumus *et al.* (2011), have noted that some farmers do not feel necessarily threatened by prosecution. Other studies have shown that while incentives could encourage to adopt BMPs, many farmers do not find them attractive due to their inflexible nature, often with many constraints (Macgregor and Warren, 2006a, Barnes et al., 2009, Okumah et al., 2019a).

Examining whether this more "hands-on" engagement with nutrient management planning leads to higher adoption of BMPs can advance our understanding of the role of experiential learning in support of land management strategies. Therefore, while the study is set in the context of the EU EAA SSAS in Northern Ireland it aims to provide insights that are of broader relevance with respect to the role of experiential learning in awareness-based land management policies.

5.2. Methodology

5.2.1 Case study description

In Northern Ireland, 75% of land use is for agriculture, with 93% of this being grassland and only 7% arable. While livestock farming is largely grass based, 68% of the agricultural area is classed as 'Less Favourable Area' where agricultural activity is

constrained due to adverse physical conditions such as high soil moisture, frequent rainfall or steep slopes. There are approximately 25,000 farms in Northern Ireland with meat, dairy and poultry being the largest sectors, accounting for over 80% of agricultural output. The average farm size is 41 ha, with an average income of £26,000 (DAERA, 2018). A significant proportion of farm income comes from the EU Common Agricultural Policy (CAP) subsidies such as the basic payment scheme (£194 million in 2018 ~£7700/farm on average) and greening payments (£88 million in 2018 ~£3520/farm on average), depending on farm size. The agri-food industry contributes £5 billion to the Northern Irish economy each year and is responsible for 23,000 jobs in the food and drink processing sector and input supply sectors (DAERA, 2018). This background information demonstrates the important contribution of agriculture in Northern Ireland, and the need for sustainable management practices to maintain these benefits while reducing its negative impact on the environment.

The EU EAA SSAS was a voluntary advice-centred scheme that places the focus on knowledge transfer via nutrient management plans and soil testing. The implementation of the EU EAA SSAS (2017-18) by Northern Ireland's Department of Agriculture, Environment and Rural Affairs (DAERA) consisted of two sub-schemes: (i) an open soil sampling scheme to which all Northern Ireland livestock farmers were eligible to apply (hereafter referred to as NI Wide Scheme), and (ii) a catchment scheme where livestock farmers within 11 sub-catchments of the Upper Bann catchment (hereafter referred to as the UBC Scheme), an intensively farmed area in the east of the country (Barry and Foy, 2016) (Figure 5.1), were eligible to apply. The NI Wide Scheme received applications from 3,030 farms (100,000 fields); however only 522 farms (12,629 fields) could be accommodated within the EU EAA budget and these were selected using a randomised lottery system. The UBC Scheme included

513 farms and a total of 7,340 fields with 73% of eligible farmers participating. In all, the two schemes covered 1035 farms and 19,969 fields; 4.2% of the 24,900 farms and 2.7% of the 733,932 fields in Northern Ireland. The total area sampled for soil was 33,767 ha (22,220 ha in NI Wide Scheme and 11,547 ha in UBC Scheme).

Soil sampling was managed by the Agri-Food and Bioscience Institute (AFBI[9]) from November 2017 to February 2018. Samples were sent to an accredited laboratory where they were tested for soil pH (in a 1:2.5 volume ratio of soil to water), Olsen Phosphorus (P) (in a 1:20 volume ratio of soil to sodium bicarbonate), potassium (K), Magnesium (Mg) and Calcium (Ca) (all extracted with a 1:5 volume ratio of soil to ammonium acetate or ammonium nitrate), and Loss-on-Ignition (LOI), which can be used to provide an estimate of soil organic matter content. Soil test results were sent directly to participants from the laboratory in a standardised tabular format, with recommendations on lime and nutrient application rates, the latter only where farmers had provided detail on current and planned cropping. All farmers were provided with the opportunity to participate in training, which was developed and delivered by the College of Agriculture, Food & Rural Enterprise (CAFRE), covering interpretation of the soil test results and associated recommendations regarding fertiliser and lime application and nutrient management planning. Participants who did not attend the training events were provided with the training materials by post. In total, 583 (371 in NI Wide and 212 in UBC) farmers attended training events across the two schemes (56% of the total participants).

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[9] AFBI conducts high quality research and development, statutory, analytical, and diagnostic testing functions for DAERA and other Government departments, public bodies and commercial companies in Northern Ireland.

Tabulated soil test results were supplemented by field-scale orthophotographic maps with colour-coded overlays based on the nutrient status (Olsen P and K) and lime requirement (pH) (above, below and within the respective optimum ranges) (Figure 5.2). In addition, UBC Scheme participants also received P runoff risk maps (Figure 5.3) (modelled using LiDAR topographic datasets and soil hydraulic properties (Cassidy et al., 2019)) which indicate areas within fields at high risk of generating runoff during storm events and thus the potential for losing nutrients (primarily P) from applied slurry and fertilisers, and soil P where Olsen P concentrations were elevated.

By providing a free soil sampling service, nutrient management advice and training to generate nutrient management plans in these schemes, DAERA aimed to improve farmers' understanding of the agronomic and environmental benefits of soil testing, which included recommendations on how much lime, and nutrients to apply to each field in order to maximise the quantity of crop produced. The nutrient management advice included information on how to better manage P (such as inclusion of buffer strips and changing application rates of slurry or farmyard manure) in order to reduce risks of P losses from soil to watercourses.

During training sessions, there were demonstrations on how to use online crop nutrient calculators to generate a nutrient management plan (using soil analysis results). The output from the online calculators feeds into a systematic and structured record (written document) on one or more of the following: crop requirement (i.e. how much N, P and K your crop needs to grow), how much N, P and K is supplied from slurry and how to minimise the need for chemical fertiliser by using the right type and rate of fertiliser application. After demonstrating and sending training materials to farmers, they were encouraged to generate nutrient management plans for their farms (based

on their soil analysis results). Therefore, though the scheme did not fund the preparation of nutrient management plans, it was expected to have increased awareness on the preparation and use of nutrient management plans and could contribute to the preparation of nutrient management plans. Through the preparation and use of such plans, farmers are expected to reflect on the process and benefits associated with the use of the nutrient management plan which could in turn reinforce their awareness and subsequently trigger behavioural changes, for example, through altering the type and amount of chemical fertiliser applied, and the application rates of slurry or farmyard manure. This, therefore highlights an opportunity to explore how awareness and experiential learning could contribute to behavioural changes (i.e., the adoption of BMPs).
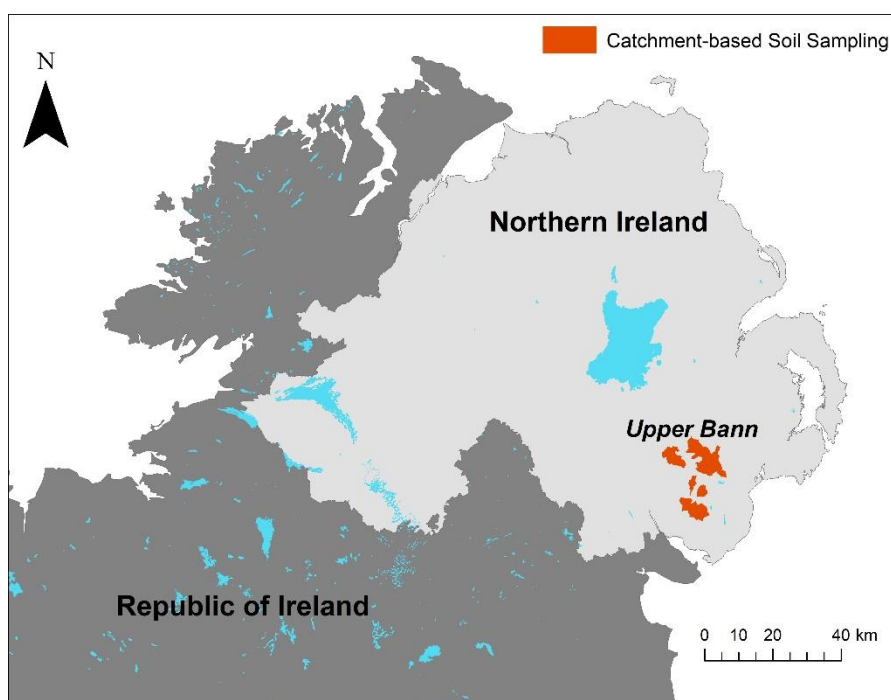
Figure 5.1: Locations of the soil sampling undertaken as part of the EU EAA SSAS. A Northern Ireland (NI-Wide) sampling scheme covered 522 farms chosen at random from applicants across Northern Ireland, while a catchment-based scheme (UBC) sampled 513 farms in 11 sub-catchments of the Upper Bann river system.
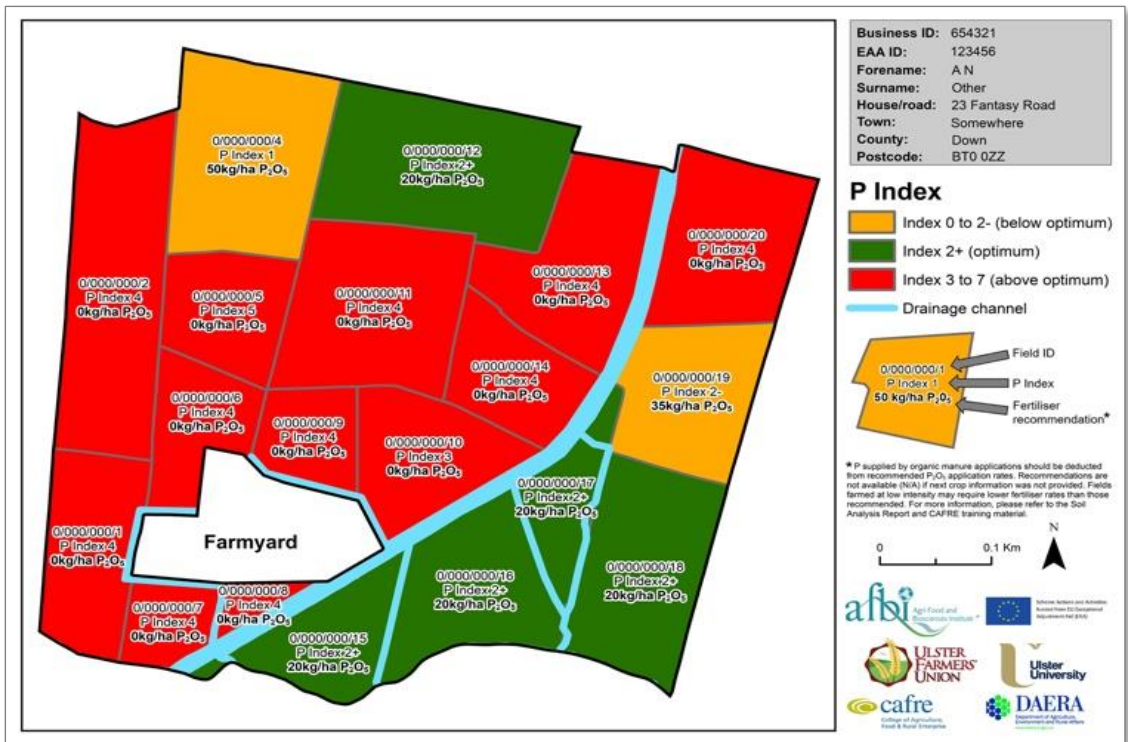
Figure 5.2: An anonymised example of a farm phosphorus map showing soil P Indices (colour-coded and labelled) for each sampled field with amendment recommendations (kg/ha P_2O_5).
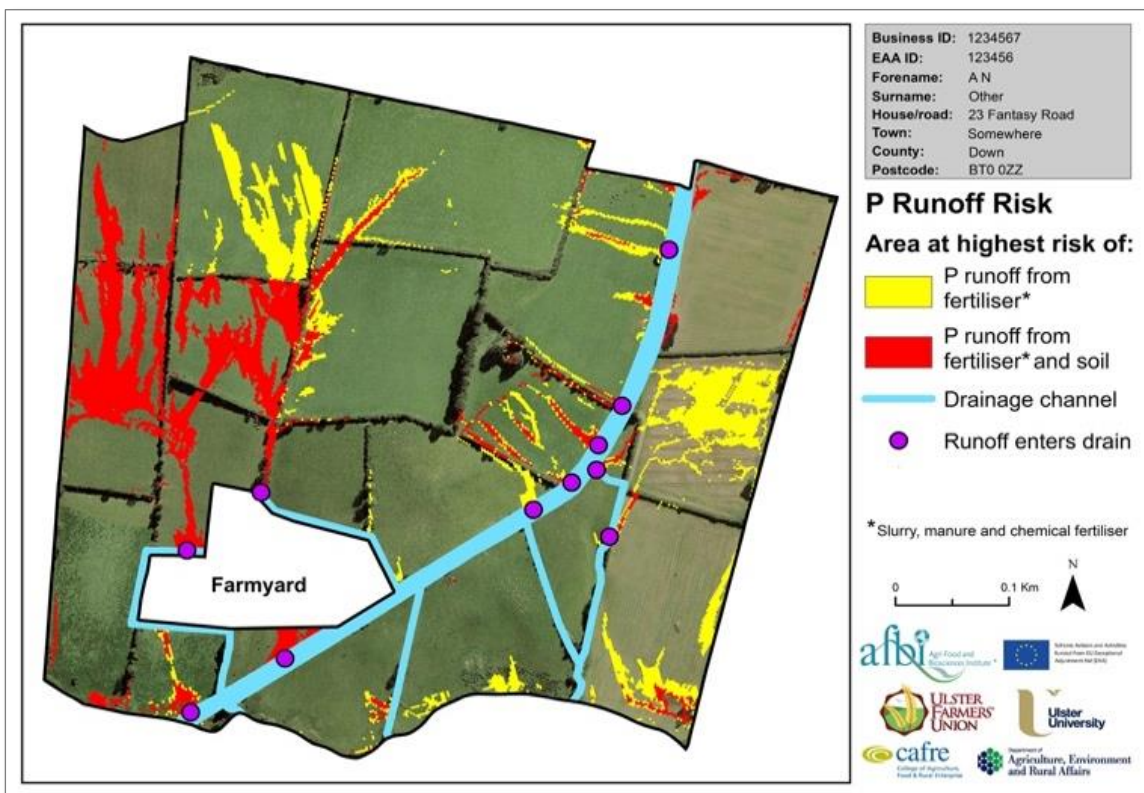
Figure 5.3: An anonymised example of a farm P runoff risk map showing areas at high risk of P runoff from both fertiliser (chemical or organic manures) and soil P. Delivery points indicate locations where runoff inflows to drainage ditches and watercourses.

5.2.2 Data and methods

We applied a mixed methods approach using a questionnaire-based survey (N=408) and qualitative semi-structured in-depth interviews (N=21) to explore farmers' awareness of the link between nutrient management and water quality and the role of experiential learning in adoption of BMPs. A mixed methods approach has an advantage over purely qualitative or quantitative approaches, as quantitative surveys provide generalizable findings while qualitative interviews provide deep and rich contextual information about the phenomenon being studied (Silverman and Patterson, 2015). Quantitative data were available from a post-scheme questionnaire targeting scheme participants carried out by DAERA twelve months after farmers had received their soil test results (in March/April 2019). Follow up semi-structured in-depth interviews were designed expressly for this research and conducted in October 2019.

5.2.2.1 Post-scheme questionnaire

The post-scheme questionnaire (that had been carried out previously by DAERA and made available to the authors) focussed on evaluating actual behavioural changes (see Appendix D1 for the questionnaire used for the survey). For this, a twelve-month lag after receiving the soil test results is a reasonable time for farmers to have changed their nutrient management practices in light of the recommendations. The questionnaire contained questions on farmers' awareness of the link between nutrient management and water quality, the preparation of nutrient management plans, and whether farmers had changed nutrient management practices or not as a result of the soil test recommendations. Overall, 1,035 questionnaires were sent out and 408 were completed by farmers (39.4% response rate).

Although the post-scheme questionnaire had been prepared by DAERA with the intention of merely checking whether the scheme had been successful in increasing awareness and uptake of the measures, it contained information that could be conceptualised as experiential learning, and that we use here to explore its role in the adoption of BMP. To operationalise the concept of experiential learning, we focussed on whether the farmer prepared their own nutrient management plan or whether the plan was prepared by a farm adviser; the nutrient management plan functioning here as the boundary object through which the experiential learning takes place (i.e. the object through which the 'hands-on' experience possibly occurs[10]). This conceptualisation and operationalisation was inspired by past empirical studies (e.g., Suškevičs et al., 2019) that suggested that hands-on activities can reinforce awareness and contribute to the adoption of BMPs.

Questionnaire data from farmers were consequently grouped into two – those who prepared their own nutrient management plans and those whose plans were drawn up by a farm adviser. We then applied conditional process modelling on these two groups to analyse their differential adoption of BMPs. Conditional process modelling is a statistical technique that allows the researcher to identify direct, indirect and conditional relationships (Hayes, 2013). Accordingly, it is best suited where the researcher is interested in identifying the mechanisms through which a variable directly or indirectly transmits its effects onto others as well as the conditions under which such relationships operate (referred to as moderators). Moderators are variables that potentially influence the statistical significance, direction and/or strength of the link between two or more other variables (Hayes, 2013).

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[10] A boundary object refers to information – such as plans, field notes, and maps – that could be used in diverse ways by different social groups.

Here, we were interested in whether experiential learning (operationalised through the preparation of nutrient management plans) influenced the link between having a nutrient management plan and the adoption of BMPs. Therefore, in this context, the variables of interest are (Table 5.1): (1) nutrient management plan (whether the farmer had a nutrient management tool or not) – independent variable capturing the boundary object; (2) preparation of a nutrient management plan (if the plan was prepared by the farmer themselves or by a farm adviser) – moderator capturing the role of experiential learning; and (3) adoption of BMPs (whether the farmer changed nutrient management practices as a result of the soil test recommendations or not) – dependent variable reflecting the behavioural change. This study focussed on five BMPs: changing the type of fertiliser purchased (e.g. changed from compound to straight fertiliser), changing the amount of fertiliser purchased, increasing lime usage, importing or exporting slurries, and using P runoff risk maps to help decide where to establish a buffer strip. The first four BMPs applied to farmers in the NI Wide scheme while the last one (using P runoff risk maps to help decide where to establish a buffer strip) applied to only farmers in the UBC scheme.

We combined SPSS IBM version 24 and the lavaan package within RStudio (0.5-23.1097) to perform the conditional process modelling in three stages. First, we analysed the measurement model for validity. This involved using a mix of indices to appraise model fit (Hooper et al., 2008, Hu and Bentler, 1999, Brown, 2006). Then, we tested the hypothesised relationship, regressing effect of the boundary object (i.e. availability of a nutrient management plan – independent variable) on behavioural change (i.e. adoption of BMPs - dependent variable); and establishing whether this link was dependent on whether the plan was prepared by the farmer (experiential

learning) or by a farm adviser (i.e., the moderator). This moderator was tested by running the same model for the overall sample and also for the multi-groups. We used an alpha (α) = 0.10 as our primary statistical criterion because the risk of a type II statistical error (i.e., a false negative) is relatively high when using a small sample (Schumm et al., 2013); (>200 cases is often considered large for typical structural equation modelling or conditional process modelling depending on the number of variables) (Jackson, 2001, 2003).

Table 5.1: Constructs and variables used in the conditional process modelling

Constructs	Variable category	Variable	Question	N
Boundary object	Independent variable	Nutrient management plan	Whether a farmer has a nutrient management plan (1) or not (0).	386
Experiential learning	Moderator	Preparation of nutrient management plan	Whether the plan was drawn up by a farm adviser (1) or not (0).	128
Behavioural change	Dependent variable	Adoption of BMP	Whether the farmer has changed the type of fertiliser purchased (1) or not (0).	392
			Whether the farmer has changed the amount of fertiliser purchased (1) or not (0).	375
			Whether the farmer has increased lime usage (1) or not (0).	388
			Whether the farmer has imported or exported slurries (1) or not (0).	349
			Whether the farmer has used their P Risk Run-Off Map to help decide where to establish a buffer strip (1) or not (0).	76*

Notes: N= Number of responses; * = farmers in Upper Bann catchment (UBC) scheme only.

5.2.2.2 Qualitative semi-structured interviews

The semi-structured interviews aimed at deepening our understanding of the results obtained from the questionnaire and providing further meaning and context to results of the conditional process modelling. This also gave us the opportunity to include relevant issues that were not captured in the questionnaire (e.g. although the questionnaire included questions on whether farmers had changed practices or not, it

did not ask for the direction of change, for example, whether the farmer increased or reduced the amount of fertiliser applied). The key topics covered in the interviews included: farmers' understanding of factors influencing diffuse pollution from agriculture and how to mitigate it, preparation and use of nutrient management plans and changes in nutrient management practices. See Appendix D2 for the script used for the qualitative interviews.

The interview script was collaboratively designed by the authors and DAERA. Co-designing the script helped in ensuring that it focussed on addressing key issues within the scheme's context (Devisscher et al., 2016, Kench et al., 2018, Jagannathan et al., 2020). To recruit interview participants, researchers from AFBI contacted farmers who had participated in the Post-scheme survey (described in section 5.2.2.1) via phone call and emails. Where farmers agreed to be interviewed, a date and time was scheduled for the interview session. Twenty-one farmers (who were all part of the scheme) were interviewed in October 2019. These were conducted by interviewers specifically trained for the task. All interviews were conducted through phone calls and lasted up to one hour. We applied descriptive respondent validation (Byrne, 2001) to improve the credibility and validity of the data. This process involved summarising aspects of the interview and asking participants if the summaries represented their views or not. This was implemented at the end of the interview session. Qualitative data, (i.e. transcripts or notes) from the interviews were analysed using content analysis (Mayring, 2004, Stemler, 2000), using NVIVO version 11. This was done by carefully reading through the interview notes and identifying key topics that emerged from the texts rather than on the basis of pre-defined topics. We also identified key statements that provided plausible explanations to the results of the quantitative

analysis. This analysis was iteratively reviewed by members of the research team to establish trustworthiness in the results (Cypress, 2017).

5.2.3 Limitations

The survey data was gathered by DAERA as part of the EU EAA SASS scheme to evaluate the impact of the scheme on nutrient management practices and not specifically to explore farmers' awareness and the role of experiential learning in behavioural changes. As a result, it does not cover information on variables such as farm type and years of experience, that are known to potentially influence farmer decisions and behaviours (Buckley et al., 2015, Okumah et al., 2018). Lacking such crucial data limits our ability to unpack the true impact of the scheme on farmers' awareness and behaviour because contextual factors play an important role in the awareness-behaviour link (Kollmuss and Agyeman, 2002). For instance, though some farmers may be environmentally concerned and willing to adopt best management practices, they may fail to implement such intentions due to the cost associated with uptake of some mitigation measures. Understanding how such contextual factors interact with awareness to influence adoption of best management practices could enhance our understanding of the real impact of advice-centred interventions on farmers' attitudes and behaviours.

Moreover, because of the lack of a baseline study, we cannot categorically conclude that improvements in knowledge and behaviour would not have happened without the scheme. We attempted to mitigate these limitations by complementing the data with semi-structured in-depth interviews – where we collected data covering some of these aspects. In any case, this does not invalidate the results, since the aim is not to assess

the effectiveness of the scheme itself but the role that experiential learning played in the awareness-behavioural link.

Additionally, the research may be prone to social desirability bias given that we relied on self-reported behaviours (Schuman and Presser, 1981, Jackman, 1973), i.e. it is possible that some farmers reported pro-environmental practices to project themselves as environmentally minded people, when these reports may not be a true reflection of their practices. It is important to note that self-reported behaviours are widely accepted in the behavioural sciences (Kormos and Gifford, 2014). This potential limitation was partly addressed through the in-depth interviews as farmers' spontaneous description of their practices could reveal their understanding and engagement in them.

There are also concerns regarding farmers' non-engagement post-scheme. Though the survey's response rate (39.4%) was quite high compared to what many recent studies have reported (e.g., Tepic et al. 2012, Zhong 2016), there are concerns regarding why more than half of farmers who participated in the scheme failed to participate in the survey. Though farmers' busy schedule and thus unavailability for post-scheme surveys could have contributed to this rate, it is possible that some of these farmers developed apathy towards the scheme due to poor implementation and/or the scheme not meeting their expectations. Having the views of such farmers in the dataset could have enriched the data and by extension, our understanding of the true impact of the scheme on farmers' awareness, experiential learning and adoption of best management practices. This important data was however not available as there was no follow up to obtain the reasons for farmers' lack of response.

Another potential limitation stems from the interviewers. Due to cultural sensitivities (i.e., most of the farmers were reluctant to be recorded) it was not possible to voice record the interviews and conversations were recorded by means of note taking. Taking only notes implies that some information could be lost in the process and the decision to consider which information was important could have been influenced by interviewers' biases (Agar, 1986). We attempted to resolve aspects of this limitation by providing thorough training to the interviewers and asking them to send (at the end of each day) immediate impressions, their thoughts, and things that appeared to be surprising and confusing, as this could help provide some context to the data and provide additional informational relevant for interpreting results (Agar, 1986). Moreover, it is worth noting that the interviewers had very good knowledge of farming practice in Northern Ireland, which helped them to understand the key issues that farmers raised during the interviews.

5.3 Results

This section presents results of the questionnaires and the semi-structured qualitative interviews based on the objectives of the study. First, we present results on farmers' awareness of link between nutrient management practices, yield and water pollution. Following this, we explore whether exposure to advice changed farmers' practices and how experiential learning plays a role in behavioural change (section 5.3.2).

5.3.1 Are farmers aware of the link between nutrient management and water quality?
The questionnaire data show that 85.8% of responding farmers acknowledged a link between good healthy soil and good water quality. From the qualitative interviews, farmers provided explanations on the link between nutrient management and water quality, demonstrating a good understanding. For instance, they explained that without

knowledge of the nutrient status of their soils, a farmer could apply nutrients in excess of crop requirement, and this could be transferred from the soil to watercourses. To reduce the risk of nutrient runoff, most farmers explained that a farmer needs to sample and to test their soils; i.e. they understood that soil testing highlights the nutrient status of soil and is the basis for fertiliser rate recommendations required for optimum yield for a given crop. By following such recommendations, farmers realised they could maximise yield while helping to reduce risk of water pollution.

Because we did not conduct a pre-scheme evaluation of farmers' understanding of the link between nutrient management and water quality, we cannot (categorically) attribute their awareness to the advice or training provided in the EU EAA SASS scheme. However, further qualitative evidence from the in-depth interviews suggest that the training or advice provided in the scheme had contributed to consolidating a high level of understanding of nutrient management, and of the link between soil management practices, grass yield and water pollution. For instance, some farmers reported that prior to participating in the scheme, they had a poor understanding of these issues but following their participation, they were now generally aware, as illustrated by these quotes: "*[I] went to the meeting, got [soil analysis] results explained and gained a greater understanding*" (Farmer 8) and "*[I] went to the meeting, got a broader understanding and found it very useful. [I] would recommend it to others*" (Farmer 19). While these farmers emphasised general awareness, others pointed out specific areas of knowledge improvement. For example, some farmers mentioned awareness regarding nitrogen, phosphorus, and potassium requirements:

> "*Yes [I] attended 2 meetings. [I] found them useful for determining fertiliser requirements. Now I feel more informed regarding which type of fertiliser to use rather than solely going on the fertiliser merchants recommendations*" (Farmer 18).

> *"Yes [I] went to the meeting and found it very valuable. [It] helped me to understand the analysis and to implement a nutrient management plan. Previously didn't understand N, P, K requirements; only understood the pH before the [training] course* (Farmer 10).

Additional evidence obtained from the in-depth interviews suggests that the P runoff risk maps had contributed to farmers' understanding of the link between P application and water pollution and had made them more conscious of nutrient loss in runoff in general. Some farmers noted that the "*maps had made them conscious of the P content of the land*"; making them "*less careless*". This improved awareness could be attributed (in part) to the colour coding of the maps as the first interviewee noted that they "*understood the colour coded maps*" and *"realised low lying fields were most at risk*".

5.3.2 Does awareness contribute to uptake of BMPs? The role of experiential learning

Descriptive statistics from the questionnaire show that the majority of farmers reported behavioural changes in relation to type of fertiliser purchased, amount of fertiliser purchased, amount of lime used, while less than 30% reported changes in import and export of slurries (Figure 5.4). Evidence from the qualitative interviews corroborate this finding as some farmers noted that "*previously,[I] applied grazing ground with 20:10:10 [compound fertiliser] based on historical practices, but now [I] apply just [straight] nitrogen [fertiliser] based on soil test results*" (Farmer 1). Another farmer added that I "*would have applied 20-10-10 [compound fertiliser] but now I use straight N fertiliser*" (Farmer 8). Straight fertilisers supply only one primary nutrient. Therefore, by switching from compound fertilisers (those with two or more primary nutrients) to straight fertiliser (using only nitrogen where P and K indexes suggest no additional amendments are

required), farmers are able to avoid over applying other nutrients or avoid applying more nutrients than the crop requires.

Next, we focus on the potential role that experiential learning played in the adoption of BMPs (i.e., in leading into actual behavioural change). Results of the conditional process modelling revealed that having a nutrient management plan alone did not influence the uptake of any of the BMPs (p-value>0.1, overall sample models in Table 5.2). However, this relationship is moderated by the experience of preparing their own nutrient management plan (as opposed to having it drawn up by a farm adviser); we observe statistically significant effects (through multi-group analysis models in Table 5.2). For two of the BMPs (importing/exporting slurries and use of runoff maps for establishing buffer strips), we find a positive significant effect of the plan having been drawn by the farmers themselves (p-value <0.1). For two of the other BMPs (change of fertiliser type and increase in lime use), we also observe the significant negative effect of the plan having been drawn by the farm advisor (p-value<0.1). For change in the amount of fertiliser purchased, there was no statistically significant relationship betwen amout of fertiliser purchased and who had prepared the nutrient plan (p-value >0.1).

While nuanced, these results yield a clear picture of the effect of experiential learning on the adoption of BMPs: who prepares a nutrient management plan influences the relationship between having a nutrient management plan and adopting BMPs, and if the plan is prepared by the farmer themselves it is more likely that this adoption happens. These results indicate that there are positive benefits when a farmer prepares their own nutrient management plan, highlighting the crucial role of experiential learning as a moderator of behavioural change. To be able to prepare and

to update their nutrient management plans, farmers explained they needed a good understanding of their soils, crop requirements and how to use the online nutrient calculator. By following these processes and reflecting on them, farmers acquired tacit knowledge: the realisation that they could maximise yield while helping to reduce risk of water pollution. Another farmer who applied the nutrient calculator to prepare their nutrient management plan indicated that, through the process, they realised that the plan "*needs to be updated based on crop rotations*" (Farmer 2). It is therefore reasonable to assume that this tacit knowledge was produced through farmers' active involvement in the preparation of nutrient management plans, thus reinforcing the value of experiential learning.
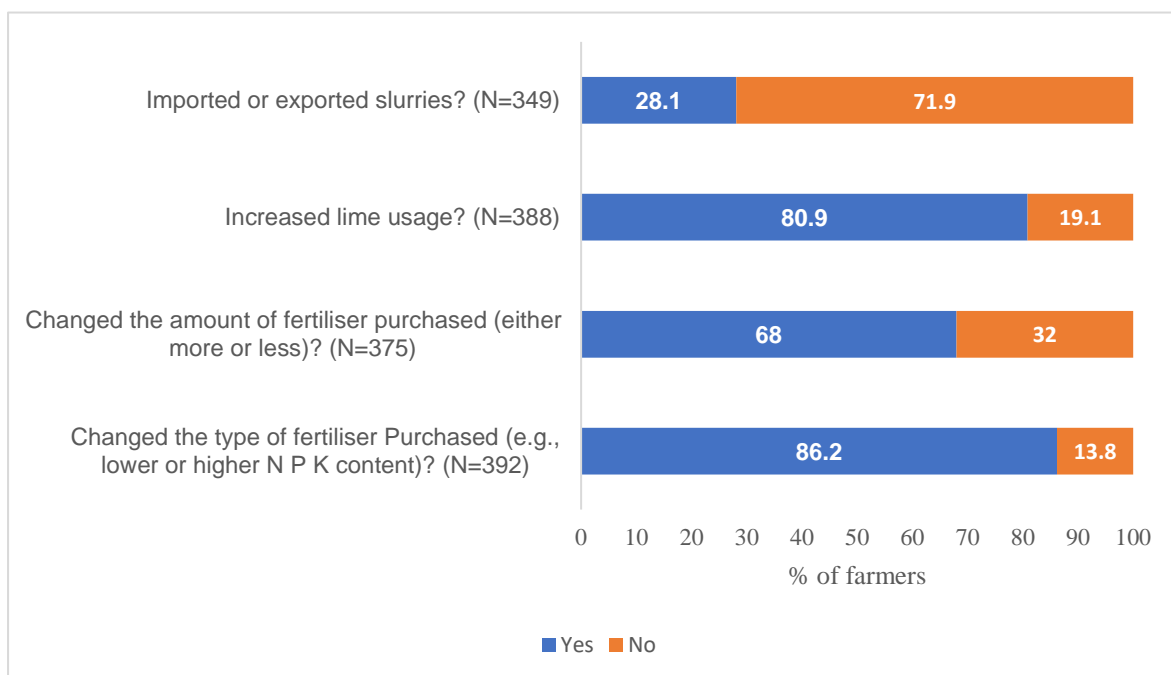
Figure 5.4: Survey participants who reported changes in various nutrient management practices.

Table 5.2: The moderating effects on preparation of nutrient management plan on uptake of BMPs

Independent variable	Dependent variable	N	Estimate	Std. Err	P-Value	Model fit indices	Model fit Judgement
BMP 1: Changing fertiliser type							
Overall Sample							
Nutrient Management Plan	Changing the type of fertiliser purchased	371	-0.046	0.167	0.784	χ2 = 1, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.000	Satisfactory
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Changing the type of fertiliser purchased	116	-0.610	0.169	0.001***		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Changing the type of fertiliser purchased	116	0.130	0.393	0.741		
BMP 2: Changing the amount of fertiliser purchased							
Overall Sample							
Nutrient Management Plan	Changing the amount of fertiliser purchased	356	-0.020	0.140	0.888	χ2 = 1, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.000.	Satisfactory
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Changing the amount of fertiliser purchased	109	0.025	0.120	0.838		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Changing the amount of fertiliser purchased	109	-0.711	0.450	0.114		
BMP 3:Increasing lime usage							
Overall Sample						χ2 = 1, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.000.	Satisfactory
Nutrient Management Plan	Increasing lime usage	367	-0.935	0.152	0.306		
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Increasing lime usage	116	-0.626	0.138	0.059*		

	Group 2: Plan drawn up by farmer						
Nutrient Management Plan	Increasing lime usage	116	0.489	0.369	0.186		
BMP 4: Importing or exporting slurries							
Overall Sample							
Nutrient Management Plan	importing or exporting slurries	331	0.196	0.149	0.189	χ2 = 1, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.00.	Satisfactory
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Importing or exporting slurries	109	0.004	0.111	0.972		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Importing or exporting slurries	109	0.928	0.532	0.081*		
BMP 5: Using P runoff risk map to decide where to establish a buffer strip							
Overall Sample							
Nutrient Management Plan	Decide where to establish a buffer strip	68	0.069	0.351	0.834	χ2 = 1, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.000.	Satisfactory
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Decide where to establish a buffer strip	68	-0.486	0.319	0.128		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Decide where to establish a buffer strip	68	0.949	0.191	0.001***		

Notes: ***p-value < 0.001, * *p-value < 0.01, *p-value < 0.1.

5.4 Discussion

As calls for research on the need for effective information provision strategies to eliminate pollutive practices intensify (Vrain and Lovett, 2019, Okumah et al., 2020), it is critical to understand the mechanisms that enhance farmers' awareness and uptake of best management practices (BMPs). Our results have shown how farmers had a good understanding of the link between nutrient management practices, yield and water pollution, and that the training and materials provided to farmers have been useful in that regard. However, more importantly, our findings corroborate the emerging literature that information provision alone may not be enough for this to translate into actual behavioural change (e.g., (Brédart and Stassart, 2017, Okumah et al., 2018, Nguyen et al., 2019). We observed that while advice could encourage behavioural changes, experiential learning plays a critical role in this process leading to farmers' adoption of BMPs. For instance, while access to advice and nutrient management plans had a role to play in the adoption of BMPs, farmers were more likely to have changed practices if they prepared their own nutrient management plans. This evidence suggests that there are greater benefits when farmers 'practise what they are taught' rather than being provided with advice only, and relying solely on farm advisers. This finding is consistent with previous studies on factors influencing adoption of BMPs and reinforces the role of experiential learning (Brédart and Stassart, 2017, Franz et al., 2010, Foster and Rosenzweig, 1995). It is worth noting that none of these previous studies investigated how advice interacts with experiential learning to trigger behavioural changes; they only established direct connections between advice and adoption of BMPs. Okumah et al. (2018) attempted to model the interaction between advice, experiential learning and behavioural changes among

Scottish farmers although the study provided quite speculative results due to data limitation.

This research refines existing knowledge through its methodological approach. Conditional modelling allows us to statistically test the moderating role of experiential learning and helps to consolidate the evidence that while advice is important, there are greater benefits when farmers engage in the process. This relates to the reflective process from experience which underpins learning and active experimentation (Kolb, 1984). Thus, experiential learning enhances farmers' awareness of the link between their practices and environmental outcomes. As found in this study, where farmers followed nutrient management advice, they highlighted that they were convinced that knowledge of the nutrient status of their soil yielded a win-win situation: helped them maximise their yield while reducing production costs and risks of water pollution, resonating with previous studies that have found tacit knowledge to be useful in the identification of pollution sources (Boiral, 2002). A deeper understanding of pollution sources and mitigation measures boosts farmers' self-efficacy and increases their chances of adopting BMPs (Sewell et al., 2017). This could explain why experiential learning reinforces awareness and contributes to behavioural changes not just in this study but also in previous works on the establishment of wildlife friendly habitats (Science for Environment Policy, 2017) and adoption of measures to tackle diffuse pollution from agriculture (Okumah et al., 2018).

Our results also confirm the findings of previous studies on action-oriented learning in the broader context of natural resources management. For instance, previous studies in this area have shown that boundary objects and intentional experimentation enabled learning as it opened up stakeholders' minds to new ideas (Suškevičs et al., 2019).

Further evidence suggests that while this 'experiential knowledge' may reflect in cognitive or relational advancement at the individual level, and in the adoption of BMPs (Suškevičs et al., 2018), such changes may not be readily observed and clearly articulated (Fazey et al., 2006, Suškevičs et al., 2019). Over time, the experience of engaging in BMPs shape individuals' understanding of the complex socio-environmental systems within which they operate (Whiteman et al., 2004) and this understanding has implications on their decisions and behaviours (Woodwell, 1989, Adams and Sandbrook, 2013, Sutherland et al., 2004). Nonetheless, how contextual factors and time influence learning and the acquisition of such tacit knowledge remains poorly understood and addressed vaguely. For intervention-based learning such as the case of the present study, Suškevičs et al. (2019) suggests that future studies employ research designs that integrate ex-ante and ex-post assessments. Such research designs could provide further understanding of the specific links between time, action-oriented learning and what has been learnt over time, as well as the retention of such knowledge (Noguera-Méndez et al., 2016, Environment Agency, 2014).

The finding on the role of experiential learning suggests the need to consider a two-way relationship between awareness and behaviour rather than the one-way relationship (from awareness to behaviour) often considered in existing models (Dwyer et al., 2007, Floress et al., 2017, Nguyen et al., 2019, Okumah et al., 2019). Specifically, the results show that awareness could be improved via experiential learning (i.e. doing some actions can lead to reflecting on them, which in turn leads to a better understanding and subsequent changes in such behaviours). So rather than being a unidirectional relationship (the notion that the relationship always starts from awareness to behaviour), it could be a bidirectional one (i.e. also occurring from

behaviour to awareness) and that such interactions need to be understood through analysing the feedback loops overtime. It is also important to explore other benefits of action-oriented learning such as improved trust and ownership. Stakeholders' active participation in conservation actions contributes to co-ownership of the process and the product of such practices (in this case, the nutrient management plan) (Suškevičs et al., 2019). This is likely to increase their trust in the plan and their commitment to meeting conservation objectives.

Another relevant finding is that, while the preparation of the nutrient management plans has significantly influenced farmers' behaviour in relation to the import and export of slurry, these changes were less compared to other recommendations (28.1% reported changes in the import and/or export of slurries). This might suggest that the impact of experiential learning on behavioural changes is still affected by other circumstantial factors that may vary across the type of BMP. Situational factors (such as cost and infrastructure) may modulate the effect of different variables on adoption of BMPs (Barnes et al., 2011, Macgregor and Warren, 2006a, Okumah et al., 2019a, Okumah et al., 2018, Inman et al., 2018, Baumgart-Getz et al., 2012, Okumah and Ankomah-Hackman, 2020). In this particular case study, this could be due to the large surplus of slurry in Northern Ireland and a limit on suitable area for its redistribution (Cassidy et al., 2019). Another important situational factor concerns the economic value in transporting slurry from farm to farm or one sub-catchment to another. While this option is feasible, some farms may not have the required vehicles for conveying slurry over long distances cost effectively. In such cases, the services of a contractor may be needed to transport the slurry, adding cost to the exportation of slurry. Evidence from the Republic of Ireland suggests that transporting manure from livestock farms to arable farms may yield limited economic benefits beyond 50–75 km

in cases where trucks are used and even worse when tractors are used (Fealy and Schröder, 2008).

As explained in section 5.2.3, other factors may also influence the relationship between awareness and behavioural change. For instance, Buckley et al. (2015) reported that a wide range of variables impacted on adoption of nutrient management plans on Irish farms including farmer age and off-farm employment. While including these variables in the statistical analysis is valuable, we did not include this in our analysis due to lack of data. Therefore, there is abundant room for further progress in exploring factors that drive farmers' decisions and behaviours regarding soil testing, preparation and use of nutrient management plans, and uptake of BMPs. This could help advance our understanding of the topic as the limited empirical studies have often focussed on behavioural intentions (Daxini et al., 2018, Daxini et al., 2019a, Daxini et al., 2019b), and not on actual adoption. While these studies provide insights into determinants of adoption, their focus implies a lack of the complete picture on the drivers of behavioural change. For instance, these studies may fail to provide a full account of the adoption process as intentions do not always translate into actions (Hines et al., 1987, Kollmuss and Agyeman, 2002). Past studies have shown that there could be a gap between intentions and actual implementation of BMPs due to the moderating roles of cost, time, institutional support, flexibility of schemes and farm characteristics (Barnes et al., 2011, Macgregor and Warren, 2006a, Okumah et al., 2019a, Okumah et al., 2018, Inman et al., 2018, Baumgart-Getz et al., 2012).

Finally, our study provides a detailed example of a specific process and set of tools for provoking pro-environmental change among farmers in a highly livestock dependent Northwest European context. However, such a hands-on approach may

well be successful elsewhere, especially in the Global North, and future research could examine the efficacy of adapting this or identifying analogous schemes to develop a versatile tool-kit for operationalising lasting food-water systems transformations at the farm-level in-line with urgent calls from scientists and policy initiatives (Steiner et al., 2020).

5.5 Conclusions

In order to address existing and potential environmental impacts of agriculture, policymakers are increasingly focussing on influencing farmers' behaviour to adopt best management practices (BMPs). One of the strategies adopted is the provision of advice aimed at raising awareness on environmental pollution and mitigation measures. By improving farmers' awareness, policymakers expect changes in behaviour that would reflect in the adoption of BMPs, suggesting a straightforward link between awareness and uptake of BMPs. So far, however, the limited empirical research examining whether awareness-focussed strategies influence uptake of BMPs has shown that while there is a link between awareness and adoption, this link is indirect – and is mediated and moderated by other factors. One of the potential intervening factors that remains poorly understood is the enabling capacity that experiential learning brings. Overall, we found that farmers had a good understanding of the link between nutrient management and water quality as well as the agronomic and environmental benefits of engaging in BMPs. While advice seems to have contributed to uptake of BMPs, we found that likelihood of adoption increased if the farmers had prepared the nutrient management plans themselves. This is interpreted as the effect of experiential learning that deepens farmers' understanding, and increase their chances of adopting BMPs. This provides support for the conceptual

premise that while information provision is important, farmers need to actively engage in and be able to reflect on the practice for it to lead to behavioural changes. The role of experiential learning also suggests the need to move from the predominant unidirectional relationship being modelled (the notion that the relationship always starts from awareness to behaviour), as the relationship could be a bidirectional one (i.e. from behaviour to awareness) and such interactions need to be understood through analysing the feedback loops overtime.

Given that farmers who had attended or received nutrient management training were more likely to have prepared nutrient management plans for their farms, we encourage policymakers to incentivise farmers to attend training events and to engage in practical interventions, such as the preparation of farm nutrient plans. On the other hand, it is important to note that while low adoption might be related to knowledge, other contextual factors could be responsible. Understanding the role of situational factors could help policymakers tailor their policies to different BMPs and contexts. More research on this could offer insights into effective ways to help farmers manage their soils sustainably and ultimately contribute to reducing the environmental impacts of (agricultural) land management.

References

ADAMS, W. & SANDBROOK, C. 2013. Conservation, evidence and policy. *Oryx,* 47**,** 329-335.

ADUSUMILLI, N. & WANG, H. 2018. Analysis of soil management and water conservation practices adoption among crop and pasture farmers in humid-South of the United States. *International Soil and Water Conservation Research,* 6**,** 79-86.

AGAR, M. H. 1986. *Speaking of ethnography*, Sage.

ANONYMOUS 2011. Adaptive Water Management and Policy Learning in a Changing Climate: a Formal Comparative Analysis of Eight Water Management Regimes in Europe, Africa and Asia. *Environmental Policy and Governance,* 21**,** 145-163.

BARNES, A. P., WILLOCK, J., HALL, C. & TOMA, L. 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management,* 96**,** 1715-1722.

BARNES, A. P., WILLOCK, J., TOMA, L. & HALL, C. 2011. Utilising a farmer typology to understand farmer behaviour towards water quality management: Nitrate Vulnerable Zones in Scotland. *Journal of Environmental Planning and Management,* 54**,** 477-494.

BARRY, C. & FOY, R. 2016. Assessing the success of regional measures for lowering agricultural nutrient pollution in headwater streams. *Journal of environmental quality,* 45**,** 1329-1343.

BAUMGART-GETZ, A., PROKOPY, L. S. & FLORESS, K. 2012. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of environmental management,* 96**,** 17-25.

BLACKSTOCK, K. L., INGRAM, J., BURTON, R., BROWN, K. M. & SLEE, B. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the Total Environment,* 408**,** 5631-5638.

BOIRAL, O. 2002. Tacit knowledge and environmental management. *Long Range Planning,* 35**,** 291-317.

BRÉDART, D. & STASSART, P. M. 2017. When farmers learn through dialog with their practices: A proposal for a theory of action for agricultural trajectories. *Journal of Rural Studies,* 53**,** 1-13.

BROWN, T. 2006. Confirmatory factor analysis for applied research. The Guilford Press. *New York.*

BUCKLEY, C., HOWLEY, P. & JORDAN, P. 2015. The role of differing farming motivations on the adoption of nutrient management practices. *International Journal of Agricultural Management,* 4**,** 152-162.

BYRNE, M. M. 2001. Evaluating the findings of qualitative research. *AORN journal,* 73**,** 703-703.

CASSIDY, R., THOMAS, I. A., HIGGINS, A., BAILEY, J. S. & JORDAN, P. 2019. A carrying capacity framework for soil phosphorus and hydrological sensitivity from farm to catchment scales. *Science of the total environment,* 687**,** 277-286.

D'ANGELO, M. J. & BRUNSTEIN, J. 2014. Social learning for sustainability: supporting sustainable business in Brazil regarding multiple social actors, relationships and interests. *International Journal of Sustainable Development & World Ecology: Managing Organizations for Sustainable Development in Emerging Countries,* 21**,** 273-289.

DAERA. 2018. Statistical Review of Northern Ireland Agriculture 2017 [Online]. Belfast: Department of Agriculture Environment and Rural Affairs. Available: https://www.daera-ni.gov.uk/publications/statistical-review-ni-agriculture-2007-onward [Accessed 21/02 2020].

DAXINI, A., O'DONOGHUE, C., RYAN, M., BUCKLEY, C., BARNES, A. P. & DALY, K. 2018. Which factors influence farmers' intentions to adopt nutrient management planning? *Journal of environmental management,* 224**,** 350-360.

DAXINI, A., RYAN, M., O'DONOGHUE, C. & BARNES, A. P. 2019a. Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour. *Land Use Policy,* 85**,** 428-437.

DAXINI, A., RYAN, M., O'DONOGHUE, C., BARNES, A. P. & BUCKLEY, C. 2019b. Using a typology to understand farmers' intentions towards following a nutrient management plan. *Resources, Conservation and Recycling,* 146**,** 280-290.

DEVISSCHER, T., VIGNOLA, R., BESA, M. C., CRONENBOLD, R., PACHECO, N., SCHILLINGER, R., CANEDI, V., SANDOVAL, C., GONZALEZ, D. & LECLERC, G. 2016. Understanding the socio-institutional context to support adaptation for future water security in forest landscapes. *Ecology and Society,* 21.

DPMAG 2015. Strategy to reduce diffuse pollution. Edinburgh: Scottish Environment Protection Agency.

DWYER, J., MILLS, J., INGRAM, J., TAYLOR, J., BURTON, R., BLACKSTOCK, K., SLEE, B., BROWN, K., SCHWARZ, G. & MATTHEWS, K. 2007. Understanding and influencing positive behaviour change in farmers and land managers. *CCRI, Macaulay Institute*.

ENVIRONMENT AGENCY 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report. Bristol: Environment Agency

ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. . Bristol: Environment Agency.

FAZEY, I., FAZEY, J. A., SALISBURY, J. G., LINDENMAYER, D. B. & DOVERS, S. 2006. The nature and role of experiential knowledge for environmental conservation. *Environmental Conservation,* 33**,** 1-10.

FEALY, R. & SCHRÖDER, J. J. 2008. *Assessment of manure transport distances and their impact on economic and energy costs*, IFS.

FOSTER, A. D. & ROSENZWEIG, M. R. 1995. Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of political Economy,* 103**,** 1176-1209.

FRANZ, N., PIERCY, F., DONALDSON, J., RICHARD, R. & WESTBROOK, J. 2010. HOW FARMERS LEARN: IMPLICATIONS FOR AGRICULTURAL EDUCATORS. *Journal of Rural Social Sciences,* 25**,** 37-59.

HINES, J. M., HUNGERFORD, H. R. & TOMERA, A. N. 1987. Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *Journal of Environmental Education,* 18**,** 1-8.

HOOPER, D., COUGHLAN, J. & MULLEN, M. R. 2008. Structural equation modelling: Guidelines for determining model fit. *Electronic journal of business research methods,* 6**,** 53-60.

HOSONUMA, N., HEROLD, M., DE SY, V., DE FRIES, R. S., BROCKHAUS, M., VERCHOT, L., ANGELSEN, A. & ROMIJN, E. 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters,* 7**,** 044009.

HU, L. T. & BENTLER, P. M. 1999. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: a multidisciplinary journal,* 6**,** 1-55.

HUTCHINS, M. G. 2012. What impact might mitigation of diffuse nitrate pollution have on river water quality in a rural catchment? *Journal of Environmental Management,* 109**,** 19-26.

INMAN, A., WINTER, M., WHEELER, R., VRAIN, E., LOVETT, A., COLLIN, A., JONES, I., JOHNES, P. & CLEASBY, W. 2018. An exploration of individual, social and material factors influencing water pollution mitigation behaviours within the farming community. *Land Use Policy,* 70**,** 16-26.

JACKMAN, M. R. 1973. Education and prejudice or education and response-set? *American Sociological Review,* 327-339.

JACKSON, D. L. 2001. Sample Size and Number of Parameter Estimates in Maximum Likelihood Confirmatory Factor Analysis: A Monte Carlo Investigation. *Structural Equation Modeling: A Multidisciplinary Journal,* 8**,** 205-223.

JACKSON, D. L. 2003. Revisiting Sample Size and Number of Parameter Estimates: Some Support for the N:q Hypothesis. *Structural Equation Modeling: A Multidisciplinary Journal,* 10**,** 128-141.

JAGANNATHAN, K., ARNOTT, J. C., WYBORN, C., KLENK, N., MACH, K. J., MOSS, R. H. & SJOSTROM, K. D. 2020. Great expectations? Reconciling the aspiration, outcome, and possibility of co-production. *Current Opinion in Environmental Sustainability,* 42**,** 22-29.

KENCH, P. S., RYAN, E. J., OWEN, S., BELL, R., LAWRENCE, J., GLAVOVIC, B., BLACKETT, P., BECKER, J., SCHNEIDER, P. & ALLIS, M. 2018. Co-creating resilience solutions to coastal hazards through an interdisciplinary research project in New Zealand. *Journal of Coastal Research,* 85**,** 1496-1500.

KOLB, D. A. 1984. Experience as the source of learning and development. *Upper Sadle River: Prentice Hall.*

KOLLMUSS, A. & AGYEMAN, J. 2002. Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research,* 8**,** 239-260.

KORMOS, C. & GIFFORD, R. 2014. The validity of self-report measures of proenvironmental behavior: A meta-analytic review. *Journal of Environmental Psychology,* 40**,** 359-371.

KUMLER, L. M. & LEMOS, M. C. 2008. Managing Waters of the Paraíba do Sul River Basin, Brazil a Case Study in Institutional Change and Social Learning. *Ecology and Society,* 13.

MACGREGOR, C. J. & WARREN, C. R. 2006. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. *Agriculture, Ecosystems & Environment,* 113**,** 108-119.

MAGUIRE, R. O. & SIMS, J. T. 2002. Soil testing to predict phosphorus leaching. *Journal of environmental quality,* 31**,** 1601-1609.

MAYRING, P. 2004. Qualitative content analysis. *A companion to qualitative research,* 1**,** 159-176.

MERRILEES, D. & DUNCAN, A. 2005. Review of attitudes and awareness in the agricultural industry to diffuse pollution issues. *Water Science and Technology,* 51**,** 373-381.

NOVOTNY, V. 2013. Diffuse pollution from agriculture — A worldwide outlook. *Water Science and Technology* 39**,** 1-13.

OECD 2012. Water quality and agriculture: meeting the policy challenge. OECD Studies on Water. . Paris: Organisation for Economic Co-operation and Development.

OENEMA, O., KROS, H. & DE VRIES, W. 2003. Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. *European Journal of Agronomy,* 20**,** 3-16.

OKUMAH, M. & ANKOMAH-HACKMAN, P. 2020. Applying conditional process modelling to investigate factors influencing the adoption of water pollution mitigation behaviours. *Sustainable Water Resources Management,* 6**,** 17.

OKUMAH, M., CHAPMAN, P., MARTIN-ORTEGA, J. & NOVO, P. 2019a. Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway. *Water,* 11**,** 29.

OKUMAH, M., JULIA, M.-O., PAULA, N. & PIPPA, J. C. 2020. Revisiting the Determinants of Pro-Environmental Behaviour to Inform Land Management Policy: A Meta-Analytic Structural Equation Model Application. *Land (Basel),* 9**,** 135.

OKUMAH, M., MARTIN-ORTEGA, J. & NOVO, P. 2018. Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: A conditional process modelling. *Land Use Policy,* 76**,** 36-45.

OKUMAH, M. & YEBOAH, A. S. 2019. Exploring stakeholders' perceptions of the quality and governance of water resources in the Wenchi municipality. *Journal of Environmental Planning and Management*.

OKUMAH, M., YEBOAH, A. S., NKIAKA, E. & AZERIGYIK, R. A. 2019b. What Determines Behaviours Towards Water Resources Management in a Rural Context? Results of a Quantitative Study. . *Resources,* 8.

PAHL-WOSTL, C. & HARE, M. 2004. Processes of social learning in integrated resources management. *Journal of Community & Applied Social Psychology,* 14**,** 193-206.

POSTHUMUS, H., DEEKS, L., FENN, I. & RICKSON, R. 2011. Soil conservation in two English catchments: linking soil management with policies. *Land degradation & development,* 22**,** 97-110.

SCHUMAN, H. & PRESSER, S. 1981. Questions and Answers in Attitude Surveys Academic Press New York. *SchumanQuestions and Answers in Attitude Surveys1981*.

SCHUMM, W. R., PRATT, K. K., HARTENSTEIN, J. L., JENKINS, B. A. & JOHNSON, G. A. 2013. Determining Statistical Significance (Alpha) and Reporting Statistical Trends: Controversies, Issues, and Facts1. *Comprehensive Psychology,* 2.

SCIENCE FOR ENVIRONMENT POLICY. 2017. Agri-environmental schemes: how to enhance the agriculture-environment relationship. [Online]. European Commission Available: http://ec.europa.eu/science-environmentpolicy [Accessed 12/12 2017].

SEPA. 2015. *Diffuse Pollution* [Online]. Scottish Environment Protection Agency. Available: http://www.sepa.org.uk/water/diffuse_pollution.aspx [Accessed].

SEWELL, A., HARTNETT, M., GRAY, D., BLAIR, H., KEMP, P., KENYON, P., MORRIS, S. & WOOD, B. 2017. Using educational theory and research to refine agricultural extension: affordances and barriers for farmers' learning and practice change. *The Journal of Agricultural Education and Extension,* 23**,** 313-333.

SILVERMAN, R. M. & PATTERSON, K. L. 2015. *Qualitative research methods for community development.*

STEMLER, S. 2000. An overview of content analysis. *Practical Assessment, Research, and Evaluation,* 7**,** 17.

STRINGER, L. C., FRASER, E. D. G., HARRIS, D., LYON, C., PEREIRA, L., WARD, C. F. M. & SIMELTON, E. 2020. Adaptation and development pathways for different types of farmers. *Environmental Science & Policy,* 104**,** 174-189.

SUŠKEVIČS, M., HAHN, T. & RODELA, R. 2019. Process and Contextual Factors Supporting Action-Oriented Learning: A Thematic Synthesis of Empirical Literature in Natural Resource Management. *Society & Natural Resources,* 32**,** 731-750.

SUŠKEVIČS, M., HAHN, T., RODELA, R., MACURA, B. & PAHL-WOSTL, C. 2018. Learning for social-ecological change : a qualitative review of outcomes across empirical literature in natural resource management.

SUTHERLAND, W. J., PULLIN, A. S., DOLMAN, P. M. & KNIGHT, T. M. 2004. The need for evidence-based conservation. *Trends in Ecology & Evolution,* 19**,** 305-308.

TEPIC, M., J. H. TRIENEKENS, R. HOSTE, S. W. F. OMTA. 2012. The influence of networking and absorptive capacity on the innovativeness of farmers in the Dutch pork sector. International Food and Agribusiness Management Review 15(3):1–34.

UNCCD. 2015. *Land Degradation Neutrality: resilience at local, national and regional levels* [Online]. Bonn, Germany: United Nations Convention to Combat Desertification. Available: http://bit.ly/2vJ0ZJm [Accessed 23/10 2016].

UNITED NATIONS. 2015. *Transforming our World: the 2030 Agenda for Sustainable Development.* [Online]. New York: United Nations Available: http://bit.ly/1OTd4Sr [Accessed 20/10/2016].

UNITED NATIONS 2016. Global Sustainable Development Report 2016. New York, US: Department of Economic and Social Affairs.

UNITED NATIONS ENVIRONMENT PROGRAMME 2017. Towards a pollution free planet background report. . Nairobi, Kenya: United Nations Environment Programme.

UNITED NATIONS WORLD WATER ASSESSMENT PROGRAMME 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris United Nations Educational, Scientific and Cultural Organization.

VRAIN, E. & LOVETT, A. 2019. Using word clouds to present farmers' perceptions of advisory services on pollution mitigation measures. *Journal of Environmental Planning and Management***,** 1-18.

WHITEMAN, G., FORBES, B. C., NIEMELÄ, J. & CHAPIN, F. S. 2004. Bringing feedback and resilience of high-latitude ecosystems into the corporate boardroom. *Ambio,* 33**,** 371.

WOODWELL, G. M. 1989. On Causes Of Biotic Impoverishment. *Ecology,* 70**,** 14-15.

ZHONG, H. 2016. Essays on farmer willingness to participate in best management practices in the Kentucky River watershed. Theses and dissertations. Agricultural Economics 40.

Chapter 6

Do awareness-focussed approaches to mitigating diffuse pollution work? A case study using behavioural and water quality evidence

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Abstract

Efforts to tackle diffuse water pollution from agriculture (DWPA) are increasingly focussing on improving farmers' awareness under the expectation that this would contribute to adoption of best management practices (BMPs) and, in turn, result in water quality improvements. To date, however, no study has explored the full awareness-behaviour-water quality pathway; with previous studies having mostly addressed the awareness-behaviour link relying on disciplinary approaches. Using an interdisciplinary approach, we investigate whether awareness-focussed approaches to mitigating DWPA indeed result in water quality improvement, addressing the pathway in full. We worked with Dŵr Cymru Welsh Water (a water and waste utility company in the UK) on a pesticide pollution intervention programme, referred to as "weed wiper trial". The main goal of the trial was to raise farmers' awareness regarding pesticide management practices and to promote uptake of BMPs to tackle the rising concentrations of the pesticide MCPA (2-methyl-4-chlorophenoxyacetic acid) in raw water in three catchments in Wales. Using factorial analysis of variance, we analysed MCPA concentrations from 2006 to 2019 in the three catchments and in three control catchments. This was followed by semi-structured in-depth interviews with institutional stakeholders and farmers with varying degrees of exposure to the weed wiper trial. Results show that MCPA concentration for both treatment and control catchments had

reduced after the implementation of the weed wiper trial. However, the decline was significantly larger for the treatment catchments compared to the control catchments. Results from the stakeholder interviews indicate that improved awareness contributed to changes in farmers' behaviour and that these can be related to the water quality improvements reflected by the decline in MCPA concentration. Alongside awareness, other psychosocial, agronomic factors and weather conditions also influenced farmer's ability to implement BMPs and thus overall water quality improvements.

Keywords: Best Management Practices; Glyphosate; MCPA (2-methyl-4-chlorophenoxyacetic acid); Pesticides; Wales; Water quality

6.1 Introduction

Diffuse water pollution from agriculture (DWPA) is one of today's major environmental problems, with great social impacts such as cost of water treatment and reduced recreational potential of water resources (Damania et al., 2019, OECD, 2012, OECD, 2017, United Nations, 2016). Policy interventions are increasingly focusing on improving farmers' awareness on these problems under the expectation that this can lead to adoption of best management practices (BMPs), i.e. practical measures to reduce the amount of fertilisers, pesticides and other pollutants entering watercourses. Examples of these policies include, for example, the Water Quality Scheme and the Environmental Quality Incentive Programme in the United States, the Monitor Farms Programme in New Zealand (Dwyer et al., 2007), the Catchment Sensitive Farming Delivery Initiative in England (Environment Agency, 2011, Environment Agency, 2014) and the Diffuse Pollution Management Strategy in Scotland (DPMAG, 2015). Improving farmers' awareness is expected to deepen their understanding of the link between land management practices and DWPA, motivating a change in behaviour that increases uptake of BMPs and that, in turn, reduces risks of DWPA, ultimately

contributing to improving water quality (DPMAG, 2015, Blackstock et al., 2010, Okumah et al., 2019, Kay et al., 2009, Martin-Ortega and Holstead, 2013, Gibbons et al., 2014). This expectation is based on the assumption of a relatively straightforward relationship between awareness, behaviour and water quality, herein referred to as the awareness-behaviour-water quality pathway.

However there is lack of evidence on how this pathway works. Previous studies have often addressed partial aspects of the pathway from disciplinary perspectives. For instance, some studies have focussed on farmers' behavioural intentions, but not on actual adoption of BMPs (e.g., Daxini et al., 2018, Daxini et al., 2019a, Daxini et al., 2019b, Zeweld et al., 2017, Floress et al., 2017a). While these studies provide insights into factors influencing uptake of BMPs, they fail to provide a full account of the determinants of behavioural change. This is because farmers' intentions might not always translate into behavioural changes due to the influence of contextual factors such as cost, time, available (or lack of) institutional support and farm tenure (Barnes et al., 2009, Macgregor and Warren, 2006, Baumgart-Getz et al., 2012). Other studies have focussed on the link between awareness and actual adoption of BMPs (e.g., Macgregor and Warren, 2006, Okumah et al., 2018, Vrain and Lovett, 2016), but have not considered the impact of the uptake of BMPs on water quality. Other studies that have investigated the impact of BMPs on water quality responses but did not include information on factors driving adoption of BMPs by farmers (e.g., Kay et al., 2012, Collins et al., 2016).

There is therefore an urgent need to overcome this partial and mono-disciplinary approach to the understanding of the awareness-behaviour-water quality pathway in order to inform awareness-focussed interventions (Giri and Qiu, 2016, Okumah et al.,

2019a). In this study, we take an interdisciplinary approach, where farmers and institutional stakeholders' perceptions of DWPA and factors influencing actual (rather than intended) adoption of BMPs are considered alongside changes in water quality. By combining semi-structured in-depth interviews and water quality data from a case study in Wales (UK), we examine how farmers' awareness and adoption of BMPs interact with psychosocial, agronomic and biophysical factors and whether pesticide concentrations in three catchments in Wales have declined following an awareness-focussed trial aimed at reducing pesticide pollution.

The pesticide of focus is MCPA (2-methyl-4-chlorophenoxyacetic acid), a chemical that is extensively used in agriculture to control broad-leaf weeds such as thistles, docks and the common rush (*Juncus effusus*). Due to the high solubility of MCPA and poor absorption to the soil matrix, it is prone to leaching directly into watercourses or via land drains, with a recent study showing that MCPA is frequently detected in watercourses and drinking water sources around the world (Morton et al., 2020). Though EU standards stipulate that the maximum concentration of any individual pesticide in drinking water remains below one tenth of part per billion (0.1 µg/L[11]), the equivalent of one blade of grass in a 100,000 hay bale (Morton et al., 2020, Welsh Water, 2014), available data shows that between five to 10% of raw water samples from surface water exceed 0.1 µg/L limit for MCPA in England and Wales (Defra, 2012). Specifically, the study seeks to investigate: 1) whether MCPA concentration in drinking water sources declined significantly following an awareness-focussed intervention, 2) whether the decline in MCPA concentration can be attributed to

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[11] Our analysis shows that between 2006 and 2015, 18 water samples from the treatment catchments exceeded the 0.1 µg/L limit for MCPA, while eight samples in the control catchments exceeded the limit.

adoption of BMPs, and 3) whether awareness contributed to adoption of BMPs. While the study is set in the context of pesticide pollution in Wales, it sets out to provide insights into the role of awareness-based interventions towards mitigating the environmental impact of land management practices on DWPA more broadly. To our knowledge, this is also the first study exploring awareness-behaviour-quality pathway in full.

6.2 Materials and Methods

6.2.1 Case study – Welsh Water's pesticide pollution reduction strategy

Dŵr Cymru Welsh Water (hereafter referred to as Welsh Water) is a water and waste utility operating in Wales (UK) responsible for the supply of high quality drinking water to over three million people, as well as treating and disposing of wastewater. In 2013, through their routine raw water monitoring programme, Welsh Water found that MCPA[12] concentrations were increasing in drinking water sources (Welsh Water, 2014). Welsh Water's root cause analysis and discussions with stakeholders revealed that it was common practice for farmers to boom spray MCPA to tackle common rush (*Juncus effusus*) infestation (Welsh Water, 2014), which is mainly a problem in permanent pastures on poorly drained soils in high rainfall areas, especially after wet winters and/or summers. Although annual mean MCPA concentration were too low to pose a risk to those drinking the water (Figure 6.1), continuous increase in MCPA concentration in raw water may result in breaching EU Drinking Water standards and therefore were a concern for the utility company (Welsh Water, 2014). By safeguarding and improving raw water quality before it gets to water treatment works, they can avoid the need for using additional chemicals and energy to get drinking water to meet

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[12] https://www.dwrcymru.com/en/WaterSource/MCPA-Weedwiper.aspx

regulatory standard. This helps them to keep bills low for their customers and safeguard the environment for generations to come (Welsh Water, 2014).

To address this issue, Welsh Water decided to work with the farming industry and other stakeholders in the land management sector, placing particular emphasis on providing farmers with advice and increasing their awareness of the problem and how to tackle it. Welsh Water argued that without the support of key industry partners, they were less likely to be successful. As a result, key industry partners were engaged at the beginning after their root cause analysis. They worked with them to identify solutions and to create a trial that was 'fit for purpose' for the target audience and to tackle the issue.

In 2015, they launched a programme called the Weed wiper trial in three targeted catchments (hereafter referred to as 'treatment catchments') – Teifi, Towy and Wye, where routine water monitoring detected the most significant increase in MCPA concentrations. The initiative encouraged farmers and land managers to sign up for free hire of a weed wiper. A weed wiper is a technology where a wick wetted with herbicide is connected to a boom and dragged or rolled across the tops of the taller weed plants (Table 6.1). This allows treatment of taller grassland weeds by direct contact, without affecting related but desirable shorter plants in the grassland sward beneath. The technology has the benefit of avoiding spray drift that occurs with other conventional methods (Table 6.2) of application that use self-propelled sprayers equipped with long booms, of 18 to 37 m with spray nozzles spaced every 510–760 mm apart. In addition, only glyphosate based products are licenced to be used in a weed wiper. This is because, compared to MCPA that takes 15 – 25 days to break down in water, glyphosate takes considerably less time (three days) so it has less

impact on watercourses (Welsh Water, 2014). There was a total of 292 weed wiper hires between 2015 and 2019 across the three treatment catchments (Table 6.2).

In addition to attending a wider range of agricultural shows and various workshops to promote the weep weed wiper, information packs on the use of weed wipers and advice films on safe measures of pesticide application were distributed to farmers within and outside the three-targeted catchments to raise their awareness of BMPs and their benefits, including to water quality. Between 2015 and 2019, a total of 628 information packs were distributed (Table 6.2), of which 444 packs (70.7% of total) were within the treatment catchments. In addition to the weed wiper, Welsh Water encouraged farmers to use non-chemical techniques, such as topping with a rotary or flail mower before the rush plants produce seed, alongside pesticide use to achieve a long-term control of rushes. Thus, farmers were encouraged to take up pest management practices that could help tackle all possible sources of pesticide pollution to drinking water sources (see Table 6.3 for an overview of the practices).

The weed wiper trial is considered by the Welsh Water to be a win-win solution that is expected to provide effective control for the farmer and lower risk of pollution to water sources. Allowing farmers to hire the machine to provided first-hand experience to 'try before buying' was expected to help farmers appreciate the benefits of using the technology, raising awareness of the impact of poor pesticide management practices. It was hoped that farmers would be more likely to adopt the weed wiper and other non-chemical techniques that could be used alongside (instead of pesticide) to provide longer term control (Welsh Water, 2014).The weed wiper trial is therefore 'advice-centred' and voluntary approach that focusses on increasing farmers' awareness to stimulate their adoption of BMPs, with the specific intent to reduce pesticide leaching

and thus improvement in water quality. This makes the weed wiper trial a suitable case

study for exploring the full awareness-behaviour-water quality pathway.

Table 6.1: Common chemical control strategies to manage weeds

Equipment	Description
Boom sprayer	Most commonly used to apply liquid fertilizers or pesticides to crops during their vegetative cycle, b*oom sprayers* distribute the product from a tank *through a* pipe with nozzles. The *sprayer's* height is adjustable. Using a boom sprayer, MCPA can be applied to grass. However, this must be applied with care, as MCPA could damage most broad-leaved plants, including clover.
Knapsack sprayer	Most commonly used to spray fungicides or insecticides, knapsack sprayer consists of a knapsack tank together with pressurising device, line, and sprayer nozzle. A knapsack sprayer is versatile and enables the farmer to target areas with rush. However, spray can drift in windy weather onto other plants and ultimately reach watercources.
Weed wiper	Using a weed wiper, Glyphosate can be applied, in conditions where rush plants are actively growing and stand higher than the surrounding grass. Because glyphosate has potentially less impact on water quality and broad-leaved plants than MCPA, the use of weed wipers (with glyphosate) is widely recommended than regular boom spraying with MCPA.

Table 6.2: Summary of number of information packs distributed and weed wiper hires within and outside the targeted catchments

Year	Catchment			Outside treatment catchments	Total
	Teifi	Wye	Towy		
Information packs distributed					
2015	79	57	0	55	191
2016	45	34	0	32	111
2017	37	36	44	44	161
2018	28	18	21	30	107
2019	15	12	18	23	68
Total	**204**	**157**	**83**	**184**	**628**
Weed wiper hires					
2015	45	18	-	-	63
2016	41	22	-	-	63
2017	26	25	22	-	73
2018	18	16	13		47
2019	22	13	11		46
Total	**152**	**94**	**46**	**-**	**292**

Note: 1) In 2015 and 2016, farmers in Towy did not receive any packs and there were no hires as this catchment was only included in the scheme in 2017.

Table 6.3: Summary of BMPs promoted as part of the weed wiper trial

Component	Recommended Practice
Storage	Keep pesticides in a clearly marked lockable, bunded store at least 10m away from any watercourse or drain.
	Keep pesticides in their original (clearly labelled) containers and legally dispose of any unwanted or out of date chemicals.
	Ensure you have a spill kit located near the store and/or filling area to contain any spillages.
In yard	Check application equipment is working correctly and has a valid National Sprayer Testing Scheme certificate.
	Ensure operator is suitably trained, competent and has required protective clothing e.g. overalls, gloves, masks.
	Ideally, fill equipment in a covered, concrete bunded area where drainage can be contained. Alternatively, fill on grass using a drip tray or portable bund.
In field	Carefully follow instructions for application. Do not over apply – this can wash off into drains or residues can stay in soils effecting the next crop grown.
	Do not fill at the entrance of a field or any bare earth especially if adjacent to a watercourse, or a road/track that could channel run-off water into a watercourse.
	Establish buffer strips adjacent to any ditches or watercourse.
	Do not apply pesticide prior to rainfall or in windy conditions or when ground is frozen.
	Plan your route through fields. Do not cross any ditches or streams to avoid accidents that could lead to involuntary pouring out of pesticides, and prevent pollution.
Disposal	Wash the outside of the sprayer before leaving the field, since there may remain residue on the machine or in the mud on tyres.
	Spray washings on to the crop or target area - be careful not to over apply.
	Ensure all cleaning activities take place away from watercourses.
	Return any unused pesticide to store. Alternatively, use a registered waste disposal company.
	Record all pesticide applications.

6.2.2 Methods

To determine whether Welsh Water's awareness focussed approach has resulted in a decline in MCPA concetrations in drinking water sources, and whether this can be related to an increased adoption of BMPs, we used two strands of data: water quality data (i.e., MCPA concentration) from Welsh Water's routine raw water programme, and qualitative data gathered via semi-structured in-depth interviews with farmers and other relevant regional stakeholders. This interdisciplinary approach aims at overcoming the limitations of partial mono-disciplinary methodologies unsuitable to addressing the complexity of 'wicked problems' such as DWPA (Martin-Ortega et al., 2015, Duckett et al., 2016, Termeer and Dewulf, 2019, Raymond et al., 2010, Stoate et al., 2019).

Stakeholder consultation was carried out in Wales to gain insights into farmer awareness of DWPA, pesticide management, DWPA and other contextual factors, from the perspectives of different stakeholders. The consultation process (which happened in July 2018 at the Royal Welsh Show, Builth Wells) was face-to-face and involved two farmers, two people from Welsh Water and one person from each of the following institutions: National Farmers' Union, Farming Connect, Welsh Government, and Natural Resources Wales. At the end of the consultation, all stakeholders emphasised the need for awareness creation and a demonstration of a win-win situation given that farmers are running a business where yield influences profit margins. Therefore, demonstrating that best management practices reduce input costs, contribute to higher profits and a reduction in environmental pollution is a good step. Other contextual factors including the role of social pressure, collective action and cost of adoption, were highlighted. These initial ideas, insights from the systematic review in Chapter 4 and the results of water quality analysis (section 6.2.2.2) informed the design of an interview guide (section 6.2.2.3, and Appendix E) – which was collectively developed and drew knowledge from different disciplines and stakeholders.

Working with these relevant stakeholders to identify important issues for research and to develop the data collection tools (interview guides) helps to look at the problem from multiple perspectives, understand contextual factors that could affect policy outcomes and to tap into the rich knowledge and experiences of the different stakeholders. Moreover, such a collaborative approach offers the platform to identify potential synergies, develop innovative strategies and maximise the use of resources (Fry, 2001). In the end, this helps to reduce the duplication of efforts and the tendency to develop potentially conflicting interventions (Macleod et al., 2007).

6.2.2.1. Analysis of water quality changes

Welsh Water's monitoring assesses raw water quality based on a number of parameters, including MCPA concentration (measured in µg/L). Welsh Water provided MCPA data from 2006 to 2019 for all water treatment works (WTW) in the three

treatment catchments. In addition, they also provided MCPA data for all WTW within three control catchments that had not been in the trial but were in a similar location and of similar characteristics to the treatment catchments (Table 6.4). Together, the treatment catchments constitute 16.4% of the total land area of Wales, while the control catchments account for 14.0% (Table 6.4). For the Teifi and the Wye catchments, April 2015 served as the separation point between pre and post intervention, while April 2017 was used as the separation point for the Towy catchment; as this is when it became part of the weed wiper trial. For all control catchments, April 2015 served as the separation point.

We explored the potential effects of the weed wiper trial on MCPA concentrations using factorial analysis of variance (ANOVA). Factorial designs are effective for examining treatment variations and to investigate interaction effects. Factorial designs enable us to effectively combine these data into one and examine the main and interaction effects of different variables. The Type III sum of squares estimation option was selected. This option allows us to evaluate the effect of each variable after other factors have been accounted for. Using this option has an advantage over estimation options such as Type I as the Type III option is not sample size dependent. The factorial ANOVA was ran using SPSS IBM version 23. In the model, MCPA concentration was classified as the dependent variable while condition, time and catchment were included as independent categorical factors (Table 6.3). This allowed us to test whether there were differences in observed MCPA concentrations, whether such differences were statistically significant as well as the interaction between variables. Following the interdisciplinary approach of this research, results of the water quality analysis informed the focus of the interview sessions and helped us to gain insights into the perspectives of different stakeholders (see 6.2.2.2).

Table 6.4: Sample Distribution

Variable	Groups	Code	Number of water samples	Percentage	Land area (Hectares)
Condition	Control (C)	1	1339	43.5	339502.8
	Treatment (T)	2	1738	56.5	289644.8
Time	Pre intervention	1	1420	46.1	-
	Post Intervention	2	1657	53.9	-
Catchment	T-Towy	1	507	16.5	109219.1
	T-Teifi	2	467	15.2	90627.3
	T- Wye	3	764	24.8	139656.4
	C Cleddau	4	488	15.9	42331.5
	C-Teme	5	395	12.8	143379.5
	C-Usk	6	456	14.8	103938.8
Total	-	-	3077	-	2,073,500

6.2.2.2 Semi-structured in-depth interviews

Semi-structured interviews were conducted with sixteen farmers and six institutional stakeholders between July 2019 and February 2020 (see Appendix E for the interview scripts). In-depth interviews lasted up to about one hour and focussed on understanding interviewees perceptions on: 1) whether water quality outcomes can be attributed to land management practices, 2) whether and how awareness has contributed to adoption of BMPs, and 3) other factors that could influence land management practices and water quality outcomes. During the interviews, we also asked stakeholders for their opinions of what influenced water quality within the study catchments. Relying on different stakeholders' perceptions enables us to gather different 'knowledges' and understanding from policymakers and local stakeholders as this could offer useful insights into understanding the complex factors influencing behaviours and DWPA (Morgan, 2014). This helps to bridge the gap between science and society, elicit information that would otherwise be missed and help us to capture a more "ground-truthed" picture of reality (Tress et al., 2005). The value of qualitative data collected through the interviews lies in the deep insights it provides, not the 'number of persons explaining what', as the goal is not to generalise but to 'make

sense' of the phenomenon that is under investigation (Onwuegbuzie and Leech, 2005, Rossman and Wilson, 1985). Consequently, as with any other qualitative social science study, sampling, analysis and study outcomes are not necessarily (motivated by and/or) dependent on sample size.

Farmers were our primary stakeholders as they were the ones whose knowledge and behaviours were expected to change through the weed wiper trial. At the same time, institutional stakeholders (e.g., representatives of farmer unions, local environmental organisations, and water utility) play important regulatory and advisory roles in land and water management and their views are therefore useful to further our understanding of the context and provide further insights (see Table 6.5a for the justification for their inclusion in this study and 6.5b for the characteristics of participating farmers). Of the sixteen farmers who participated in the interviews, eight had participated in the weed wiper trial while the remaining eight had not participated in it (although they had knowledge of the weed wiper trial and some had received information regarding the BMPs promoted). Implications of the views of these different farmers are considered in the discussion. Interviewees were predominantly livestock farmers (Table 6.5b).

Interviewees were recruited using a combination of connections with local partners (Welsh Water and the Farming Connect), face-to-face contact at the Royal Welsh Show in Builth Wells in 2019 and snowballing, where some interview participants referred us to other stakeholders. Ten of the farmers and stakeholder interviews were conducted through phone calls while twelve were face-to-face at the Royal Welsh Show (Tables 6.5a and 6.5b describe interview participants). To enhance the credibility and validity of the data, we applied descriptive respondent validation (Byrne,

2001). This involved summarising key aspects of the interview and asking participants whether they represented their views or not. This was implemented either during or after the interview session. We applied the intelligent verbatim transcription method to transcribe the interviews (Golota, 2018).

Interviews were analysed using a grounded theory approach (Strauss and Corbin, 1998) to first perform an open coding of emergent themes, using NVIVO version 11. This was done by carefully reading through the interview transcripts and identifying recurring topics that emerged from the texts rather than on the basis of pre-defined topics. We identified statements that provided plausible explanations to the water quality results. Next, using axial coding, we compared codes to establish similarities and differences and categorised them to identify the most dominant themes being discussed. To establish validity of our results, the procedure was reviewed in an iterative process until the results became stable. Following a process of selective coding, results of the in-depth interviews are presented in Section 3 using a manifest style (Bengtsson, 2016), where key findings are presented and reference made to interviewees' statements.

Table 6.5a: List of stakeholders and justification for their inclusion in the interviews

#	Stakeholder	Justification for Inclusion
1	Farmers	Frontlines of land use and their farm activities may impact river water quality. Also, they are the ones that the weed wiper trial aimed to change their awareness and behaviours (see description of the farmers in Table 5b).
2	Welsh Water	Responsible for the supply of high quality drinking water to over three million people in Wales. They implemented the weed wiper trial.
3	Farming Connect	It is a knowledge transfer, innovation and advisory service for farming and forestry businesses in Wales funded through Welsh Government Rural Communities – Rural Development Plan 2014-2020.

4	National Farmers' Union	They influence public policy related to agriculture and have a role to play in encouraging their members (farmers) to engage in environmentally friendly farming practices.
5	Natural Resources Wales	They advise and regulate the activities of farmers including practices that affect water resources.
6	Daltons ATV	Welsh Water's trusted intermediary and delivered the weed wipers to farmers. They also provide advice on best pesticide application techniques and how to use the weed wipers.
7	Lantra	They provide pesticide application training to farmers in Wales.

Table 6.5b: Profile of the farmer participants in-depth interviews

#	ID	Participated in weed wiper trial	Weed wiper use	Location	Tenancy	Farm type
1	P1	No	No*	Cleddau	Owner occupier	Arable
2	P2	No	No	Teifi**	Owner occupier	Grassland
3	P6	No	Yes	Towy**	Owner occupier	Grassland
4	P8	No	No	Cwmcarno	Rent (Tenant)	Sheep/cattle
5	P10	No	No	River Severn	Rent (Tenant)	Sheep
6	P12	No	Yes	Teifi**	Owner occupier	Sheep
7	P13	No	No*	Teifi**	Rent (Tenant)*	Sheep
8	P14	No	Yes	-------	Rent (Tenant)*	Sheep/cattle
9	P15	Yes	No*	Towy**	Owner occupier	Livestock
10	P16	Yes	No*	Towy**	Owner occupier	Livestock
11	P17	Yes	No*	Teifi**	Owner occupier	Livestock
12	P18	Yes	No*	------	Owner occupier	Livestock
13	P19	Yes	Yes	Wye**	Owner occupier	Livestock
14	P20	Yes	Yes	Wye**	Owner occupier	Livestock
15	P21	Yes	No*	Teifi**	Owner occupier	Livestock
16	P22	Yes	No*	----	Owner occupier	Livestock

No* = farmer not using the weed wiper at the time of the interview but has used it in the past; * in tenancy types suggests that the farmer owns some portion of the land, with others being rented; **treatment catchments; ------ = information not available.

6.3. Results

6.3.1 Has MCPA concentration in drinking water sources declined significantly?

Between 2006 and 2019, MCPA concentrations in all raw water samples ranged from below detection (<0.1 µg/L) in 98.3% of samples to a maximum of 2.400 µg/L in the Teifi catchment in September 2014. Concentrations exceeded the drinking water limit

of 0.1 µg/L on 47 occasions; 26 in treatment catchments and 21 in control catchments.

A seasonal pattern in detections has emerged, with exceedances mostly evident during May, June, and July and again in September and October. This coincides with periods when MCPA is commonly applied to grassland for the control of ragwort, rush and thistle (Welsh Water, 2014).

Table 6.6 shows that before the weed wiper trial, the mean MCPA concentration in the treatment catchments (0.0137   µg/L) was higher than in the control catchments (0.0091 µg/L). Further results show that MCPA concentrations for both treatment and control catchments declined after the implementation of the weed wiper trial (see Table 6.6). However, the decline was significantly larger ($F(1)$ = 6.551, p<0.05, n= 3077, *Partial eta-squared* (ηp^2) = 0.002) for the treatment catchments (mean = 45.2%) compared to the control catchments (mean = 10.9%). It was further revealed that the MCPA response post intervention was different between individual catchments: ($F(5)$ = 6.249, p < 0.001, n= 3077), ηp^2 = 0.01). Figure 6.1 shows that a substantial decline (between 3.1 and 55%) in MCPA concentration occurred in all three treatment catchments (with the highest decline observed in the Teifi catchment). In contrast, only one of the control catchments (the Teme) recorded a decline in MCPA concentration (mean % decline = 31.6%) while the Usk and the Cleddau catchments recorded an increase in MCPA concentration post 2015 (mean % increase = 20.2% and 31.6% respectively). Additional results indicate evidence of an interaction effect between the weed wiper trial and catchments: ($F(5)$ = 1.997, p < 0.1, n= 3077), ηp^2 = 0.003), suggesting that the impact of the weed wiper trial on MCPA concentration depends on location or catchment characteristics.

Table 6.6: Mean concentration of MPCA for treatment and control catchments pre- and post-intervention

Period	Condition	Mean	Std. Deviation	Number of water samples
Pre-intervention	Treatment	0.0182	0.0968	783
	Control	0.0097	0.0285	637
Post-intervention	Treatment	0.0100	0.0231	955
	Control	0.0086	0.0181	702
Total	Treatment	0.0137	0.0673	1738
	Control	0.0091	0.0236	1339
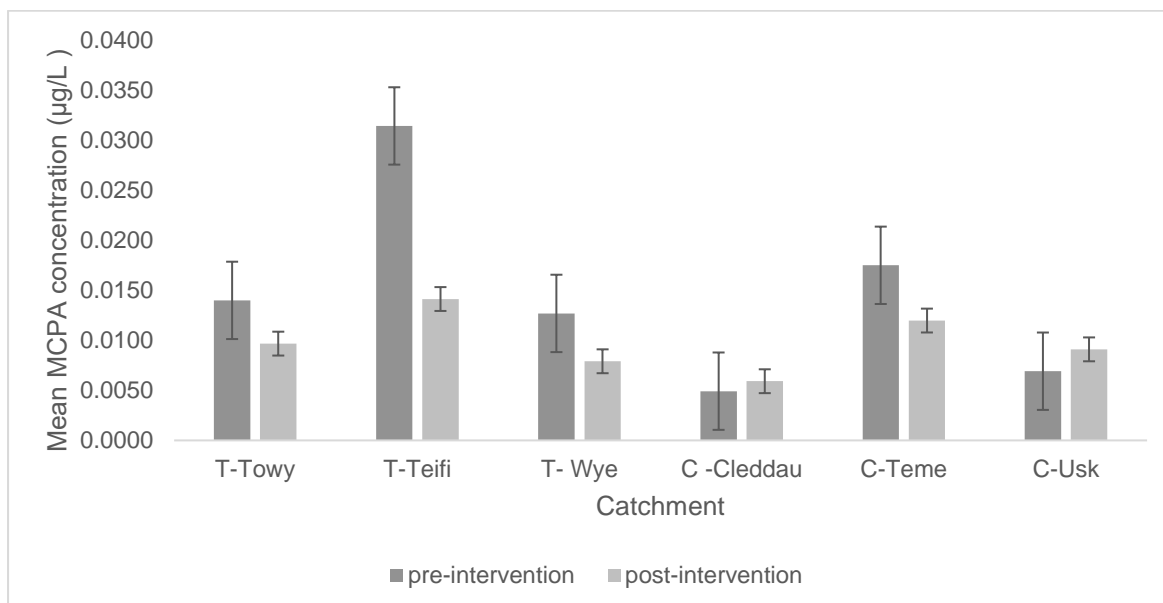
Figure 6.1: Average MCPA concentration in all catchments, pre and postintervention.
Notes: T. = Treatment catchments; C. = Control catchments

6.3.2. Has awareness and the adoption of BMPs contributed to a decline in MCPA concentration?

Results of the water quality analysis show that MCPA concentrations declined more rapidly in the catchments where the weed wiper trial had been carried out. The interviews allowed us explore the role that awareness and behavioural change (through the adoption of BMPs), might have had on this effect. Statements from some farmers clearly showed an effect of the weed wiper trial and the adoption of more responsible pesticide practices beyond the trial. For instance, Participant 19 noted, "*I now only use a weed wiper and several of my neighbours have also bought their own weed wiper using grants*". Another added *"Yeah, I'm being very sort of responsible... The weed wiper only targets the weed so you are going to have less risk of any runoff*

or anything getting into watercourses. I think pretty much we're operating at a high standard. A lot of the businesses using chemicals and pesticides are operating at very high standards in terms of technology and precision. I think people have probably got more aware, rightly so" (Participant 3).

Farmers believed that their practices (since their involvement in the trial and use of the information packs) contribute to reducing pesticide pollution because a lower amount of spray is used and it only touches the targeted weeds. This is reinforced by the positive relationship between number of weed wiper hires and percentage decline in MCPA concentration as catchments with more hires recorded the highest net reductions ($p < 0.05$, $R^2 = 0.60$, $N = 6$, see Figure 6.2). This is also backed by the fact that catchments where more information packs had been distributed also recorded higher declines in MCPA concentration ($p < 0.05$, $R^2 = 0.59$, $N = 6$, see Figure 6.3).

From the interviews, we established that indeed, awareness – promoted through the weed wiper trial – seems to have contributed to uptake of the weed wiper. Statements on how applying chemicals near watercourses, failing to follow calibration standards for chemical applications, and applying excess chemicals particularly in wet conditions could result in on-farm pesticide pollution reflect farmers' awareness of the factors causing pesticide pollution. As Participant 14 noted "*….when you have a thunderstorm, like we did last night, heavy rain came in a matter of minutes from a dry condition to that. They could have just sprayed that ground with so much chemicals per acre, okay? All of a sudden comes down the rain, the surface wash off, goes into ditches, ends up in a water stream. That's pollution. Because the conditions were wrong at that specific moment. And there was heavily used chemicals… Or if there's a chemical spillage, you know, I mean, if somebody left the water running in a tank*

when they were filling, and they had already added the chemicals and ouch, over the top it came down the drain, and it found a ditch which then went to a river, then you'd have that. They are very minor ones and human error". This clearly shows awareness, although responsibility is deflected mainly to weather conditions and human error.

On how awareness contributes to adoption, one farmer pointed out that the main reason they were engaged in best practice (including the use of the weed wiper) was because they were aware of the impacts of their practices and how best to mitigate pesticide pollution: "…*knowing what to do. We know there are issues of water supply so we're very conscious of where our water supply is on the farm and where our neighbouring water supply is, so we're not spraying near them as well. And then we'll watch the wind speed so there's no spray going into the watercourse as well"* (Participant 12). Another farmer, highlighting the role of the information pack indicated that "*the information pack was good and helped me…without this trial I wouldn't have tried out the* [weed wiper*] machine for myself and I'd probably still be using a knapsack*" (Participant 20). Other farmers indicated that "*the ability to try out one of the weed wipers for free before committing to buying one was the best way of me improving my knowledge and understanding of pesticide management. Without hiring one for free I would probably still be using a boom sprayer…The machine worked well for me, that's why I went to buy my own. I now only use a weed wiper*" (Participant 19). This view further points to the role of experiential learning, as a first-hand experience of the use of the weed wiper gave him/her the opportunity to appreciate the benefits of using the technology, which in turn contributed to his decision to acquire it.

All this evidence suggests that awareness promoted through the weed wiper trial played a crucial role in the adoption of the weed wiper. Further evidence (Figure 6.4)

shows that since the peak in MCPA concentration in 2014, concentrations have declined in both control and treatment catchments, but at a much faster rate in the treatment catchments to such an extent that in 2019 mean MCPA concentration was lower for the treatment than control catchments for first time since 2010 (Figure 6.4).
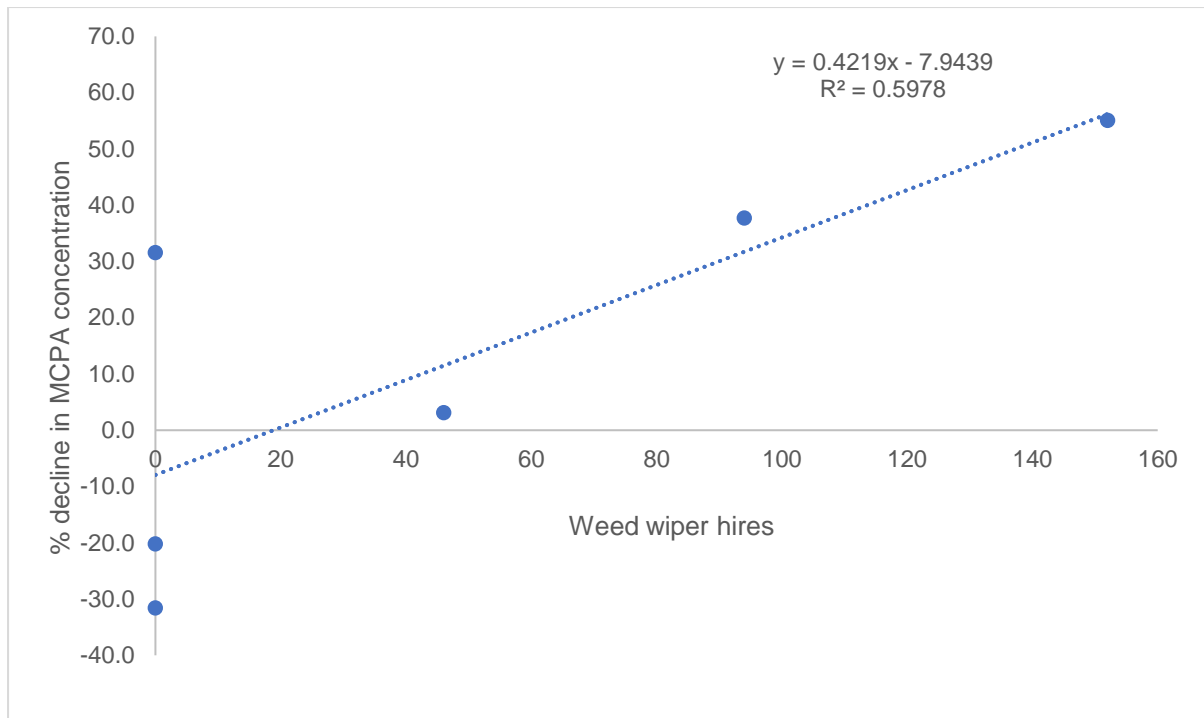
Figure 6.2: Relationship between weep wiper hires and % decline in MCPA concentration
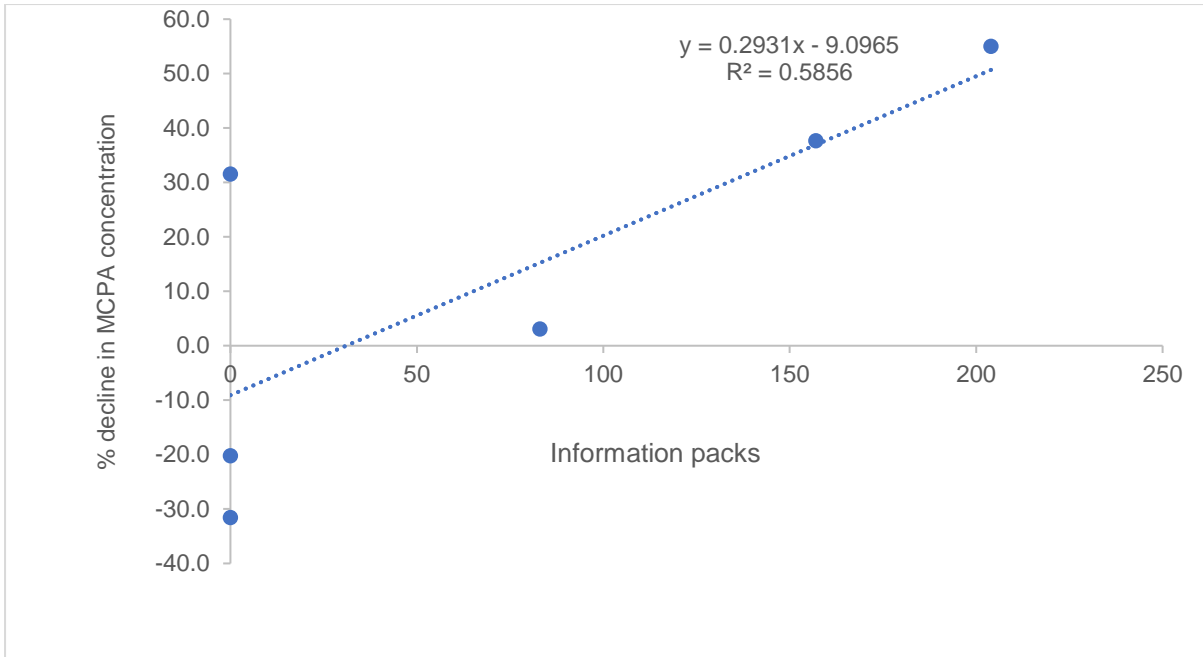
Figure 6.3: Relationship between number of information packs distributed in each catchment and % decline in MCPA concentration
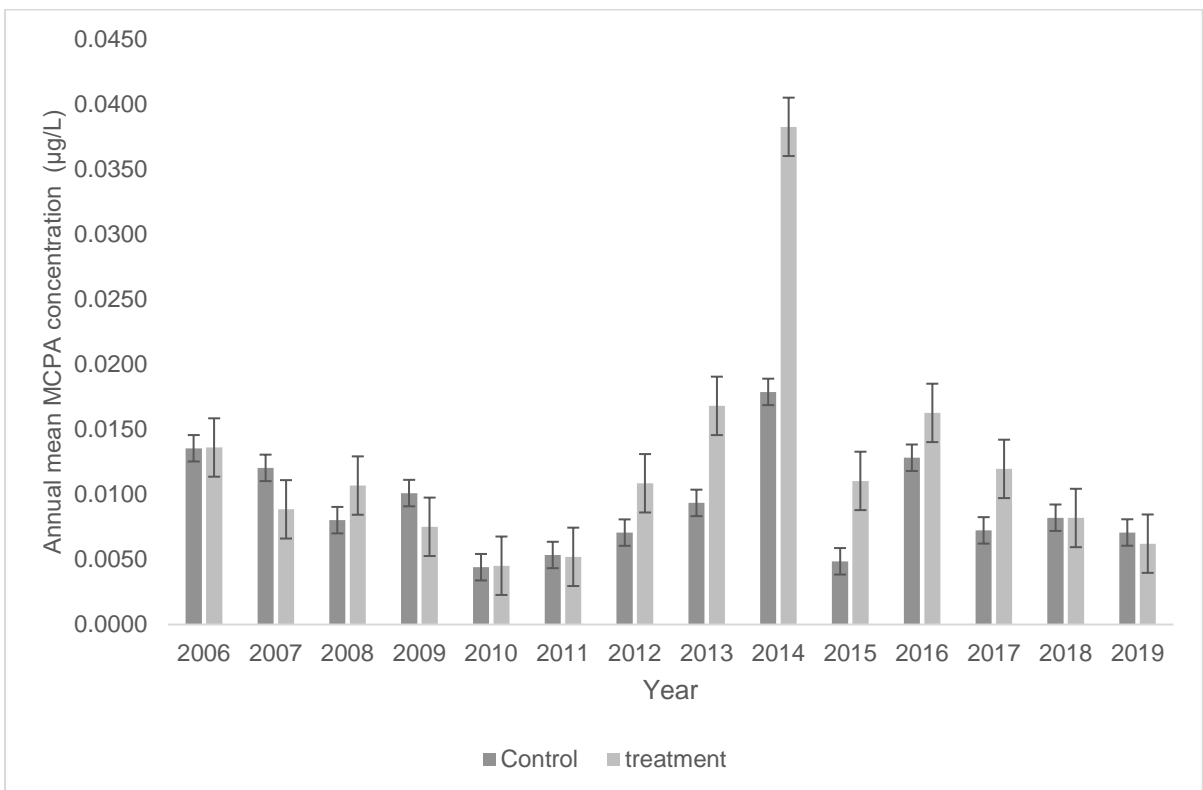
Figure 6.4: Annual mean MCPA concentration for both treatment and control catchments

6.3.3. Other factors contributing to adoption of BMPs

Awareness was not the only factor contributing to behavioural changes. This study was able to identify other factors that influenced the adoption of the weed wiper. These relate to psychosocial factors, such as social pressure, information source and trust, farmers' desire to protect their reputation, regulations, and beliefs towards old and new practices. Regarding social pressure, we found that neighbours' opinions have a role in encouraging or discouraging farmers in using the weed wiper. Similarly, perceived pressure from landlords was influential in farmers' decision to acquire the weed wiper. As Participant 14 noted "*the weed wiper was more acceptable with our landlords so we upgraded our old weed wiper and had a new one. Our landlords obviously wouldn't want us putting chemicals anywhere near water source*".

We also found that some farmers would not want to be associated with pollution problems and this desire to protect their reputation was influential in their decision to use the weed wiper. As participant 7 stated, *"it has to be in their [the farmers'] interests as well. I think because some farmers would want to make sure that they aren't kind of associated with any issues of pollution, maybe, you know, such as water runoff or similar, that would be in their interest".* The regulatory context, in this case the need to acquire a pesticide application license prior to the purchase of the weed wiper, was a hindrance to the uptake of the weed wiper. In responding to why some farmers may not be able to use the weed wiper, Participant 4 said *"...how difficult it is to take the licences before using the weed wiper and the use of that chemical, because it's a really strong chemical, Round up Glyphosate*", while Participant 8 noted that "*we haven't got our pesticide application licence and that's going to inhibit us from using the weed wiper*".

Some farmers are less likely to change practices because they feel uncomfortable about dealing with a new technology. They feel comfortable keeping practices that have been passed on from generations. This is illustrated in the account of participant 14 who indicated that one reason some farmers are not using the weed wiper is "*probably because they feel uncomfortable about something they've never used before. Maybe the older generation who don't like machinery and say, Oh, I can't do that. Because I've never done it before. A younger person will be more adaptable to things…It's only a generation thing real*ly".

Interview results also revealed that time and availability of resources such as technology (the weed wiper), complementary equipment (e.g., quad bike), the required herbicide (Glyphosate), and time were key factors driving the decision to use the weed wiper. These resources are all needed to be able to use the weed wiper, and are therefore conditional of its adoption. As Participant 1 noted, *"the other [barrier] would be availability of the technology such that farmers tend to be very busy now and some don't plan very well. And suddenly, I can do it today, well, the weed wiper is not available*". Participant 2 added that "*the main reason I didn't do it [participate in the trial] is I don't have a quad bike. I need something to pull it with*".

We found that agronomic factors such as the type of weed and extent of weed problem, type of crop, land use and farm size may also determine whether a farmer adopts the weed wiper, and sustains its use on his/her farm in the future . For example, when asked if they would use the weed wiper in future, one farmer responded "…*Yes, possibly! But the main weed that I control is dock. And the best way to control a dock is when it's small. So if you leave it until it's big enough to be controlled by a weed wiper, it's too big to kill it. You're supposed to kill docks when it's*

just starting to grow, in the spring. But you can't use a weed wiper for that" (Participant 2). In relation to farm size, a participant of the weed wiper trial who had not pursued using the technology afterwards indicated that "*I have thought about buying more land and expanding my farm, if I did this, I would consider hiring the weed wiper. I'd consider using one in the future if I bought more land with more rush to treat*" (Participant 17). The fact that this farmer mentions additional land "with more rush to treat" suggests that the extent of weed problem may interact with farm size to influence the decision to adopt the weed wiper.

Other crucial agronomic factors include the need to not kill off the clover, keep healthy soil, and to apply a fast and easy weed management technique. Beyond these, perceived financial benefits were identified as a motivation for adoption while cost was a potential barrier. Participant 8 explaining why they were unable to use the weed wiper stated that "*...because there's no plenty of money for other things. Because we haven't got our pesticide application licence, we'd probably need a contractor to do it and I don't know how costly that is. So it's been a question of priorities and we got other things to do. When you got X amount to spend, you know, that might not be your concern. Maybe it's wrong, but it's a bit lower priority. If we had unlimited cash, we could do something different*". A participant of the weed wiper trial also indicated that "*We're not able to use the weed wiper [again] as we cannot afford to buy our own machine. If we were able to hire one for free again we definitely would as it was amazing*" (Participant 22). While these farmers highlighted cost as a barrier, another farmer from the Wye catchment who participated in the weed wiper trial indicated that "*the low cost of using a weed wiper in comparison to other methods is the main driver, along with the good results. I can't think of anything that would prevent me from using one*" (Participant 20). This suggests that financial considerations can act both as a

driver and a barrier depending on the farmers' circumstances, thus highlighting a potential moderating role of situational factors.

Season and weather conditions appear to influence weed management practices. Some farmers explained that wet seasons pose major challenges to them and this may determine the extent to which they are able to follow best practice. One farmer explained that, "*…season does have impact because our land is quite wet. So in a wet year, we struggle to get on with the tractor and the topper to do the topping. So some years we wouldn't touch because we can't basically get on there to top them. If we can't top them, they grow too strong...And then it's no good spraying them because they're too big; you need to spray them when they're small. So yeah, the season is important. Generally, in a wet year, we wouldn't do so much weed control. But in a dry year like this, we've got more opportunities to top the weeds*" (Participant 13, Farmer). Similarly, locational characteristics seem to influence practices as some farmers mentioned that very steep landscapes makes it difficult to in move spraying machines.

Just as the awareness-behaviour link is influenced by other factors, the relationship between adoption of BMPs and MCPA concentration is influenced by contextual factors. From the interviews, we identified other factors that could influence MCPA concentration. For instance, some interview participants indicated that MCPA concentration depends on the number of farmers implementing the recommended practices within a catchment, how long the practice has been implemented, external interventions (e.g., work from other companies within the catchment) and differences in land uses. In fact, Participant 9 suggested that the declining MCPA concentration recorded in the Teme, one of the control catchments, might be due to a different land use, which in turn contributes to different pesticides being applied in the catchment:

"…if you looked at other grassland pesticides, not just MCPA, that catchment [the Teme] will be really high. Because that's quite a heavy arable land area so they could be using more grassland herbicides, not necessarily MCPA".

6.4. Discussion

Results show that the mean MCPA concentration declined significantly in all the treatment catchments post the weed wiper trial (Figure 6.1); decreasing in all three catchments. In contrast, mean MCPA concentration displayed a variety of response in the control catchments; one declined and two increased (Figure 6.1). The largest decline in MCPA (55%) was observed in the Teifi catchment (Figure 6.2) where almost double the weed wiper hires occurred than in the Upper Wye (152 and 94, respectively) and where most information packs were distributed (Table 6.2). This is strong evidence that the weed wiper trial has resulted in the adoption of the weed wiper and that this is likely to account for the decline in MCPA concentrations in drinking water sources. This is because the use of weed wiper ensures precision in terms of pesticide application by avoiding spray drift that occurs with conventional methods of application that use self-propelled sprayers equipped with long booms. By wiping pesticides directly onto the weeds, the weed wiper reduces spray drift and uses less chemicals, thereby reducing risk of runoff. This finding supports results of previous studies on measures that reduce spray drift to pesticide pollution (e.g., de Snoo and de Wit, 1998, see also, Kay et al., 2009 for a review), as they found that such BMPs could be highly efficient in reducing pesticide pollution, although none of these earlier works focussed specifically on MCPA. Even more importantly, all weed wipers were only licensed for use with Glyphosate, a chemical which has potentially less impact on water quality as it can break down quicker than MCPA, at around three

days and therefore not detected in such high concentration in raw water. As found by Baker et al. (1995), product substitution can potentially contribute to a reduction in pesticide pollution in surface waters although this depends on the efficacy of the new product (Reichenberger et al., 2007), which seems to have been the case here.

Results from the in-depth interviews show that farmers had a good understanding of both pesticide pollution and BMPs. Farmers' awareness of pesticide pollution and BMPs could be attributed in part to the weed wiper trial. Moreover, Welsh Water used different information dissemination channels to reach many farmers including those who did not participate in the trial (29.3% of information packs were distributed among farmers outside the treatment catchments). Past studies have shown that dissemination mechanisms involving multiple channels are effective in reaching out to a wide audience and improving farmers' awareness particularly where the message is personally relevant (Dwyer et al., 2007). As observed in this study, even farmers who did not participate in the trial reported that they received information on pesticide pollution, the weed wiper and other BMPs from different sources[13] including their neighbours. For those that participated, they indicated how the information packs were useful in improving their understanding of safe measures of pesticide management.

While advice (via the information packs) seems to have improved farmers' awareness, experiential learning seem to have played a crucial role in further advancing farmers' understanding and contributed to uptake of BMPs (specifically, the weed wiper). Experiential learning refers to learning-by-doing, and has been shown to be an effective mechanism for improving farmers' knowledge and uptake of BMPs (Drangert

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[13] These sources include Welsh Water, Farming Connect, Farmers Weekly, Farming Press, the Farmers Guardian and the Agriculture and Horticulture Development Board.

et al., 2017, Suškevičs et al., 2019). As some farmers noted, having the opportunity to use the weed wiper during the trial was critical in improving their knowledge of best pesticide management, and helped them to appreciate the benefits of adopting BMPs. Without this first-hand experience, they were likely to be using their old practices of weed management (e.g., knapsack spraying). This finding consolidates the evidence that while information provision is important, farmers' are more likely to take up BMPs when given the opportunity to 'practise what they are taught' (Suškevičs et al., 2019, Okumah et al., 2019b, Dwyer et al., 2007). This can be linked to the reflective process that individuals go through when they engage in an activity, thus offering them the opportunity to learn from active experimentation, subsequently enhancing their chances of adoption (Kolb, 1984). In this case, adoption could be linked to two issues: first, a better understanding of the benefits (Kolb, 1984) and thus, the motivation to do it, and second, improved self-efficacy i.e., the confidence that they would be able to engage in the practice and do it well (Bandura, 1997). Consistent with these results, previous studies have demonstrated that farmers with a profound understanding of environmental pollution and BMPs are more likely to be environmentally concerned, have higher self-efficacy (Sewell et al., 2017) and are more likely to take up BMPs (Floress et al., 2017).

The extensive dissemination of information among farmers means that some farmers who did not participate in the trial had knowledge of the practices being promoted, with some of them acquiring and using a weed wiper (although the vast majority of information packs were distributed in the treatment catchments). This is not surprising, since farming communities do not operate in 'close bubbles' and some permeability of information is to be expected. Moreover, other existing advisory services implies that farmers who did not participate in the scheme still had knowledge of BMPs from other

sources. As some farmers and institutional interviewees indicated, there are ongoing efforts to raise awareness of BMPs to reduce DWPA and farmers are increasingly taking advantage of the advice being provided. While it would have been interesting to point out potential differences in levels of awareness and behavioural changes between farmers who participated in the trial and those who did not, this was not possible with the available data. However, the results of this study still show that awareness does play a key role in explaining behavioural changes and improvements in water quality.

While awareness contributes to adoption of BMPs, our findings confirm that such link is mediated by other factors (Suškevičs et al., 2019, Okumah et al., 2019a, Okumah et al., 2018). Pressure from neighbours, landlords and institutions seem to play a role in uptake of BMPs in our case. This evidence supports the findings of previous studies on the role of social norms. For some farmers, the decision to engage in sustainable practices depends on what their neighbours think or do, and their perceptions on what they ought to do (Dessart et al., 2019). This is particularly true for people with a strong tendency to conform to the majority (Asch, 1956) as well as 'conditional co-operators' – those who would do it if others do (Fischbacher et al., 2001). This is reinforced by the finding that some farmers do not want to be associated with pollution problems as they perceive other people's opinions to be important and sometimes need social approval (Talcott, 2013). Consequently, these farmers feel that engaging in bad practices could project them as 'bad' people (Defrancesco et al., 2008).

Openness to change is another important factor. We found that some farmers were less likely to change practices because they are not comfortable dealing with a new technology; they prefer to keep practices that have been passed on from generations.

This corroborates the findings of previous studies on the role of 'resistance to change' in farmers' adoption of BMPs (e.g., Burton et al., 2008). We know from past empirical studies that farmers who score low on openness to engage in new experiences were more reluctant to change due to the status quo bias (George and Zhou, 2001), i.e., these farmers desire to keep existing practices as new ones are (sometimes) perceived to have negative consequences (Samuelson and Zeckhauser, 1988, Dessart et al., 2019). A recent study on the influence of status quo bias in adoption of agri-environment policy concluded that a large proportion of farmers do not accept change (Barreiro-Hurle et al., 2018), a potential reason for low adoption of BMPs in (some) farming communities.

Another important factor driving farmers' decision to engage in BMPs is time and availability of resources (in this case, technology – the weed wiper, complementary equipment – quadbike and the required pesticide) (Baumgart-Getz et al., 2012). Where these resources are needed to be able to implement the recommended practice, – as was the case for the weed wiper, – the lack of any or all of them makes it difficult for farmers to adopt the practice in question. Furthermore, the availability or lack of these resources may influence perceived behavioural control, i.e., farmers' perception on their ability to adopt BMPs, and the ease or difficulty with which the measures have to be implemented (Defrancesco et al., 2008, Dessart et al., 2019, Okumah et al., 2019a, Daxini et al., 2018, Daxini et al., 2019a, Daxini et al., 2019b). Farmers are less likely to adopt BMPs where they feel it will be extremely difficult to engage in such practices due to the resource requirements (Kuhfuss et al., 2016a, Ranjan et al., 2019, Reimer et al., 2012, Knook et al., 2019), especially where this involves significant structural changes (Barreiro-Hurlé et al., 2010).

We also found that agronomic factors (e.g., the type of weed and extent of weed problem and land use) may determine whether a farmer adopts the recommended practice or not. These results corroborate the findings of a great deal of the previous work on the role of farm characteristics and situational factors on adoption (Capitanio et al., 2011, Defrancesco et al., 2008, Barnes et al., 2009, Morris et al., 2000, Okumah et al., 2018). Farmers are more likely to adopt BMPs where the requirements fit the farm situation, especially when the costs of taking up such measures are low (Wynn et al., 2001, Wilson, 1997, Sattler and Nagel, 2010, Morris et al., 2000). Therefore, there seem to be an interaction between farm situation and financial considerations, with perceived financial benefits acting as a motivation while cost of adoption, a potential barrier. Season, weather and locational factors may also influence uptake as physical incompatibility may hinder uptake of BMPs (see, Ranjan et al., 2019, Dessart et al., 2019, Okumah et al., 2019a).

While the use of the weed wiper appears to be promising, sustaining results of this initiative depends on the future of environmental management policy. There are currently political debates on phasing out glyphosate – the approved product for the weed wiper – in the agricultural sector by 2022 (European Parliament., 2017). If this should happen, an alternative pesticide would be needed, otherwise farmers are likely to return to the use of MCPA which may negate the benefits Welsh Water have seen as a result of their weed wiper trial. In the midst of these uncertainties, additional efforts will be needed towards encouraging farmers to use integrated methods of weed management (i.e., the use non-chemical and targeted chemical). Although non-chemical methods were previously seen as less effective means of rush control, it is thought that modern farm technology could facilitate their use (Morton et al., 2020).

While this study opens up an avenue for investigating the awareness-behaviour-water quality pathway, the use of qualitative interviews poses a limitation. This is because qualitative interviews do not rely on a representative sample and thus lack the attribute of generalisability (Onwuegbuzie and Leech, 2005). Therefore, we are unable to generalise the findings of this study to the entire population of farmers within the study catchments. Future studies should thus focus on implementing surveys and to recruit a wider sample of farmers to test the findings of this study. As the evidence suggests, it is possible that some farmers are changing practices and substituting MCPA with other pesticides. It will be important to survey all farm practices and pesticides and quantify the interaction between awareness creation interventions, land uses and water quality while accounting for other contextual factors.

6.5. Conclusion

Efforts to tackle DWPA are increasingly focusing on improving farmers' awareness under the expectation that this would contribute to adoption of BMPs and result in water quality improvements. To date, however, no study has studied the full awareness-behaviour-water quality pathway; with previous studies having mostly addressed the awareness-behaviour link relying on mono-disciplinary approaches. To address this important knowledge gap, we examined whether awareness-focussed approaches to mitigating DWPA do result in increased adoption of BMPs and improved water quality, adopting an interdisciplinary approach to address the pathway in full. To do this, we worked with the Welsh water utility in the UK and their campaign to reduce levels of pesticide MCPA (2-methyl-4-chlorophenoxyacetic acid) in drinking water sources.

Analysis of MCPA concentrations from 2006 to 2019 shows a significant decline in MCPA concentration for the treatment catchments. Results from stakeholder interviews suggest that awareness – promoted through the weed wiper trial – had contributed to adoption of BMPs and that these are very likely to have resulted in the water quality improvements. The combination of findings from this study provides some support for the emerging theoretical premise that the awareness-behaviour-water quality pathway exists but that this relationship may be mediated and/or moderated by other variables. This provides evidence that awareness-focussed approaches do work, however, policymakers and catchment managers need to consider the complex nature of the pathway and factors influencing it. Additionally, the findings of this study show promising results for awareness-focussed approaches not just in relation to DWPA, but more generally for the uptake of BMPs and their impact in different environmental management areas.

References

ASCH, S. E. 1956. Studies of independence and conformity: I. A minority of one against a unanimous majority. *Psychological monographs: General and applied,* 70**,** 1.

BARNES, A. P., WILLOCK, J., HALL, C. & TOMA, L. 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management,* 96**,** 1715-1722.

BARREIRO-HURLÉ, J., ESPINOSA-GODED, M. & DUPRAZ, P. 2010. Does intensity of change matter? Factors affecting adoption of agri-environmental schemes in Spain. *Journal of environmental planning and management,* 53**,** 891-905.

BARREIRO-HURLE, J., ESPINOSA-GODED, M., MARTINEZ-PAZ, J. M. & PERNI, A. 2018. Choosing not to choose: A meta-analysis of status quo effects in environmental valuations using choice experiments. *Economía Agraria y Recursos Naturales-Agricultural and Resource Economics,* 18**,** 79-109.

BAUMGART-GETZ, A., PROKOPY, L. S. & FLORESS, K. 2012. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of Environmental Management,* 96**,** 17-25.

BENGTSSON, M. 2016. How to plan and perform a qualitative study using content analysis. *NursingPlus Open,* 2**,** 8-14.

BLACKSTOCK, K. L., INGRAM, J., BURTON, R., BROWN, K. M. & SLEE, B. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the Total Environment,* 408**,** 5631-5638.

BURTON, R. J., KUCZERA, C. & SCHWARZ, G. 2008. Exploring farmers' cultural resistance to voluntary agri-environmental schemes. *Sociologia ruralis,* 48**,** 16-37.

BYRNE, M. M. 2001. Evaluating the findings of qualitative research. *AORN journal,* 73**,** 703-703.

CAPITANIO, F., ADINOLFI, F. & MALORGIO, G. 2011. What explains farmers' participation in rural development policy in Italian southern region? An empirical analysis. *New Medit,* 10**,** 19-24.

COLLINS, A. L., ZHANG, Y. S., WINTER, M., INMAN, A., JONES, J. I., JOHNES, P. J., CLEASBY, W., VRAIN, E., LOVETT, A. & NOBLE, L. 2016. Tackling agricultural diffuse pollution: What might uptake of farmer-preferred measures deliver for emissions to water and air? *Science of The Total Environment,* 547**,** 269-281.

DAMANIA, R., DESBUREAUX, S., RODELLA, A.-S., RUSS, J. & ZAVERI, E. 2019. Quality Unknown: The Invisible Water Crisis. The World Bank.

DAXINI, A., O'DONOGHUE, C., RYAN, M., BUCKLEY, C., BARNES, A. P. & DALY, K. 2018. Which factors influence farmers' intentions to adopt nutrient management planning? *Journal of environmental management,* 224**,** 350-360.

DAXINI, A., RYAN, M., O'DONOGHUE, C. & BARNES, A. P. 2019a. Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour. *Land Use Policy,* 85**,** 428-437.

DAXINI, A., RYAN, M., O'DONOGHUE, C., BARNES, A. P. & BUCKLEY, C. 2019b. Using a typology to understand farmers' intentions towards following a nutrient management plan. *Resources, Conservation and Recycling,* 146**,** 280-290.

DE SNOO, G. R. & DE WIT, P. J. 1998. Buffer zones for reducing pesticide drift to ditches and risks to aquatic organisms. *Ecotoxicology and environmental safety,* 41**,** 112-118.

DEFRA. 2012. *Observatory monitoring framework – indicator data sheet: Environmental Impact Water* [Online]. London: The Department for Environment, Food and Rural Affairs. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/162165/defra-stats-observatory-indicators-da4.-120224.pdf [Accessed 18/05 2020].

DEFRANCESCO, E., GATTO, P., RUNGE, F. & TRESTINI, S. 2008. Factors affecting farmers' participation in agri-environmental measures: A Northern Italian perspective. *Journal of agricultural economics,* 59**,** 114-131.

DESSART, F. J., BARREIRO-HURLÉ, J. & VAN BAVEL, R. 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. *European Review of Agricultural Economics,* 46**,** 417-471.

DPMAG 2015. Strategy to reduce diffuse pollution. Edinburgh: Scottish Environment Protection Agency.

DRANGERT, J.-O., KIEŁBASA, B., ULEN, B., TONDERSKI, K. S. & TONDERSKI, A. 2017. Generating applicable environmental knowledge among farmers: experiences from two regions in Poland. *Agroecology and Sustainable Food Systems,* 41**,** 671-690.

DUCKETT, D., FELICIANO, D., MARTIN-ORTEGA, J. & MUNOZ-ROJAS, J. 2016. Tackling wicked environmental problems: The discourse and its influence on praxis in Scotland. *Landscape and Urban Planning,* 154**,** 44-56.

DWYER, J., MILLS, J., INGRAM, J., TAYLOR, J., BURTON, R., BLACKSTOCK, K., SLEE, B., BROWN, K., SCHWARZ, G. & MATTHEWS, K. 2007. Understanding and influencing positive behaviour change in farmers and land managers. *CCRI, Macaulay Institute*.

ENVIRONMENT AGENCY 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report. Bristol Environment Agency

ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. Bristol Environment Agency.

EUROPEAN PARLIAMENT. 2017. MEPs demand glyphosate phase-out, with full ban by end 2022 European Parliament News: European Parliament.

FISCHBACHER, U., GÄCHTER, S. & FEHR, E. 2001. Are people conditionally cooperative? Evidence from a public goods experiment. *Economics letters,* 71**,** 397-404.

FLORESS, K., DE JALON, S. G., CHURCH, S. P., BABIN, N., ULRICH-SCHAD, J. D. & PROKOPY, L. S. 2017. Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality. *Journal of Environmental Psychology,* 53**,** 73-80.

GEORGE, J. M. & ZHOU, J. 2001. When openness to experience and conscientiousness are related to creative behavior: an interactional approach. *Journal of applied psychology,* 86**,** 513.

GIBBONS, J. M., WILLIAMSON, J. C., WILLIAMS, A. P., WITHERS, P. J. A., HOCKLEY, N., HARRIS, I. M., HUGHES, J. W., TAYLOR, R. L., JONES, D. L. & HEALEY, J. R. 2014. Sustainable nutrient management at field, farm and regional level: Soil testing, nutrient budgets and the trade-off between lime application and greenhouse gas emissions. *Agriculture, Ecosystems & Environment,* 188**,** 48-56.

GIRI, S. & QIU, Z. 2016. Understanding the relationship of land uses and water quality in Twenty First Century: A review. *Journal of Environmental Management,* 173**,** 41-48.

GOLOTA, H. 2018. Get Smart: Understanding Intelligent Verbatim Transcription. *Globalme Language and Technology,* 10.

KAY, P., EDWARDS, A. C. & FOULGER, M. 2009. A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. *Agricultural Systems,* 99**,** 67-75.

KAY, P., GRAYSON, R., PHILLIPS, M., STANLEY, K., DODSWORTH, A., HANSON, A., WALKER, A., FOULGER, M., MCDONNELL, I. & TAYLOR, S. 2012. The effectiveness of agricultural stewardship for improving water quality at the catchment scale: experiences from an NVZ and ECSFDI watershed. *Journal of hydrology,* 422**,** 10-16.

KNOOK, J., DYNES, R., PINXTERHUIS, I., DE KLEIN, C. A. M., EORY, V., BRANDER, M. & MORAN, D. 2019. Policy and Practice Certainty for Effective Uptake of Diffuse Pollution Practices in A Light-Touch Regulated Country. *Environmental Management.*

KOLB, D. A. 1984. Experience as the source of learning and development. *Upper Sadle River: Prentice Hall.*

KUHFUSS, L., PRÉGET, R., THOYER, S., HANLEY, N., LE COENT, P. & DÉSOLÉ, M. 2016. Nudges, social norms, and permanence in agri-environmental schemes. *Land Economics,* 92**,** 641-655.

MACGREGOR, C. J. & WARREN, C. R. 2006a. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. *Agriculture, Ecosystems & Environment,* 113**,** 108-119.

MACGREGOR, C. J. & WARREN, C. R. 2006. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: the view from the farm. *Agriculture, ecosystems & environment,* 113**,** 108-119.

MARTIN-ORTEGA, J. & HOLSTEAD, K. L. 2013. Improving Implementation and Increasing Uptake of Measures to Improve Water Quality in Scotland. . Aberdeen: The James Hutton Institute.

MARTIN-ORTEGA, J., PERNI, A., JACKSON-BLAKE, L., BALANA, B. B., MCKEE, A., DUNN, S., HELLIWELL, R., PSALTOPOULOS, D., SKURAS, D. & COOKSLEY, S. 2015. A transdisciplinary approach to the economic analysis of the European Water Framework Directive. *Ecological Economics,* 116**,** 34-45.

MORGAN, D. L. 2014. Pragmatism as a Paradigm for Social Research. *Qualitative Inquiry,* 20**,** 1045-1053.

MORRIS, J., MILLS, J. & CRAWFORD, I. 2000a. Promoting farmer uptake of agri-environment schemes: the Countryside Stewardship Arable Options Scheme. *Land Use Policy,* 17**,** 241-254.

MORRIS, J., MILLS, J. & CRAWFORD, I. 2000b. Promoting farmer uptake of agri-environment schemes: the Countryside Stewardship Arable Options Scheme. *Land Use Policy* 17**,** 241}254.

MORTON, P. A., FENNELL, C., CASSIDY, R., DOODY, D., FENTON, O., MELLANDER, P. E. & JORDAN, P. 2020. A review of the pesticide MCPA in the land-water environment and emerging research needs. *Wiley Interdisciplinary Reviews: Water,* 7**,** e1402.

OECD 2012. Water quality and agriculture: meeting the policy challenge. OECD Studies on Water. . Paris: Organisation for Economic Co-operation and Development.

OECD 2017. Diffuse Pollution, Degraded Waters: Emerging Policy Solutions. Paris OECD Publishing.

OKUMAH, M., CHAPMAN, P., MARTIN-ORTEGA, J. & NOVO, P. 2019a. Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway. *Water,* 11**,** 29.

OKUMAH, M., MARTIN-ORTEGA, J., CHAPMAN, P. J., LYON, C. & NOVO, P. 2019b. Behavioural impacts of Northern Ireland's Funded Soil Sampling and Training Schemes 2017-2019. A Rephokus project report prepared for the Department of Agriculture and Rural Affairs (Northern Ireland). .

OKUMAH, M., MARTIN-ORTEGA, J. & NOVO, P. 2018. Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: A conditional process modelling. *Land Use Policy,* 76**,** 36-45.

OKUMAH, M., MARTIN-ORTEGA, J. & NOVO, P. submitted Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: a conditional process modelling *Land Use Policy*.

ONWUEGBUZIE, A. J. & LEECH, N. L. 2005. On becoming a pragmatic researcher: The importance of combining quantitative and qualitative research methodologies. *International journal of social research methodology,* 8**,** 375-387.

RANJAN, P., CHURCH, S. P., FLORESS, K. & PROKOPY, L. S. 2019. Synthesizing Conservation Motivations and Barriers: What Have We Learned from Qualitative Studies of Farmers' Behaviors in the United States? *Society & Natural Resources,* 32**,** 1171-1199.

RAYMOND, C. M., FAZEY, I., REED, M. S., STRINGER, L. C., ROBINSON, G. M. & EVELY, A. C. 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management,* 91**,** 1766-1777.

REIMER, A. P., WEINKAUF, D. K. & PROKOPY, L. S. 2012. The influence of perceptions of practice characteristics: An examination of agricultural best management practice adoption in two Indiana watersheds. *Journal of Rural Studies,* 28**,** 118-128.

ROSSMAN, G. B. & WILSON, B. L. 1985. Numbers and words: Combining quantitative and qualitative methods in a single large-scale evaluation study. *Evaluation review,* 9**,** 627-643.

SAMUELSON, W. & ZECKHAUSER, R. 1988. Status quo bias in decision making. *Journal of risk and uncertainty,* 1**,** 7-59.

SATTLER, C. & NAGEL, U. J. 2010. Factors affecting farmers' acceptance of conservation measures—A case study from north-eastern Germany. *Land Use Policy,* 27**,** 70-77.

SEWELL, A., HARTNETT, M., GRAY, D., BLAIR, H., KEMP, P., KENYON, P., MORRIS, S. & WOOD, B. 2017. Using educational theory and research to refine agricultural extension: affordances and barriers for farmers' learning and practice change. *The Journal of Agricultural Education and Extension,* 23**,** 313-333.

STOATE, C., JONES, S., CROTTY, F., MORRIS, C. & SEYMOUR, S. 2019. Participatory research approaches to integrating scientific and farmer

knowledge of soil to meet multiple objectives in the English East Midlands. *Soil Use and Management,* 35**,** 150-159.

STRAUSS, A. & CORBIN, J. 1998. Basics of qualitative research: techniques and procedures for developing grounded theory. Sage Publications. *Thousand Oaks, CA.*

SUŠKEVIČS, M., HAHN, T. & RODELA, R. 2019. Process and Contextual Factors Supporting Action-Oriented Learning: A Thematic Synthesis of Empirical Literature in Natural Resource Management. *Society & Natural Resources,* 32**,** 731-750.

TALCOTT, P. 2013. The social system. Routledge, Hove, East Sussex.

TERMEER, C. J. & DEWULF, A. 2019. A small wins framework to overcome the evaluation paradox of governing wicked problems. *Policy and Society,* 38**,** 298-314.

TRESS, G., TRESS, B. & FRY, G. 2005. Clarifying Integrative Research Concepts in Landscape Ecology. *Landscape Ecology,* 20**,** 479-493.

UNITED NATIONS 2016. Global Sustainable Development Report 2016. New York, US: Department of Economic and Social Affairs.

VRAIN, E. & LOVETT, A. 2016. The roles of farm advisors in the uptake of measures for the mitigation of diffuse water pollution. *Land Use Policy,* 54**,** 413-422.

WELSH WATER 2014. PestSmart: Controlling weeds, pests and diseases while looking after people, water and wildlife. Aguide for farmers and land managers. Mid Glamorgan, UK: Dwr Cymru Welsh Water.

WILSON, G. A. 1997. Factors influencing farmer participation in the environmentally sensitive areas scheme. *Journal of environmental management,* 50**,** 67-93.

WYNN, G., CRABTREE, B. & POTTS, J. 2001. Modelling farmer entry into the environmentally sensitive area schemes in Scotland. *Journal of agricultural economics,* 52**,** 65-82.

ZEWELD, W., VAN HUYLENBROECK, G., TESFAY, G. & SPEELMAN, S. 2017. Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *Journal of Environmental Management,* 187**,** 71-81.

Chapter 7

Mitigating diffuse pollution from agriculture — a synthesis of findings and conclusions

This PhD research was designed to advance our understanding of the complex awareness-behaviour-water quality pathway, in order to augment the knowledge base to support addressing the persistent problem of diffuse water pollution from agriculture (DWPA). In doing so, I aim to contribute to addressing one of the major global conflicts between food security and environmental conservation. To do this, I applied state-of-the-art interdisciplinary approaches, combining behavioural and catchment science to explore different aspects of the pathway, using the UK as the context for this research. This has served to address the two objectives of this PhD, which were:

1. **To further our understanding of the complexities of the awareness-behaviour link**, by investigating whether and how awareness affects farmers' behaviour regarding the adoption of best management practices (BMPs).

2. **To disentangle the complexities of the relationship between awareness, behaviour and water quality and whether and how this pathway is influenced by other factors**, by exploring the pathway in full.

This final chapter presents a thorough discussion of key findings in relation to the two objectives above and their corresponding research questions (Table 7.1). In section 7.1, I discuss the main findings. Section 7.2. presents the contribution of the PhD, with a focus on the academic and policy relevance. In section 7.3, I reflect on key limitations, existing gaps and future research directions in the context of land management research and how knowledge advancement in these areas could help evaluate the real impact of awareness-focussed interventions on farmers' behaviour

and water quality at the catchment scale. Finally, section 7.4. provides the concluding remarks of the research, reiterating the important gap that was addressed, how the collaborative and interdisciplinary approach has contributed to maximising the value of resources and advancing our understanding of the awareness-behaviour-water quality pathway and implications beyond the Global North.

7.1 Key findings

In this section, I present a detailed discussion of the key findings in relation to each of the objectives (Table 7.1 presents a summarised version).

7.1.1 Objective 1: To further our understanding of the complexities of the awareness-behaviour link

Through the analysis of data associated with Scotland's Priority Catchment Approach (PCA), Chapter 2 explored whether and how farmers' stated awareness of diffuse pollution mitigation measures influenced their compliance with diffuse pollution General Binding Rules (GBRs). Results showed that awareness influences behaviour but not directly; this relationship is mediated and moderated by other factors. In this particular case in Scotland, mediation occurred by farmers' participation in agri-environmental schemes. It was then hypothesised that participation in agri-environmental schemes provides opportunity for experiential learning that would enhance farmers' awareness and compliance. Chapter 2 also showed that this indirect relationship between awareness and compliance was dependent on farm type and location of farm. This finding highlighted the complexity of the awareness-behaviour link and the potential role of other factors, which was further explored in a meta-analysis on the determinants of pro-environmental behaviour (Chapter 3).

The findings of Chapter 3 suggest a strong evidence base for the Theories of Planned Behaviour and Reasoned Action, Attitude-Behaviour-Context Model, and the

Persuasion Theory, but a weak evidence base for the Value-Belief-Norm Theory and the Norm Activation Model. It was further revealed that type of environmental policy area moderates the relationship between different variables. For instance, when the same model was applied to explore the awareness-behaviour link across four environmental policy areas, the evidence showed a moderate relationship in sustainable consumer behaviour, general ecological behaviour, but was not significant in recycling and land management behaviours. Additional evidence from Chapter 5 confirmed that awareness influences behaviour but that this relationship is indeed moderated by experiential learning. Results in the Northern Ireland case study showed that while advice seems to have contributed to increased uptake of BMPs, likelihood of adoption increased if the farmers had prepared the nutrient management plans themselves.

Overall, the results from Chapters 2, 3, and 5, support the idea that through its moderating role, experiential learning improves farmers' understanding of diffuse water pollution from agriculture (DWPA) and BMPs and this, in turn, increases their likelihood of taking up such BMPs. The role of experiential learning in the adoption of BMPs as established in this PhD, highlights the need to consider a two way complex relationship between awareness and behaviour rather than the conventional one-way and straightforward relationship (i.e. just from awareness to behaviour) frequently considered in existing models. This finding shows that awareness could be improved via experiential learning i.e., engaging in some BMPs can lead to reflecting on them, which, in turn, leads to a better understanding and subsequent changes in practices.

It is important to note that, while experiential learning influences farmers' adoption of BMPs, this role varies across different BMPs. As found in Chapter 5, while the

preparation of nutrient management plans significantly influenced farmers' behaviour in relation to the import and export of slurry, these changes were less compared to other recommendations. This finding suggests that the impact of experiential learning on behavioural changes is affected by other situational factors that may vary for different BMPs. Chapter 2 also highlighted how farm type and location moderates the crucial role of farmers' participation in agri-environment scheme on their compliance with Scotland's GBRs. Indeed, situational factors such as cost and infrastructure may moderate the effect of different variables on adoption of BMPs (Macgregor and Warren, 2006, Baumgart-Getz et al., 2012, Okumah and Ankomah-Hackman, 2020) and this needs to be considered when designing policies to encourage uptake of BMPs.

7.1.2 Objective 2: To disentangle the complexities of the relationship between awareness, behaviour and water quality

In response to the second objective, results of the evidence review on the full awareness-behaviour-water quality pathway (Chapter 4) showed that uptake of BMPs can contribute to water quality improvements, however, this is contingent on several factors including type of BMPs being adopted, how long BMPs have been adopted and land use (see Table 7.1). An important finding in Chapter 4 was, however, that the full awareness-behaviour-water quality pathway has hardly been addressed by the literature. This severely limits our understanding and provides a weak evidence base to help in the design and implementation of effective policy strategies to encourage BMPs and improve water quality. Chapter 6 contributed to fill this knowledge gap with an empirical study associated with Welsh Water's weed wiper trial which aimed at promoting farmers' awareness and uptake of BMPs to tackle the rising concentrations

of the pesticide MCPA (2-methyl-4-chlorophenoxyacetic acid) in drinking water sources in three catchments in Wales.

Results from Chapter 6 showed that MCPA concentration for both treatment and control catchments reduced following the introduction of the weed wiper trial, however, the decrease was only significant for the catchments where the weed wiper trial had been carried out. Results from the stakeholder interviews in Chapter 6 suggested that awareness – promoted via the weed wiper trial - had contributed to changes in behaviour which has resulted in the improvements in water quality. In addition the interviews in Chapter 6 confirmed the results of the evidence review presented in Chapter 4, as they highlighted that other psychosocial (e.g., norms and attitudes), agronomic (e.g., type of weed and the need to improve soil health), catchment and climate factors also influenced behaviour and water quality.

Overall, the evidence presented throughout this thesis (from chapters 2 to 6) shows that the awareness-behaviour-water quality pathway exists, but that this relationship is mediated and/or moderated by other factors.

Table 7.1: Summary of Findings

Objectives	Research Questions	Finding	Chapter
1. To further our understanding of the complexities of the awareness-behaviour link	1.1 Does awareness of DWPA and BMPs lead to uptake of such BMPs?	Awareness contributes to the adoption of BMPs but this role is not direct; it is mediated and moderated by other factors (e.g. experience in BMPs).	Chapter 2
	1.2 Which other factors influence uptake of BMPs?	Uptake of BMPs is influenced by various psychosocial, contextual and agronomic factors.	Chapters 2, 3, 4, 5 and 6
	1.3 How does awareness interact with these other factors to influence uptake of BMPs?	While awareness appears to be a necessary precondition for uptake of many BMPs, experiential learning seems to increase farmers' understanding, and this improves their chances of adopting the BMPs.	Chapters 2, 5 and 6
2. To disentangle the complexities of the relationship between awareness, behaviour and water quality (i.e., the full pathway).	2.1 Does awareness contribute to an improvement in water quality?	Awareness contributes to changes in behaviour and that these are likely to result in an improvement in water quality (in this case, a decline in MCPA concentration).	Chapter 4 and 6
	2.2 How does awareness interact with other factors to influence water quality within catchments?	But other psychosocial, agronomic, and catchment characteristics also influence farmers' behaviour and, in turn, water quality improvements.	Chapter 4 and 6

7.2. Contribution of the PhD: What does the evidence mean for academia and policy?

This research has adopted an interdisciplinary approach, relying on mixed-methods and collaboration with policymakers and industry stakeholders. By disentangling the mechanisms through which different variables influence one another as well as the conditions under which these relationships operate, this project has advanced our understanding of the complexity of the awareness-behaviour-water quality pathway, offering insights into what policymakers need to consider when designing, implementing and evaluating awareness-based interventions. These findings and lessons are applicable more generally to awareness-based interventions aiming to influence behaviours in relation to different environmental issues (e.g., climate change), and offer a foundation upon which sustainability research could further our understanding of these complex links. Beyond these broad contributions, different aspects of the thesis make specific contributions, which are outlined below.

Through meta-analytic structural equation modelling (Chapter 3), this PhD provides evidence on two important issues: first, results show a strong evidence base for some behaviour theories (the Theories of Planned Behaviour and Reasoned Action, Attitude-Behaviour-Context Model, and the Persuasion Theory) but a weak evidence base for others (the Value-Belief-Norm theory and the Norm Activation model). The second important finding and contribution from Chapter 3 is that the type of environmental policy area moderates the relationship between different variables. That is, when the same model was applied to explore the relationship between different determinants of pro-environmental behaviour, the results were different for the four environmental policy areas explored (i.e., recycling, land management, sustainable consumer behaviour and general ecological behaviour). This finding has

important policy implications since, while lessons can be learnt from other environmental policy areas, land management policies aimed at influencing farmers' behaviours will need to be tailored to the specific context rather than simply 'imported' from other fields.

The systematic review of the awareness-behaviour-water quality pathway (Chapter 4) was important in realising the paucity of evidence on the full pathway, the failure of current research to acknowledge the complexity of the pathway and the nearly mono-disciplinary nature of such existing research. Through the systematic review, Chapter 4 revealed the complex mechanisms and potential conditions under which different factors influence the full pathway (which is often not acknowledged by researchers trying to understand the role of awareness on water quality responses). The evidence further highlighted the need for interdisciplinary, multi-disciplinary and transdisciplinary research, allowing social and natural scientists to work collaboratively with stakeholders to help advance our understanding of the impact of awareness-focussed interventions and how to improve water quality through behavioural changes. This more synergistic approach could offer insights that are useful for developing effective policies to mitigate water pollution and improve other environmental management outcomes.

This thesis also makes an important contribution to the growing literature on effective mechanisms for influencing farmers' awareness and behaviours. For instance, Chapter 2 makes a major contribution as the first study to model quantitatively the potential role of experiential learning in farmers' awareness and adoption of BMPs. Findings of this chapter highlighted the potential role that experiences, such as those acquired via the participation in agri-environmental schemes, may have in the adoption

of BMPs. Chapter 2 hypothesised that this might be related to the role of experiential learning, which was then tested empirically in Chapter 5. Chapter 5 showed that hands-on activities have a greater value in helping farmers appreciate the benefits of engaging in BMPs and also giving them the "assurance" that they are '*doing the right thing*'. This combined finding between Chapter 2 and Chapter 5 makes a critical contribution to the literature and policy design in their confirmation of the role of experiential learning has as a useful way through which farmers deepen their understanding of DWPA and mitigation measures. Through continuous engagement in BMPs, farmers learn through reflection and this increases the likelihood of them adopting BMPs.

However, as Drangert et al. (2017) have shown, relying solely on farmers' tacit knowledge has its limitations, as this knowledge could be misleading in some situations (for example, where farmers rely so much on their experiences and past observations, without knowledge of best practice standards). This underscores the need for environmental regulators and advisors to work closely with farmers to help provide reliable guidelines to avoid outcomes that are counterproductive to the objectives of awareness-based interventions (Merrilees and Duncan, 2005). As shown in Chapter 2, some agri-environment schemes seem to be providing this avenue where regulators and advisors engage with farmers through workshops and on a one-to-one basis (DPMAG, 2015). However additional efforts are required to make farmers aware that they contribute to the problem and should therefore help in the solution process (Barnes et al., 2009, Macgregor and Warren, 2006). As noted by Posthumus *et al.* (2011), some farmers do not feel threatened by prosecution to change to more environmentally sustainable management practices. Hence, relying heavily on prosecution may be a weak strategy to get farmers to adopt BMPs. It is therefore

important that regulators build a good relationship with farmers to gain their trust and support (Dwyer et al., 2007). Results in Chapter 6 show that one of the ways to do this is to work collaboratively with trusted stakeholders. As found in Chapter 6, Welsh Water was successful in raising farmers' awareness of DWPA by using an authorised dealer of machinery and equipment as a conduit for the delivery of information and supply of the weed wiper.

Providing information via a combination of avenues (including agricultural shows and magazines) could be effective. For instance, the in-depth interviews in Chapter 6 revealed that some farmers are not able to enrol on some courses on sustainable land management practices due to financial constraints. Beyond financial constraints, time was identified as an important resource. In Chapter 5, it was revealed that, due to differing schedules and commitments, farmers are not always available to attend training events. Therefore, courses could be subsidised and a more varied schedule of opportunities should be given to farmers.

In Chapter 5, farmers indicated that shared learning and one-to-one advice provision are effective means to improve farmers' knowledge. Given that different farmers highlight the benefits of one-to-one and shared learning, it would be good to consider a combination of the two in awareness based interventions. As was shown in the two case studies in Northern Ireland (Chapter 5) and Wales (Chapter 6), farmers are more likely to adopt BMPs when they see evidence of a win-win situation. Stakeholders mentioned the use of case studies as an important strategy to provide farmers with scientific evidence. Additional efforts are therefore required to engage farmers though more dialogical approaches (Morris et al., 2000, Merrilees and Duncan, 2005). Through field visits and regular engagement with farmers, regulators could understand

the socio-ecological conditions of farmers, to be able to provide context specific guidelines – information that is usually appreciated by farmers (Environment Agency, 2011, 2014, DPMAG, 2015, Defra, 2013, Merrilees and Duncan, 2005). Past studies have shown that dissemination mechanisms involving multiple channels are effective in reaching out to a wide audience and improving farmers' awareness particularly where the message is personally relevant (Dwyer et al., 2007).

Another important finding of this research relates to how the availability of the needed resources affects adoption of BMPs. Specifically, in Chapter 6, I found that farmers need the relevant technology (e.g., the weed wiper), ancillary equipment (e.g., the quad bike) and the herbicide licenced for application (glyphosate). Therefore, a key policy priority should be addressing unavailability of resources. This is particularly important in the case of Wales, where only glyphosate-based products are licensed for weed wiper use, which could be banned for used in farming by 2022 (European Parliament, 2017). If this should happen, an alternative pesticide would be needed, otherwise farmers are likely to return to the use of MCPA which may negate the positive impacts of the weed wiper trial. In the midst of these uncertainties, additional efforts will be needed to encourage farmers to use non-chemical methods of weed management.

Finally, Chapter 6 explored, for the first time in the literature, the awareness-behaviour-water quality pathway in full. The findings of Chapter 6 show that awareness of the link between pesticide management practices and DWPA as well as BMPs contributed to changes in farmers' behaviour and that these are very likely to have resulted in water quality improvements. Additionally finding in the Chapter revealed, however, that psychosocial, agronomic and catchment characteristics also influenced farmers'

behaviour and water quality response. Therefore, while awareness is an important step towards improving water quality, policymakers and catchment managers need to consider the role of these variables in their interventions and how they interact with awareness. Despite the fact that the study is set in the context of pesticide pollution in Wales, it makes an important contribution to the environmental management sector by offering insights into the role of awareness-based interventions towards mitigating the environmental impact of land management practices more broadly.

As indicated earlier, this PhD project has adopted a participatory, collaborative and integrative approach by engaging with key partners beyond a mere interaction with them. This approach paved the way for direct and immediate uptake of research findings (see Table 7.2 for an overview of the direct – realised or potential- impact of this PhD research).

Table 7.2: Collaborative approach and impacts of this thesis

Chapter	Institution	Role	How the collaborative approach has contributed to potential and/or realised impact in this project
Chapter 2	SEPA	SEPA is Scotland's principal environmental regulator, protecting and improving Scotland's environment. SEPA is regulates the activities of farmers including practices that affect water resources in Scotland.	Although SEPA had already designed the survey and collected data on farmers awareness and compliance with general binding rules, the data had not been analysed. Following analysis of survey data and interview transcripts, we produced a technical report to inform SEPA and the Scottish Government of the impact of their Priority Catchment Approach on farmers' awareness and compliance with diffuse pollution mitigation measures. This has informed Scotland's Diffuse Pollution Mitigation Strategy through the Environment, Agriculture and Food Strategic Research Programme via The James Hutton Institute (to which one of the supervisors of this PhD belongs to).
Chapter 5	DAERA and AFBI	DAERA has responsibility for food, farming, environmental, fisheries, forestry and sustainability policy and the development of the rural sector in Northern Ireland.	We collaboratively developed the research questions and the data collection instruments with both DAERA and AFBI. This helped to focus the research on policy and context-relevant issues in Northern Ireland and the UK. Following analysis of survey data and interview transcripts, I produced a technical report for DAERA covering the impact of the scheme on farmers' awareness and adoption of BMPS, and recommendations to enhance uptake of BMPs.
		AFBI conducts high quality research and development, statutory, analytical, and diagnostic testing functions for DAERA and other Government departments, public bodies and commercial companies in Northern Ireland.	The content the study are currently part of policy discussions of the National Steering Committee (Northern Ireland) on whether the scheme is rolled out nationally, and how the government can augment the scheme to maximise benefits. This report was taken up by DAERA and is being used to discuss the deployment of a £35M nationwide programme. This impact was preliminarily confirmed via an email communication to the main PhD supervisor and a confirmation formal letter is expected following the next meeting of the Steering Committee (delayed because of disruptions related to COVID-19).
Chapter 6	Welsh Water and Farming Connect	Welsh Water is responsible for the supply of high quality drinking water to over three million people in Wales. They implemented the weed wiper trial.	We collaboratively developed the research questions and data collection instruments with Welsh Water and with contributions from Farming Connect. This helped to improve the quality and relevance of the instrument, to address the most pressing issues within the Welsh context. Following a training programme that I designed and delivered, Welsh Water staff helped to conduct farmer interviews (with farmers who had

			participated in the weed wiper trial). They also provided date on the water quality from the study catchments.
		Farming Connect is a knowledge transfer, innovation and advisory service for farming and forestry businesses in Wales funded through Welsh Government Rural Communities – Rural Development Plan 2014-2020.	Knowledge exchange briefs will be developed for Welsh Water. These briefs will cover effective ways to engage farmers, raise awareness and to encourage adoption of BMPs. Results of this case study is informing Welsh Water of the potential impact of their intervention and providing insights into the design of their "Disposal Scheme". Knowledge exchange briefs covering effective ways to raise awareness, engage farmers, and influence behaviour will be produced for Welsh Water to guide future interventions. The influence that this PhD research is having in Welsh Water's strategy has been confirmed via personal communications and a formal letter will be produced by Welsh Water when the knowledge exchange briefs are submitted.
Chapters 2 to 6	Systematic reviews and empirical cases	Defra is the government department responsible for environmental protection, food production and standards, agriculture, fisheries and rural communities in the UK. Defra is currently undertaking a policy discussion on the Environmental Land Management (ELM) scheme, for which it has opened a public consultation.	Results of Chapters 5 and 6 have also been added to the evidence submitted by the University of Leeds (via the Yorkshire Integrated Catchment solution programme in which two of the supervisors participate) to Defra's consultations for the Environmental Land Management schemes (ELMs). Specifically, outputs from the PhD research were used to answer to consultation questions 8 ("What is the best way to encourage participation in ELM? What are the key barriers to participation, and how do we tackle them?") and 14 ("As we talk to land managers, and look back on what has worked from previous schemes, it is clear that access to an adviser is highly important to successful environmental schemes. Is advice always needed? When is advice most likely to be needed by a scheme participant?").

7.3 Future research directions

7.3.1 Maximise the value of secondary data

The systematic review method applied to synthesise the literature (Chapters 3 and 4) was useful in identifying key research gaps and areas requiring further attention. However, it is important to note that the review on the awareness-behaviour-water quality pathway (Chapter 4) was restricted to Europe and North America. While this decision was justified (due to limited papers from other regions and also different socio-cultural and climatic regions that could create a variation in norms, behaviours and water quality), such a restriction could potentially hinder our ability to draw lessons from other regions. This is because though socio-cultural factors may influence norms, behaviours and water quality, insights from these other regions could help us better understand farmers' decision processes and practices, as well as the different mechanisms through which water resources respond to land management practices. Future studies could explore the evidence across the globe (when there are more studies across regions). A good way to approach this is to introduce socio-cultural and climatic regions as moderators (through multi-group analysis). This helps to provide insights at the global scale, offer rich information about different subgroups and additional (potential) reasons for variation in results of the primary studies. This suggestion was not considered in this project as the search returned a limited number of primary studies from the regions that were excluded in the final analysis (e.g., only one study from Africa). In such situations, the researcher is unable to conduct a meaningful meta-regression across different sub-categories. Therefore, while I encourage more primary research on the topic, I recommend that future synthesis studies should employ moderation analysis to help

explore whether and how location, climate and other factors could influence the awareness-behaviour-water quality pathway.

7.3.2 Need for integrative models

Chapters 2 to 6 have demonstrated the complexity of the awareness-behaviour-water quality pathway. Together, the results highlight the need to develop more comprehensive and integrative models to fully capture how farmers' awareness and behaviour interact with other psychosocial and biophysical factors to affect land management and water quality. An important observation throughout this thesis is that, to apply integrative models, more data is needed. For instance, in chapter 2, results highlighted the potential role that agri-environment schemes play in farmers' awareness and uptake of BMPs. While data on the type of agri-environment schemes and how long farmers' had participated in them could advance our understanding of the crucial role they play in farmers' compliance with BMPs (Science for Policy Environment, 2017), this data was lacking.

Similarly, in Chapter 6, while results supported the potential role of awareness-focussed approaches in adoption of BMPs and improvement in water quality, there were a number of unknowns (that could have affected the water quality results). For instance, farmers' awareness could interact with factors such as how much pesticide was used in the different catchments, number of farms in each catchment that swapped MCPA for other pesticides (including glyphosate), and the number of fields on which the weed wiper was used. This interaction, could then affect MCPA concentration but this data was lacking.

To develop a full picture of the impact of awareness-focussed approaches, further quantitative research, involving large sample sizes, more data, experimental designs

and multivariate analytical techniques could be useful in further investigating how awareness interacts with other variables at different spatial and temporal scales. This should still be complemented with qualitative data to provide rich contextual insights into these complex interactions.

Further evidence from Chapter 5 suggests that while 'experiential knowledge' may reflect in cognitive or relational advancement at the individual level, and in the adoption of BMPs, such changes may not be readily observed and clearly articulated (Fazey et al., 2006, Suškevičs et al., 2019). It is however, evident that the experience of engaging in BMPs shape individuals' understanding of the complex socio-ecological systems within which they operate (Whiteman et al., 2004) and this understanding has implications on their behaviours (Woodwell, 1989, Adams and Sandbrook, 2013, Sutherland et al., 2004). What remains poorly understood is how situational factors and time influence learning and the acquisition of such tacit knowledge. Suškevičs et al. (2019) suggest that future studies employ research designs that integrate ex-ante and ex-post assessments as these methods could provide further insights into the specific links between time, learning and what has been learnt over time.

7.3.3 Scaling up the scope of analysis

Chapter 4 demonstrated that, to date, research on the impact of BMPs on water quality at the catchment scale remains limited; existing empirical studies have mostly focussed on the plot and individual field scales. Further research at the catchment scale is therefore, urgently needed. Furthermore, many BMPs are carried out at the field or farm scale. Therefore, to see improvements at the catchment scale, efforts are required to encourage farmers across the catchment to implement BMPs; the

higher the number of farms in the catchment engaging with the BMPs, the more rapid the improvement in water quality (Kay et al., 2009, Meals et al., 2010).

As highlighted in the Welsh case study (Chapter 6), while the weed wiper trial seem to have contributed to improving water quality in the treatment catchments, we are unable to attribute the entire success to only adoption of weed wipers as this could be due to the implementation of other measures e.g., some farmers following advice such as not applying pesticides when land is frozen, saturated or rain is forecast in next three days (Kay et al., 2009). It will be important, in future, to survey BMPs in all the study catchments and comprehensively evaluate the overall impact of such practices on water quality. Furthermore, it is important to consider a wide range of pollutants including other pesticides (e.g., Glyphosate).

7.4. Concluding remarks

Recent evidence shows that conventional agricultural systems, which currently dominate global food production, contribute to diffuse water pollution from agriculture (DWPA). This threatens ecosystems' and human health, reduces the recreational value of water bodies and increase water treatment costs. As human population grows, the pressure to increase food production intensifies. At the same time, climate change is likely to create a substantial alteration to the hydrological cycle. DWPA is likely to worsen due to increased pressure to expand food production, coupled with substantial alteration to the hydrological cycle. This is likely to impede our progress towards achieving the UN Sustainable Development Goals, particularly SDGs 6 and 15. Therefore, there is an urgent need for integrating agricultural and environmental policies to sustain food production systems while safeguarding water quality.

Past studies have shown that some farmers do not have a good understanding of the link between their practices and DWPA whilst others are unaware of existing best management practices (BMPs). In their search for measures to tackle DWPA, policymakers are increasingly focussing on how to improve farmers' awareness of the link between their practices and water pollution, under the expectation that this will lead to adoption of best management practices (BMPs) and improvement in water quality. This suggests the assumption of a straightforward relationship. To date, however, there is no known study that explores the whole awareness-behaviour-water quality pathway. Moreover, our understanding of the links between the different components (i.e., awareness-behaviour link, and behaviour-water quality link) remains limited. Previous studies have often addressed partial aspects of the pathway using descriptive approaches and have failed to provide the holistic understanding needed to determine the actual impacts of awareness-focussed interventions.

Therefore, I applied state-of-the-art interdisciplinary approaches, combining behavioural and catchment science to disentangle the complexities of the relationship between awareness, behaviour and water quality, with a focus on the UK. Due to the complex nature of DWPA, and the failure of top-down approaches, this PhD research adopted a bottom-up and collaborative approach. Working with academics from different scientific disciplines, policymakers and farmers helps to explore the problem from multiple perspectives and helps to bridge the gap between science and society. This approach has been useful in unpacking the complexity of the awareness-behaviour-water quality pathway, contributing to furthering our understanding on effective mechanisms to improve farmers' awareness, promote uptake of BMPs, and understanding how these interact with other variables to affect

water quality. In addition, this approach paves the way for the research to lead to societal impacts beyond academia. Through the collaboration with non-academic partners in two of the empirical chapters, this has led to an improved understanding that will help policymakers and industry stakeholders decide on which measures to prioritise, based on our knowledge of mechanisms that are effective.

Another important observation in this PhD was how the collaborative approach helped to attract the resources of organisations into a 'collective pool'. For instance, in the Welsh case study (Chapter 6), the team of researchers (from Leeds University) provided the technical knowhow, Farming Connect and the National Farmers' Union used their network to facilitate access to farmers, while Welsh Water, the water company, who had an established routine water monitoring programme within the study catchments, gave me access to water quality data from their water treatment works. From this pool of resources, synergies were identified and harnessed in developing innovative ideas, to generate outcomes that transcend the members' initial investment (helping to achieve results that any individual member organisation could not have achieved whilst working in isolation).

While the collaborative approach provided a great opportunity to explore the problem from multiple perspectives (i.e., scientists, practitioners and policymakers) thus advancing our understanding, it comes with challenges. One of the important challenges that I had to manage was how to meet the needs of project partners (through the design of the research instruments) while ensuring that the data collection tools (interview guides) were conceptually robust to test the objectives and research questions of the PhD (Table 7.1). This challenge was evident during co-construction of the survey and in-depth interviews in Chapters 5 and 6, where project partners wanted some issues and questions to be included and framed in a particular

way while the researchers (student and supervisors) realised that some of those suggestions were likely to significantly impact the results of the research and my ability to adequately respond to the hypotheses. This challenge was resolved through a series of dialogues among all stakeholders. Finding times that all stakeholders were able to meet and discuss issues was a huge challenge due to different schedules and this impacted project timelines.

Advancing our understanding of the interaction between the components of the pathway and the integration of this understanding into policy formulation and implementation will require social and natural scientists along with other actors to work closely in a truly interdisciplinary and transdisciplinary way (Rolston et al., 2019, Macleod et al., 2007, Martin-Ortega et al., 2015). Researchers would need to also work closely with industry and policy makers, co-develop and implement research initiatives aimed at addressing DWPA (Holden et al., 2017). Past initiatives on this (e.g., Martin-Ortega et al., 2015) still follow a quite directed approach, where the research is formulated from the lens of the researcher. While such consultative approaches could help to integrate the views of other stakeholders, this is often limited as the conceptualisation, operationalisation and implementation of research ideas are solely the decisions of the researchers.

This PhD has improved participation of stakeholders by involving them throughout the process (from prioritisation of research gaps, design of data collection instruments through to the dissemination of research outputs), and applying a nearly integrative model, where I treated behavioural change as a key mediator in the relationship between awareness and water quality, with other psychosocial, agronomic and biophysical factors acting as moderators of those relationships

across the awareness–behaviour–water quality pathway. This integrative and collaborative approach has enhanced our understanding of the different components of the pathway. Such a more profound understanding offers an opportunity to design and implement more effective policies to influence uptake of BMPs, reduce DWPA and ultimately improve water quality.

While the study is set in the context of DWPA in the UK, it sets out to provide insights into the role of awareness-based interventions towards mitigating the anthropogenic causes of environmental problems more broadly. Its relevance is possibly more directly applicable to the Global North (notably, for example, the literature review on Chapter 4 was restricted to 'developed' economies with which my findings might resonate more directly). However, findings from this thesis have the potential to be useful in promoting sustainable farm practices in the Global South, to help farmers avoid the use of poor land management practices such as large scale slash-and-burn, over application of (agro)chemicals for cultivation, animal rearing and fishing – that often result in deforestation, forest degradation, water pollution, and worsening climate conditions (Odame Appiah et al., 2018). It must be noted, however, that there are substantial differences in climate, culture, economic conditions, and governance or policy settings between the Global North and the Global South (Deasy et al., 2010), and thus policymakers need to consider such differences. Such considerations are important in designing context specific policies to help farmers adopt BMPs, and to ensure that food production is maximised to meet the needs of the growing population while safeguarding environmental resources.

References

ADAMS, W. & SANDBROOK, C. 2013. Conservation, evidence and policy. *Oryx,* 47**,** 329-335.

BARNES, A. P., WILLOCK, J., HALL, C. & TOMA, L. 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management,* 96**,** 1715-1722.

BARNES, A. P., WILLOCK, J., TOMA, L. & HALL, C. 2011. Utilising a farmer typology to understand farmer behaviour towards water quality management: Nitrate Vulnerable Zones in Scotland. *Journal of Environmental Planning and Management,* 54**,** 477-494.

BAUMGART-GETZ, A., PROKOPY, L. S. & FLORESS, K. 2012. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of environmental management,* 96**,** 17-25.

DEASY, C., QUINTON, J. N., SILGRAM, M., BAILEY, A. P., JACKSON, B. & STEVENS, C. J. 2010. Contributing understanding of mitigation options for phosphorus and sediment to a review of the efficacy of contemporary agricultural stewardship measures. *Agricultural Systems,* 103**,** 105-109.

DEFRA 2013. Catchment Based Approach: Improving the Quality of Our Water Environment, Report May 2013. . London: Department for Environment, Food & Rural Affairs.

DPMAG 2015. Strategy to reduce diffuse pollution. Edinburgh: Scottish Environment Protection Agency.

DRANGERT, J. O., KIELBASA, B., ULEN, B., TONDERSKI, K. S. & TONDERSKI, A. 2017. Generating applicable environmental knowledge among farmers: experiences from two regions in Poland. *Agroecology and Sustainable Food Systems,* 41**,** 671-690.

DWYER, J., MILLS, J., INGRAM, J., TAYLOR, J., BURTON, R., BLACKSTOCK, K., SLEE, B., BROWN, K., SCHWARZ, G. & MATTHEWS, K. 2007. Understanding and influencing positive behaviour change in farmers and land managers. *CCRI, Macaulay Institute*.

ENVIRONMENT AGENCY 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report. Bristol: Environment Agency

ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. . Bristol: Environment Agency.

EUROPEAN PARLIAMENT. 2017. MEPs demand glyphosate phase-out, with full ban by end 2022 European Parliament News: European Parliament.

FAZEY, I., FAZEY, J. A., SALISBURY, J. G., LINDENMAYER, D. B. & DOVERS, S. 2006. The nature and role of experiential knowledge for environmental conservation. *Environmental Conservation,* 33**,** 1-10.

HOLDEN, J., HAYGARTH, P. M., DUNN, N., HARRIS, J., HARRIS, R. C., HUMBLE, A., JENKINS, A., MACDONALD, J., MCGONIGLE, D. F. & MEACHAM, T. 2017. Water quality and UK agriculture: challenges and opportunities. *Wiley Interdisciplinary Reviews: Water,* 4**,** e1201.

INMAN, A., WINTER, M., WHEELER, R., VRAIN, E., LOVETT, A., COLLIN, A., JONES, I., JOHNES, P. & CLEASBY, W. 2018. An exploration of individual, social and material factors influencing water pollution mitigation behaviours within the farming community. *Land Use Policy,* 70**,** 16-26.

KAY, P., EDWARDS, A. C. & FOULGER, M. 2009. A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. *Agricultural Systems,* 99**,** 67-75.

MACGREGOR, C. J. & WARREN, C. R. 2006. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. *Agriculture, Ecosystems & Environment,* 113**,** 108-119.

MACLEOD, C. J., SCHOLEFIELD, D. & HAYGARTH, P. M. 2007. Integration for sustainable catchment management. *Sci Total Environ,* 373**,** 591-602.

MARTIN-ORTEGA, J., PERNI, A., JACKSON-BLAKE, L., BALANA, B. B., MCKEE, A., DUNN, S., HELLIWELL, R., PSALTOPOULOS, D., SKURAS, D. & COOKSLEY, S. 2015. A transdisciplinary approach to the economic analysis of the European Water Framework Directive. *Ecological Economics,* 116**,** 34-45.

MEALS, D. W., DRESSING, S. A. & DAVENPORT, T. E. 2010. Lag Time in Water Quality Response to Best Management Practices: A Review. *Journal of environmental quality,* 39**,** 85-96.

MERRILEES, D. & DUNCAN, A. 2005. Review of attitudes and awareness in the agricultural industry to diffuse pollution issues. 51**,** 373-381.

MORRIS, J., MILLS, J. & CRAWFORD, I. 2000. Promoting farmer uptake of agri-environment schemes: the Countryside Stewardship Arable Options Scheme. *Land Use Policy* 17**,** 241-254.

ODAME APPIAH, D., AKONDOH, A. C. K., TABIRI, R. K. & DONKOR, A. A. 2018. Smallholder farmers' insight on climate change in rural Ghana. *Cogent Food & Agriculture,* 4.

OKUMAH, M. & ANKOMAH-HACKMAN, P. 2020. Applying conditional process modelling to investigate factors influencing the adoption of water pollution mitigation behaviours. *Sustainable Water Resources Management,* 6**,** 17.

OKUMAH, M., CHAPMAN, P., MARTIN-ORTEGA, J. & NOVO, P. 2019. Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway. *Water,* 11**,** 29.

OKUMAH, M., MARTIN-ORTEGA, J. & NOVO, P. 2018. Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: A conditional process modelling. *Land Use Policy,* 76**,** 36-45.

POSTHUMUS, H., DEEKS, L., FENN, I. & RICKSON, R. 2011. Soil conservation in two English catchments: linking soil management with policies. *Land degradation & development,* 22**,** 97-110.

ROLSTON, A., JENNINGS, E. & LINNANE, S. 2019. Towards Integrated Water Management (TIMe) Final Report. Wexford, Ireland: Environmental Protection Agency.

SUŠKEVIČS, M., HAHN, T. & RODELA, R. 2019. Process and Contextual Factors Supporting Action-Oriented Learning: A Thematic Synthesis of Empirical Literature in Natural Resource Management. *Society & Natural Resources,* 32**,** 731-750.

SUTHERLAND, W. J., PULLIN, A. S., DOLMAN, P. M. & KNIGHT, T. M. 2004. The need for evidence-based conservation. *Trends in Ecology & Evolution,* 19**,** 305-308.

WHITEMAN, G., FORBES, B. C., NIEMELÄ, J. & CHAPIN, F. S. 2004. Bringing feedback and resilience of high-latitude ecosystems into the corporate boardroom. *Ambio,* 33**,** 371.

WOODWELL, G. M. 1989. On Causes Of Biotic Impoverishment. *Ecology,* 70**,** 14-15.

Appendices: Supplementary materials

Appendix A: Supplementary materials for chapter 2

Appendix A1: List of General Binding Rules (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 A2i: 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 A2ii: 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 A3: 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 A4: Modelling Results
Appendix A4i: 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 A4ii: 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 A4iii: 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 A4iv: Model fit indices for Model 3

N	χ²	degrees of freedom	P-value (χ²)	CFI	RMSEA	90% conf. int. (RMSEA)	SRMR
1564	1.000	1	1.000	1.000	0.000	0.000, 0.000	0.000

Appendix B: supplementary materials for chapter 3

Appendix B1: Search terms and groupings

As terms such as "pro-environmental behaviour" and "theories" are sometimes expressed differently, we used substitute words to help capture the fullness of the terms as well as wildcard symbols (e.g. asterisks) to capture the variations of the words (see samples below):

Search 1: Variations of Pro-environmental behaviour and the theories

Level 1: one of the following: pro-environment*   pro ecolog*   sustain*

environment* friend*   environment* good environmental   positive environmental

Environmentally significant   environmentally responsible

PLUS one of the following

Level 2: behavio*   attitud*   act*   habit*   practice*   measure   way*   effort*

PLUS one of the following

Norm Activation Model   Value-Belief-Norm Theory   Theory of Reasoned Action

Theory of Planned Behaviour   Persuasion Theory   Attitude-Behaviour-Context

Theory   Social Learning Theory

Search 2: Substitutions made include:

For environmental behaviour:

 Climat* adapt*   mitigat* preparedness   waste manag* conservation   green

behavio?r   green consum*   land manag*   forest manag*   antipollution

The terms theory or model were also substituted with:

Framework, concept*, proposition

Appendix B2.

Table A1. Final Papers Included in the meta-analysis.

Study	Title	Issue area	Policy
Huffman et al. (2014)	When do recycling attitudes predict recycling? An investigation of self-reported versus observed behaviour	1	X
Han and Hyun (2018)	What influences water conservation and towel reuse practices of hotel guests?	3	X
Tonglet et al. (2004)	Using the Theory of Planned Behaviour to investigate the determinants of recycling behaviour: a case study from Brixworth, UK	1	EU Landfill Directive
Adnan et al. (2017)	Understanding and facilitating sustainable agricultural practice: A comprehensive analysis of adoption behaviour among Malaysian paddy farmers	2	Sustainable Agricultural Practices
Kaiser and Scheuthle (2003)	Two challenges to a moral extension of the theory of planned behaviour: moral norms and just world beliefs in conservationism	4	X
Han (2015)	Travellers' pro-environmental behaviours in a green lodging context: Converging value-belief-norm theory and the theory of planned behaviour	3	Eco-friendly guidelines
Raymond and Kenter (2016)	Transcendental values and the valuation and management of ecosystem services	2	X
Arnocky et al. (2013)	Time Perspective and Sustainable Behaviour: Evidence for the Distinction Between Consideration of Immediate and Future Consequences	4	X
Davis et al. (2009)	Sustainable attitudes and behaviours amongst a sample of non-academic staff: A case study from an Information Services Department, Griffith University, Brisbane	3	Institutional Sustainability Initiative
Chatzidakis et al. (2014)	Socio-Cognitive Determinants of Consumers' Support for the Fair Trade Movement	3	Fair trade principles
Lalani et al. (2016)	Smallholder farmers' motivations for using Conservation Agriculture and the roles of yield, labour and soil fertility in decision making	2	Conservation Agricultural Policy
Busse and Menzel (2014)	The role of perceived socio-spatial distance in adolescents' willingness to engage in pro-environmental behaviour	4	X
Doran and Larsen (2016)	The Relative Importance of Social and Personal Norms in Explaining Intentions to Choose Eco-Friendly Travel Options	3	X
Mannetti et al. (2004)	Recycling: Planned and self-expressive behaviour	1	X
Robinson and Smith (2002)	Psychosocial and Demographic Variables Associated with Consumer Intention to Purchase Sustainably Produced Foods as Defined by the Midwest Food Alliance	3	X
Arı and Yılmaz (2016)	A proposed structural model for housewives' recycling behaviour: A case study from Turkey	1	Waste Management Policies
Wesselink et al. (2017)	Pro-environmental behaviour in the workplace and the role of managers and organisation	4	X
Kim et al. (2012)	Predictors of Pro-Environmental Behaviours of American and Korean Students: The Application of the Theory of Reasoned Action and Protection Motivation Theory	3	X

Untaru et al. (2016)	Predictors of individuals' intention to conserve water in a lodging context: the application of an extended Theory of Reasoned Action	3	General sustainability policies
Zhang et al. (2014)	Predicting residents' pro-environmental behaviours at tourist sites: The role of awareness of disaster's consequences, values, and place attachment	3	X
Price and Leviston (2014)	Predicting pro-environmental agricultural practices: The social, psychological and contextual influences on land management	2	General best land management practices
Ha and Janda (2012)	Predicting consumer intentions to purchase energy-efficient products	3	X
Han (2014)	The norm activation model and theory-broadening: Individuals' decision-making on environmentally-responsible convention attendance	4	X
Kaiser (2006)	A moral extension of the theory of planned behaviour: Norms and anticipated feelings of regret in conservationism	4	X
Gärling et al. (2003)	Moderating effects of social value orientation on determinants of Pro-environmental behaviour intention	4	X
Chen and Tung (2009)	The Moderating Effect of Perceived Lack of Facilities on Consumers' Recycling Intentions	1	The Compulsory Classification of Refuse program
Lin and Syrgabayeva (2016)	Mechanism of environmental concern on intention to pay more for renewable energy: Application to a developing country	3	Anti-pollution laws
Goh and Balaji (2016)	Linking green scepticism to green purchase behaviour	3	X
Xu et al. (2017)	Investigating willingness to save energy and communication about energy use in the American workplace with the attitude-behaviour-context model	3	X
Poškus (2016)	Investigating pro-Environmental Behaviours of Lithuanian University Students	3	X
Prakash and Pathak (2017)	Intention to buy eco-friendly packaged products among young consumers of India: A study on developing nation	3	Eco-friendly Strategies
Swaim et al. (2013)	Influences on Student Intention and Behaviour Toward Environmental Sustainability	3	X
Chen (2015b)	Impact of fear appeals on pro-environmental behaviour and crucial determinants	4	X
Duerden and Witt (2010)	The impact of direct and indirect experiences on the development of environmental knowledge, attitudes, and behaviour	4	X
Andow et al. (2017)	Heterogeneity in Intention to Adopt Organic Strawberry Production Practices Among Producers in the Federal District, Brazil	3	X
Han et al. (2015)	Guests' pro-environmental decision-making process: Broadening the norm activation framework in a lodging context	3	X
Han and Hyun (2016)	Fostering customers' pro-environmental behaviour at a museum	3	X
Dagher and Itani (2014)	Factors influencing green purchasing behaviour: Empirical evidence from the Lebanese consumers	3	X

Chen (2016)	Extending the theory of planned behaviour model to explain people's energy savings and carbon reduction behavioural intentions to mitigate climate change in Taiwane- moral obligation matters	3	The 25 G8 energy efficiency recommendations
Botetzagias et al. (2015)	Extending the Theory of Planned Behaviour in the context of recycling: The role of moral norms and of demographic predictors	1	X
Donald et al. (2014)	An extended theory of planned behaviour model of the psychological factors affecting commuters' transport mode use	3	X
Castaneda et al. (2015)	Explaining the environmentally sustainable consumer behaviour: a social capital perspective	3	X
van Birgelen et al. (2011)	Explaining pro-environment consumer behaviour in air travel	3	X
(Abdul-Muhmin, 2007)	Explaining consumers' willingness to be environmentally friendly	3	X
Martins Gonçalves and Viegas (2015)	Explaining consumer use of renewable energy: determinants and gender and age moderator effects	3	X
Chen (2015a)	An examination of the value-belief-norm theory model in predicting pro-environmental behaviour in Taiwan	4	X
Ernst et al. (2015)	Environmental action and student environmental leaders: exploring the influence of environmental attitudes, locus of control, and sense of personal responsibility	4	X
(Wynveen and Sutton, 2016)	Engaging Great Barrier Reef Stakeholders: Mediation Analyses of Barriers Among the Antecedents of Pro-Environmental Behaviour	4	X
(Blok et al., 2015)	Encouraging sustainability in the workplace: a survey on the pro-environmental behaviour of university employees	4	X
(Andersson et al., 2005)	Enacting Ecological Sustainability in the MNC: A Test of an Adapted Value-Belief-Norm Framework	4	ISO 14031
(Nordlund and Garvill, 2003)	Effects of values, problem awareness, and personal norm on willingness to reduce personal car use	3	X
Staats et al. (2016)	Effecting Durable Change: A Team Approach to Improve Environmental Behaviour in the Household	4	Eco Team Program
(Andersson and von Borgstede, 2010)	Differentiation of determinants of low-cost and high-cost recycling	1	X
(Chen and Tung, 2014)	Developing an extended Theory of Planned Behaviour model to predict consumers' intention to visit green hotels	1	X
(Clark and Finley, 2007)	Determinants of Water Conservation Intention in Blagoevgrad, Bulgaria	3	X
(Prete et al., 2017)	Determinants of Southern Italian households' intention to adopt energy efficiency measures in residential buildings	3	Energy Efficiency Policies
(Han et al., 2016)	Cruise travellers' environmentally responsible decision-making: An integrative framework of goal-directed behaviour and norm activation process	3	X

(Klöckner and Blöbaum, 2010)	A comprehensive action determination model: Toward a broader understanding of ecological behaviour using the example of travel mode choice	3	X
(Han et al., 2017)	Cognitive, affective, normative, and moral triggers of sustainable intentions among convention-goers	3	X
(Lin et al., 2012)	Behavioural intentions toward afforestation and carbon reduction by the Taiwanese public	3	Climate change Policies
(Doran et al., 2015)	Attitudes, efficacy beliefs, and willingness to pay for environmental protection when travelling	3	X
(Deng et al., 2016)	Analysis of the ecological conservation behaviour of farmers in payment for ecosystem service programs in eco-environmentally fragile areas using social psychology models	2	X
(Knussen et al., 2004)	An analysis of intentions to recycle household waste: The roles of past behaviour, perceived habit, and perceived lack of facilities	1	X
(Castro et al., 2009)	Ambivalence and conservation behaviour: An exploratory study on the recycling of metal cans	1	X
(Bissonnette and Contento, 2001)	Adolescents' Perspectives and Food Choice Behaviours in Terms of the Environmental Impacts of Food Production Practices: Application of a Psychosocial Model	3	X
(Meinhold and Malkus, 2016)	Adolescent Environmental Behaviours: Can Knowledge, Attitudes, and Self-Efficacy Make a Difference?	4	X
Hunecke et al. (2001)	Responsibility And Environment: Ecological Norm Orientation and External Factors in the Domain of Travel Mode Choice Behaviour	3	X
(Guagnano et al., 1995)	Influences on attitude-behaviour relationships: a natural experiment with curbside recycling	1	X
(Cottrell, 2003)	Influence Of Socio-demographics And Environmental Attitudes on General Responsible Environmental Behaviour Among Recreational Boaters	4	X
(CORBETT, 2002)	Motivations to Participate in Riparian Improvement Programs: Applying the Theory of Planned Behaviour	2	X
(Tanner and Kast, 2003)	Promoting Sustainable Consumption: Determinants of Green Purchases by Swiss Consumers	3	X
(Chao and Lam, 2011)	Measuring Responsible Environmental Behaviour: Self-Reported and Other-Reported Measures and Their Differences in Testing a Behavioural Model	4	X
(Rise et al., 2003)	Measuring implementation intentions in the context of the theory of planned behaviour	1	X
(Laudenslager and Holt, 2004)	Understanding air force members' intentions to participate in pro-environmental behaviours: an application of the theory of planned behaviour	4	X
(Kaiser and Gutscher, 2003)	The Proposition of a General Version of the Theory of Planned Behaviour: Predicting Ecological Behaviour	4	X
(Hamid and Cheng, 1995)	Predicting antipollution behaviour: The role of molar behavioural intentions, past behaviour and locus of control	4	X
(Bratt, 1999)	The Impact of Norms And Assumed Consequences On Recycling Behaviour	1	X

(Davies et al., 2002)	Beyond the intention–behaviour mythology An integrated model of recycling	1	X	
(Truelove and Joireman, 2009)	Understanding the Relationship Between Christian Orthodoxy and Environmentalism: The Mediating Role of Perceived Environmental Consequences	4	X	
(Joireman et al., 2001)	Integrating social value orientation and the consideration of future consequences within the extended norm activation model of pro-environmental behaviour	4	X	
(Kaiser and Shimoda, 1999)	Responsibility As A Predictor of Ecological Behaviour	4	X	
(Kaiser et al., 1999)	Environmental Attitude and ecological Behaviour	4	X	
(Minton and Rose, 1997)	The Effects of Environmental Concern on Environmentally Friendly Consumer Behaviour: An Exploratory Study	3	X	
(Nilsson and K• uller, 2000)	Travel behaviour and environmental concern	3	X	
(Nordlund and Garvill, 2003)	Effects of values, problem awareness, and personal norm on willingness to reduce personal car use	4	X	
(Tanner, 1999)	Constraints On Environmental Behaviour	4	X	
(Terry et al., 1999)	The theory of planned behaviour : Self-identity, social identity and group norms	4	X	
(Grønhøj and Thøgersen, 2012)	Action speaks louder than words: The effect of personal attitudes and family norms on adolescents' pro-environmental behaviour	4	X	
(Kim et al., 2016)	What matters to promote consumers' intention to patronize sustainable business-and-industry (B&I) food services?	3	X	
(Carrico and Riemer, 2011)	Motivating energy conservation in the workplace: An evaluation of the use of group-level feedback and peer education	3	X	
(Liobikienė et al., 2017)	Environmentally friendly behaviour and green purchase in Austria and Lithuania	3	X	
(Jakovcevic and Steg, 2013)	Sustainable transportation in Argentina: Values, beliefs, norms and car use reduction	3	Transport pricing policies	
(Chakraborty et al., 2017)	A study of goal frames shaping pro-environmental behaviour in university students	4	X	
(Hasnah Hassan, 2014)	The role of Islamic values on green purchase intention	3	X	
(Fang et al., 2017)	Physical Outdoor Activity versus Indoor Activity: Their Influence on Environmental Behaviours	4	X	
(Choi et al., 2015)	A Mediation Model of Air Travellers' Voluntary Climate Action	3	X	
(Eriksson and Forward, 2011)	Is the intention to travel in a pro-environmental manner and the intention to use the car determined by different factors?	3	X	
(Forward, 2014)	Exploring people's willingness to bike using a combination of the theory of planned behavioural and the trans-theoretical model	3	X	
(Mobley et al., 2009)	Exploring Additional Determinants of Environmentally Responsible Behaviour: The Influence of Environmental Literature and Environmental Attitudes	4	X	

(Echegaray and Hansstein, 2017)	Assessing the intention-behaviour gap in electronic waste recycling: the case of Brazil	1	X
(Eriksson et al., 2006)	Acceptability of travel demand management measures: The importance of problem awareness, personal norm, freedom, and fairness	3	X
(ALLEN and FERRAND, 1999)	Environmental locus of control, sympathy, and pro-environmental behaviour: A Test of Geller's Actively Caring Hypothesis	4	X
(Gregory and Di Leo, 2003)	Repeated Behaviour and Environmental Psychology: The Role of Personal Involvement and Habit Formation in Explaining Water Consumption	3	X
(Lynne et al., 1995)	Conservation technology adoption decisions and the theory of planned behaviour	2	Water saving irrigation technology
Werner and Makela (1998)	Motivations and behaviours that support recycling	1	X
Jorgen et al. (2003)	Effects of increased awareness on choice of travel mode	3	X
Thøgersen, & Oˇlander, (2006)	The Dynamic Interaction of Personal Norms and Environment-Friendly Buying Behaviour: A Panel Study	3	X
Bamberg et al. (2007)	Social context, personal norms and the use of public transportation: Two field studies	3	X
Veludo-de-Oliveira et al. (2012)	Accounting for Sustained Volunteering by Young People: An Expanded TPB	4	X

Note: 1=recycling; 2= land management; 3= sustainable consumer behaviour; 4= general ecological behaviour; X = No policy highlighted

Table A2. A 95%-confidence interval of the correlations calculated under the random effect assumptions (model).

SN	Construct		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Knowledge		-	-																
2	beliefs	LCI 95%	0.21	-																
		UCI 95%	0.73																	
3	Awareness or consciousness	LCI 95%	0.03 NS	-0.15NS	-															
		UCI 95%	0.49	0.45																
4	Attitude	LCI 95%	0.04	0.34	0.17	-														
		UCI 95%	0.61	0.66	0.44															
5	Habit	LCI 95%	0.12a		-0.09a	-0.24 NS	-													
		UCI 95%	0.32		0.13	0.30														
6	Intention	LCI 95%	0.06	0.05	0.28	0.43	-0.37NS	-												
		UCI 95%	0.66	0.69	0.53	0.61	0.55													
7	Behavioural willingness	LCI 95%	0.15	0.18a	0.29	-0.00	0	0.08	-											
		UCI 95%	0.38	0.28	0.48	0.38		0.68												
8	Behaviour	LCI 95%	0.17	0.17	0.13	0.27	0.09	0.35	0.19 –	-										
		UCI 95%	0.39	0.30	0.31	0.46	0.45	0.52	0.48											
9	Social norm	LCI 95%	0.04		-0.03	0.27		0.34		0.31	-									
		UCI 95%	0.39		0.56	0.46		0.50		0.51										
10	Moral norm	LCI 95%	0.13		0.32	0.36		-0.22		0.15		-								
		UCI 95%	0.32		0.50	0.79		0.68		0.54										
11	Subjective norm	LCI 95%	0.01		0.27 –	0.38 –		0.37 –		0.14 –			-							
		UCI 95%	0.86		0.51	0.52		0.48		0.35										
12	Emotions	LCI 95%	0.35a	0.06	-0.05NS			0.13			-0.24NS	-0.39NS	0.16	-						
		UCI 95%	0.53	0.40	0.56			0.58			0.43	0.65	0.44							
13	Self-efficacy	LCI 95%	0.03	0.17	0.32	0.12		0.40	0.27	0.19	0.17	0.24	0.46		-					
		UCI 95%	0.32	0.46	0.46	0.43		0.57	0.50	0.35	0.43	0.65	0.51							
14	Perceived consequences	LCI 95%	0.05		0.47	0.27		0.25		0.09	0.12	0.38				-				
		UCI 95%	0.38		0.81	0.55		0.51		0.22	0.23	0.58								
15	Ascription of responsibility	LCI 95%			0.19	0.14		0.42		0.15	0.16		0.38				-			
		UCI 95%			0.58	0.56		0.60		0.31	0.52		0.56							
16	Situational factors	LCI 95%						-0.19NS		-0.18NS								-		
		UCI 95%						0.15		0.05										
17	Environmental value	LCI 95%	0.31			0.18		0.26											-	
		UCI 95%	0.49			0.60		0.51												
18	Environmental concern	LCI 95%	0.15			0.16		0.23												-
		UCI 95%	0.44			0.33		0.37												

Note: a = no pooled correlation (i.e., only one correlation was used but we calculated the 95% CI), NS = non-significant relationship (all other r values are significant at the $p \leq 0.05$); LCI = Lower Confidence interval; UCI = upper Confidence interval

Table A3. Results of test of heterogeneity.

SN	VARIABLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Knowledge	-																	
2	beliefs	Q(158.23) df(3) P(0.00) I(98.10)	-																
3	Awareness or consciousness	Q(10.41) Df(1) P(0.00) I(90.39)	Q(93.29) Df(2) P(0.00) I(97.86)	-															
4	Attitude	Q(1218.16) Df(9) P(0.00) I(99.26)	Q(264.47) Df(6) P(0.00) I(97.73)	Q(155.59) Df(9) P(0.00) I(94.22)	-														
5	Habit	Q(0.00) Df(0) P(1.00) I(0.00)ns		Q(0.00) Df(0) P(1.00) I(0.00)ns	Q(80.56) Df(3) P(0.00) I(96.28)	-													
6	Intention	Q(915.77) Df(7) P(0.00) I(99.24)	Q(231.94) Df(3) P(0.00) I(98.71)	Q(327.09) Df(12) P(0.00) I(96.33)	Q(3460.70) Df(45) P(0.00) I(98.70)	Q(328.51) Df(4) P(0.00) I(98.78)	-												
7	Behavioural willingness	Q(18.96) Df(4) P(0.00) I(78.90)	Q(0.00) Df(0) P(1.00) I(0.00)ns	Q(35.28) Df(5) P(0.00) I(85.83)	Q(32.72) Df(3) P(0.00) I(90.83)	0	Q(99.81) Df(3) P(0.00) I(96.99)	-											
8	Behaviour	Q(106.74) Df(8) P(0.00) I(92.50)	Q(49.43) Df(6) P(0.00) I(87.86)	Q(273.26) Df(17) P(0.00) I(93.78)	Q(1350.24) Df(29) P(0.00) I(97.85)	Q(36.33) Df(3) P(0.00) I(91.74)	Q(842.73) Df(28) P(0.00) I(98.68)	Q(39.26) Df(4) P(0.00) I(89.81)	-										
9	Social norm	Q(4.91) Df(1) P(0.03) I(79.65)		Q(20.90) Df(1) P(0.00) I(95.22)	Q(65.54) Df(5) P(0.00) I(92.37)		Q(108.01) Df(8) P(0.00) I(92.59)		Q(82.66) DF(8) P(0.00) I(90.32)	-									
10	Moral norm	Q(6.31) Df(2) P(0.04) I(68.30)		Q(281.63) Df(13) P(0.00) I(95.38)	Q(4785.79) Df(17) P(0.00) I(99.64)		Q(1505.70) Df(12) P(0.00) I(99.20)		Q(2185.43) DF(18) P(0.00) I(99.18)		-								
11	Subjective norm	Q(77.03) Df(1) P(0.00) I(98.70)		Q(47.32) Df(5) P(0.00) I(89.43)	Q(1563.64) Df(41) P(0.00) I(97.38)		Q(596.75) Df(32) P(0.00) I(94.64)		Q(513.02) DF(19) P(0.00) I(96.30)			-							
12	Emotions e.g., guilt	Q(0.00) Df(0) P(1.00) I(0.00)ns		Q(289.17) DF(9) P(0.00) I(96.89)	Q(345.39) Df(5) P(0.00) I(98.55)		Q(1106.91) Df(12) P(0.00) I(98.92)		Q(230.76) DF(4) P(0.00) I(98.27)				-						
13	Self-efficacy	Q(42.99) Df(3) P(0.00) I(93.02)		Q(69.99) DF(5) P(0.00) I(92.86)	Q(1304.70) Df(36) P(0.00) I(97.24)	Q(5.73) Df(1) P(0.02) I(82.55)	Q(2218.73) Df(38) P(0.00) I(98.29)	Q(39.95) Df(5) P(0.00) I(87.48)	Q(409.37) DF(22) P(0.00) I(94.63)	Q(22.87) DF(3) P(0.00) I(86.88)	Q(202.82) DF(4) P(0.00) I(98.03)	Q(325.26) DF(8) P(0.00) I(97.54)		-						

#	Variable										
14	Perceived consequences	Q(15.21) Df(2) P(0.00) I(86.85)	Q(233.26) Df(5) P(0.00) I(97.86)	Q(214.84) Df(9) P(0.00) I(95.81)	Q(670.23) Df(18) P(0.00) I(97.31)	Q(51.40) Df(11) P(0.00) I(78.60)	Q(1.07) DF(2) P(0.59) I(0.00)	Q(315.72) DF(11) P(0.00) I(96.52)			-
15	Ascription of responsibility		Q(14.16) Df(2) P(0.00) I(85.88)	Q(82.92) Df(4) P(0.00) I(95.18)	Q(70.85) Df(7) P(0.00) I(90.12)	Q(15.87) Df(5) P(0.01) I(68.50)	Q(7.49) DF(1) P(0.01) I(86.65)		Q(6.95) DF(2) P(0.03) I(71.22)		-
16	Situational factors				Q(185.50) Df(8) P(0.00) I(95.68)	Q(159.18) DF(10) P(0.00) I(93.72)					-
17	Environmental value	Q(2.36) Df(1) P(0.12) I(57.66)ns		Q(10.16) DF(1) P(0.00) I(90.1)6	Q(78.41) Df(6) I(0.00) I(92.35)						-
18	Environmental concern	Q(22.14) Df(3) P(0.00) I(86.45)		Q(30.64) Df(6) P(0.00) I(80.42)	Q(59.53) Df(10) P(0.00) I(82.20)						-

Q = Q statistic; Df = Degrees of freedom; p = p-value; I = I squared statistic

Appendix C: supplementary material for chapter 4

Appendix C1: Application of search terms

Awareness–behaviour link:
Search terms applied covered terms in group 1, 2 and 3: e.g.,
Knowledge **PLUS** implement* **PLUS** farm practice* *(using * to capture the fullness of the topic, and "AND" to enhance relevance of returned outputs).*

Awareness–water quality link:
Search terms applied covered terms in group 1, and 4: e.g.,
Knowledge **PLUS** water quality improvement* *(using * to capture the fullness of the topic, and "AND" and "OR" enhance relevance of returned outputs and, also capture papers that included knowledge and any of the environmental outcomes under consideration).*

Behaviour–water quality link:
Search terms applied covered terms in group 2, 3 and 4: e.g.,
Adopt* **PLUS** diffuse pollution mitigation measure* **PLUS** water quality improvement *(using * to capture the fullness of the topic, and "AND" and "OR" enhance relevance of returned outputs and, also capture papers that included knowledge and any of the environmental outcomes under consideration)*

Finally, an overall search was run to cover all groups (1–4). Combinations of all these was done systematically for all search terms under each of the groups. The final process in literature search involved a snowball technique of manually tracing references from key papers such as (Kay et al., 2009, Kay et al., 2012a, Giri and Qiu, 2016).

Appendix C2: List of Final Papers Used for the Evidence Review

Study	Title	Location	Journal
(Kay et al., 2012a)	The effectiveness of agricultural stewardship for improving water quality at the catchment scale: Experiences from an NVZ and ECSFDI watershed	United Kingdom	Journal of Hydrology **
(Lobley and Potter, 1998)	Environmental Stewardship in UK Agriculture: A Comparison of the Environmentally Sensitive Area Programme and the Countryside Stewardship Scheme in South East England	United Kingdom	Geoforum *
(Barnes et al., 2009)	Farmer perspectives and practices regarding water pollution control programmes in Scotland	United Kingdom	Agricultural Water Management *
(Bechmann et al., 2008)	Monitoring catchment scale agricultural pollution in Norway: policy instruments, implementation of mitigation methods and trends in nutrient and sediment losses	Norway	Environmental Science & Policy ***
(Borin et al., 2005)	Effectiveness of buffer strips in removing pollutants in runoff from a cultivated field in North-East Italy	Italy	Agriculture, Ecosystems & Environment ***
(Deasy et al., 2010)	Contributing understanding of mitigation options for phosphorus and sediment to a review of the efficacy of contemporary agricultural stewardship measures	United Kingdom	Agricultural Systems **
(Drangert et al., 2017)	Generating applicable environmental knowledge among farmers: experiences from two regions in Poland	Poland	Agroecology and Sustainable Food Systems*
(Floress et al., 2017b)	Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality	United States	Journal of Environmental Psychology *
(Haas et al., 2017)	Assessing the impacts of Best Management Practices on nitrate pollution in an agricultural dominated lowland catchment considering environmental protection versus economic development	Germany	Journal of Environmental Management ***
(Hadrich and Van Winkle, 2013)	Awareness and pro-active adoption of surface water BMPs	United States	Journal of Environmental Management ***
(Herzog et al., 2008)	Environmental cross-compliance mitigates nitrogen and phosphorus pollution from Swiss agriculture	Switzerland	European Journal of Agronomy **
(Iital et al., 2008)	Monitoring of diffuse pollution from agriculture to support implementation of the WFD and the Nitrate Directive in Estonia	Estonia	Environmental Science & Policy ***
(Kreuger and Nilsson, 2001)	Catchment scale risk-mitigation experiences- key issues for reducing pesticide transport to surface waters	Sweden	British Crop Protection Council Symposium Proceedings **
(Worrall et al., 2009)	The effectiveness of nitrate vulnerable zones for limiting surface water nitrate concentrations	United Kingdom	Journal of Hydrology **
(Oenema et al., 2005)	Effects of lowering nitrogen and phosphorus surpluses in agriculture on the quality of groundwater and surface water in the Netherlands	Netherlands	Journal of Hydrology **
(Rehman et al., 2007)	Identifying and understanding factors influencing the uptake of new technologies on dairy farms in SW England using the theory of reasoned action	United Kingdom	Agricultural Systems **
(Ulrich-Schad et al., 2017)	Measuring and understanding agricultural producers' adoption of nutrient best management practices	United States	Journal of Soil and Water Conservation **

(Macgregor and Warren, 2006a)	Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm	United Kingdom	Agriculture, ecosystems & environment ***
(Okumah et al., 2018)	Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: a conditional process modelling	United Kingdom	Land Use Policy ***

Notes: * = Social science focused;   ** = Natural Science focused;   *** = Cuts across the social and natural sciences.

Appendix C3: Summary of variables affecting the awareness–behavioural change–water quality pathway

Categories: Focus of study	Study	Source of advice (a)	Message framing and mode of delivery (a)	Beliefs (a)	Attitude (a)	Habit (a)	Intention (a)	Behavioural Willingness (a)	Social norm (a)	Perceived consequences (a)	Ascription of responsibility (a)	Education (a)	Age (a)	Situational factors (c)	Environmental value and concern (a)	Nutrient type or type of pollutant (b)	Type of Mitigation measure (b)	Critical source of pollution (b)	Spatial, temporal and seasonal variation (b)	Intensity of land use (b)	Soil and hydrologic characteristics (b)	Time or duration of change in practices (b)	Pollutants from external sources (b)	Crop uptake of nutrients (b)	Infiltration coefficient (b)	Delayed response to other mitigation (b)	Atmospheric deposition of pollutant (b)
Awareness and behavioural change link	(Lobley and Potter, 1998)				X				X	x			x	x		x											
	(Rehman et al., 2007)	x	x	x			x																				
	(Floress et al., 2017b)			x				X						x													
	(Hadrich and Van Winkle, 2013)											x		x													
	(Ulrich-Schad et al., 2017)	x												x													
	(Barnes et al., 2009)		x	x	X	x								x													
	(Macgregor and Warren, 2006a)			x	X	x				x	x			x													
	(Drangert et al., 2017)	x	x	x	X									x													
	(Okumah et al., 2018)													x	x												
Awareness and water quality link	(Kreuger and Nilsson, 2001)	x	x					X										x									
Behavioural change and water quality link	(Borin et al., 2005)													x					x	x					x		
	(Deasy et al., 2010)													x		X	x		x								
	(Haas et al., 2017)													x			x			x		X					
	(Oenema et al., 2005)													x		X	x	x	x	x		X	x	x			
	(Worrall et al., 2009)													x			x			x	x						
	(Kay et al., 2012a)													x		X	x	x	x	x	x		x			x	
	(Iital et al., 2008)													x						x	x						
	(Bechmann et al., 2008)		x											x		X	x			x	x	x	X	x		x	
	(Herzog et al., 2008)													x		X	x				x			x		x	x
Number of studies reporting variable		4	5	5	4	2	1	2	1	3	2	1	1	17	2	6	7	3	4	7	5	3	3	3	1	3	1

Notes: x = reported in the study; Letters in parenthesis: a = factors directly affecting awareness and behaviour; b = factors directly affecting water quality; c = factor affecting awareness, behaviour and water quality.

Appendix D : supplementary material for chapter 5

Appendix D1: Survey Questionnaire

2018 Soil Testing and Analysis Results – 1 year on – post scheme evaluation questionnaire (please tick the relevant boxes)

Q1. Do you have a Nutrient Management Plan for your farm? Yes ☐ No ☐

    If yes is it: A plan drawn up by a farm adviser?   Yes ☐ No ☐

          A plan drawn up by yourself based on soil analysis results?   Yes ☐ No ☐

          Other (please state): _____

Q2. Did you take any of the following actions as a result of receiving your soil test results?

    Changed the type of fertiliser Purchased (e.g. lower or higher N P K content)?   Yes ☐ No ☐

    Changed the amount of fertiliser purchased (either more or less)?   Yes ☐ No ☐

    Increased lime usage?   Yes ☐ No ☐

    Imported or exported slurries?   Yes ☐ No ☐

    Other (please state): _____

Q3. Do you expect a crop yield increase with better knowledge of your soils? Yes ☐ No ☐ Don't know ☐

Q4. Are you more likely to carry out further soil sampling in 4 years, on your own as a result of this soil testing?

                Yes ☐ No ☐ Don't know ☐

Q5. Do you think if there were enough farmers taking part in soil sampling that water quality in your area would improve?

                Yes ☐ No ☐ Don't know ☐

Q6. Do you recognise the link between good healthy soils and good water quality?

                Yes ☐ No ☐ Don't know ☐

Q7 & Q8 for Upper Bann participants only

Q7. Do you understand your P Risk Run-Off Map? Yes ☐ No ☐

Q8. Have you used your P Risk Run-Off Map?   Yes ☐ No ☐

    If yes, have you used it to:

    Identify fields where there may be a risk of nutrient run-off into a watercourse? Yes ☐ No ☐

    Help decide where to establish a buffer strip?   Yes ☐ No ☐

    Other (please state): _____

Appendix D2: Interview script

My name is ……………………….I am calling on behalf of AFBI to have a chat with you regarding your involvement in the EAA Soil sample scheme and actions you have taken since your fields were tested. The information collected in this interview will be used exclusively for research purposes. Personal information will be kept secure in accordance with the Data Protection Act and General Data Protection Regulation under the Data Protection Act 2018 and will only be accessible to the research team. Results from this research will be published for academic purposes only and will be referred to anonymously.

By proceeding with this interview, you are consenting to the above. You may withdraw at any point if you wish.

(Please tick the relevant boxes)

Q1. **Primary Farm type:** Dairy ☐ Sheep ☐ Pigs ☐ Poultry ☐ Arable ☐ Beef ☐

Q2. **Category of lands in your farm (tick all that apply):** Owned Lands ☐ Lands taken in Conacre ☐ Lands taken on Long Term Lease ☐

Q3. **What is your total area farmed? …………………….. Acres/hectares (Please tick the appropriate unit after writing the value**).

Q4. **Have you taken part in the EAA Soil Sampling and Analysis Scheme (if yes, indicate name of scheme)?** Yes ☐ No ☐

Q5. **Length of farming experience**…………… **years**

Q6. **Gender of farmer?** Female ☐ Male ☐ Prefer not to say ☐

Interviewer: Please add any additional contextual information that you find relevant.

#	Questions	Instruction(s) for interviewer
7	a) Do you believe that the more the nutrients you apply to your fields, the better your yields? If yes, Why? If no, why not? b) If yes, would you have any concerns about excess nutrients in your soil? c) Do you think applying fertiliser or slurry based on soil test results can help reduce water pollution? Why? d) Where on the farm do you think there is greatest potential for nutrient loss to surface water? Why? e) Are there any seasons where there is a high risk of run-off? When? Explain how this happens.	In relation to (b), you can ask: What happens to the excess nutrients?
8	a) Do you have a nutrient management plan? If yes, can you explain how your plan was prepared? If No – why not? b) If Yes – how do you use the nutrient management plan? c) Has the use of the plan changed your perception about nutrient loss to surface water? How?	Regarding how the plan was prepared, we are interested in the process, who drew the plan, and whether their application of the plan is or will be affected by who draws it, i.e., themselves or by an advisor, etc. Did they use the AFBI crop nutrient calculator to prepare their NMP, was the calculator helpful, how the process could be improved.
9	From November 2017 to February 2018, DAERA and AFBI offered free soil sampling and testing service to farmers in the Upper Bann. There was a training programme to help farmers interpret soil test results. Did you participate in the training or did you opt to receive training materials instead? If yes, why? If no, why not?	We want to know if they attended the training or received only the materials. Prompts on decision to participate in training: • *Availability of time* • *Time of day when training run (e.g. 4pm would be bad for dairy farmers/part-time farmers working during day)* • *Weather on day – (e.g., might have intended to come but weather was too good to miss 'cutting silage')* • *Trust in advice source/sender/training provider* • *Anxiety about public participation – level of training being too*

			advanced/complex, having to speak
			• *Peer opinion (other farmers say it's good/bad)*
10		a) If your soil test recommendation suggested a ***change to the type of fertiliser you normally apply***, did you change *it*? If yes, what did you apply before? What do you now apply? Why? If you haven't, do you intend to change? b) If your soil test recommendation suggested a change to the ***amount of fertiliser applied, did you do that?*** Do you now use more or less? Why? If you haven't, do you intend to change? c) If your soil test recommendation suggested ***applying Lime to raise the soil pH***, did you do that? Why? If you haven't, do you intend to change? d) Will you require any support to fully implement the recommendations? If yes, what type of support?	For those who'll respond yes, If their explanation to why they changed is "because of the soil test results", please ask if they think there could be any problems when they fail to follow the recommendations. ***This could help us assess their awareness*** (*i.e., revealed awareness*) ***and environmental consciousness.*** For those who'll answer no, please ask why they have not changed or intend not to.
11		Will you carry out further soil sampling, on your own as a result of this soil testing? If yes, Why? If No – why not?	For those who'll answer yes, if they fail to mention reasons spontaneously, please use the following prompts (***for motivations***): • *Increased yield* • *Regulations/government requirements* • *What my neighbours (farmers) think or do* For those who'll answer no, if they fail to mention reasons spontaneously, please use the following prompts (**for barriers**): • *Lack of awareness* • *Time consuming – other work takes priority* *Cost*
Only for Upper Bann interviewees			

12	As part of the soil sampling service in Upper Bann, AFBI provided farmers with maps showing areas most at risk of phosphorus loss to water in surface runoff. a) Did you receive one of those runoff risk maps? If yes, did you fully understand the map? Do you find the map useful? How? Why? b) Have you used the map? If Yes, what for? If no – do you intend to use it? If no why not? c) Do you think your knowledge of the maps has improved after using them over time? d) Has the use of the map changed your perception about phosphorus loss to surface water? How? Has this influenced how you apply slurry/manure/fertiliser? How? e) If you don't use the map now, would you use it if surrounding farmers were using it? If yes Why?	If they haven't used the map or don't intend to – explore whether this is because of: • *Don't know how to interpret/use it?* • *Need support to use it – advice or financial*
13	Is there anything else you would like to tell me about what we discussed today?	

Thank you very much for your time!!!

Skipping codes/questions
Are you aware of Welsh Water's weed wiper trial? Did you participate in the trial?

Interview: Farmers who participated in the weed wiper trial

1. Please explain briefly how do you manage weeds on the farm?
2. If you use pesticides to control pests, how do you use them? What practices do you use? Do you often follow these same practices every year? When do you apply them? What type of pesticides do you use?
3. Have you always applied pesticide in this manner? Why? Or have you changed your practices over time?
4. There are reports that link pesticide use with a decline in water quality: do you believe this? Why?
5. Do you think your usage of pesticides is harmful to the environment? Why?
6. Thinking now about Welsh Water's weed wiper trial? Please are you able to describe it briefly for me? a) Describe what it consists of, b) whether and how it worked.
7. Have you changed any practices regarding your pesticide usage following the trial? Do you think you would have changed practices anyway even if you didn't participate in the trial? Why?
8. Would you say that your participation in the weed wiper trial has helped you improve your pesticide use? How?
9. Is there anything about the weed wiper trial that you believe was particularly useful in improving your understanding of best pesticide management? (e.g., how the messages were delivered, the amount of information that you received, how this information was portrayed)
10. Do you think the weed wiper is a good approach to pest management? Would you recommend it to your neighbours?
11. What might prevent/drive you (not) to use it in the future?

Catchment			
Farm type Arable [1]	Livestock [2]	Mixed farming [3]	Horticulture [4]
Which of the following best describes your status?			
Tenant Farmer [1] [3]	Owner Occupier [2]		Associate (a partner)
Farm size in acres (all sites together).	< 50 Acres [1]		>= 50 Acres [2]

Interview: Farmers who did not participate in the weed wiper trial

1. Please explain briefly how do you manage weeds in the farm?
2. If you use pesticides to control weeds, how do you use them?
3. What practices do you use? Do you often follow these same practices every year? When do you apply them? What type of pesticides do you use? Have you always applied pesticide in this manner? Why? Or have you adopted any new practices over time?
4. There are reports saying pesticides affect water quality: do you believe this? Why?
5. Do you think your usage of pesticides is harmful to the environment? Why?
6. Have you changed any practices in your pesticide usage over the past 4 years (since April 2015)? Why?
7. Do you think it would have been good to have participated in the weed wiper trial? Why?
8. Do you think you'd have done things differently if you had participated in the weed wiper trial? Why? What will you do differently?
9. Would you like to use the weed wiper in the future? Why?
10. What might prevent/drive you (not) to use it in the future?

11. Would you recommend the weed wiper to your neighbours? Why?

Catchment			
Farm type Arable [1]	Livestock [2]	Mixed farming [3]	Horticulture [4]
Which of the following best describes your status?			
Tenant Farmer [1] [3]	Owner Occupier [2]		Associate (a partner)
Farm size in acres (all sites together).	< 50 Acres [1]		>= 50 Acres [2]

Interview: (Welsh Water & Farming Connect)

1. Ask them to describe the trial: a) describe what it consists of, b) whether and how it worked c) general impression of it.
2. Can you explain how the wiper trial has improved the following?
   (a) Farmers' understanding of pesticide application
   (b) Pesticide management practices (which specific changes?)
   (c) MCPA concentration
3. Has any farmer reported major changes in pesticide handling and application? Which areas?
4. Show them water quality results and ask them to provide their views on what could explain those results.
5. Were your advice materials distributed among farmers in Teme?

Note: *The interview script for institutions (Welsh Water and Farming Connect) was adapted for interviews with other institutions (based on their roles and involvement in efforts to mitigate DWPA).*