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Transforming the food system: Are farmers ready to take phosphorus stewardship action?

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ABSTRACT

Ensuring global food security while halting ecosystem degradation is arguably one of the most fundamental current challenges. As a key component of fertilisers for which there is no substitute, phosphorus plays a central role in this challenge. Food production systems are critically vulnerable to phosphorus supply disruptions and price spikes, while high phosphorus-inefficiencies drive the greatest global threat to waters through diffuse pollution. Transformation to a more phosphorus sustainable and efficient system inevitably necessitates transition at the farm level, leading to the critical question of whether farmers are ready for such transition. This paper examines the relationship between the farmers' perceived adaptive capacity and farm-level actions that can enable a positive phosphorus transition. We innovatively apply a second-generation psycho-social mobilisation approach to adaptive capacity (based on personal experience, place attachment, competing concerns, household dynamics, and risk attitudes) and establish its relation to an extended framework of phosphorus stewardship action, using Structural Equation Modelling in a UK-wide survey. Our results confirm that the second-generation approach provides a more nuanced approximation to the understanding of farmers' adaptive capacity than traditional (first-generation) approaches (five capitals: human, natural, physical, financial, and social), allowing a more dynamic understanding and a more robust assessment of adaptive capacity. Beyond our specific results for the UK (which demonstrate relatively high levels of farmers' readiness to adapt and promising predisposition to do so, if supported), our research illustrates how this framework can be used to identify priority actions to enhance farmers' uptake of phosphorus stewardship actions more generally.

1. Introduction

Ensuring global food security while halting ecosystem degradation is arguably one of the most fundamental challenges faced by humanity (Campbell et al., 2017; FAO, 2019; Benton et al., 2021). Phosphorus is central to that challenge. It is a critical element in the global food system as a component of fertilisers for which there is no substitute. Its growing demand currently depends on the finite supply of phosphate rock and fertiliser exports, controlled by a handful geo-politically complex countries (Brownlie et al., 2021). This makes regional food production

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systems vulnerable to phosphorus supply disruptions or price spikes (Blackwell et al., 2019), as demonstrated by the four-fold increase of fertiliser prices following the Covid-19 pandemic and Russia's invasion of Ukraine (World Bank, 2022). Food systems are also very phosphorus-inefficient (Van Dijk et al., 2016; Chowdhury and Zhang, 2021). This leads to widespread losses from agriculture to waste streams, resulting in the greatest global threat to inland and coastal waters through diffuse pollution (Carpenter and Bennett, 2011; Grizzetti et al., 2021).

To address these global challenges, transformative action to make phosphorus use more efficient is critical (Springmann et al., 2018; Brownlie et al., 2021). While such transformation needs collaborative action across value chain sectors, scales, catchments and government departments (Cordell et al., 2022; Plag and Jules-Plag, 2019), changes at the farm level will be crucial. This is because farmers are the world's primary end-users of phosphorus. All farmers need access to affordable phosphorus fertilisers, and at the same time, they make fundamental business decisions, often on a daily basis, that determine which phosphorus fertilisers are used, how much, where, and when they are applied, and how their land (and water) is managed. Collectively, these micro-level decisions at the farm level can affect national and global phosphorus security at the macro-level. That is, contributing to soil fertility, agricultural productivity, food security, water quality and farmer livelihoods, among others.

Questions such as: are farmers able to take positive phosphorus action?, what may be stopping them from doing so?, and what factors can be acted upon to enable them to do so?, require urgent answers. This paper explores this space by relating farmers' adaptive capacity to the actions that can enable a positive phosphorus transition. We refer to adaptive capacity as the "ability to both manage and prepare for change through design and implementation of adaptive responses in order to minimise negative outcomes and maximise opportunities" (Brown et al., 2016, p. 1685). In the context of phosphorus, we define it as "the capacity of stakeholders to address phosphorus inefficiencies (and the consequent harmful effects in aquatic systems) and the vulnerability to phosphorus supply (and possible disruption and shortages)" (Lyon et al., 2022, p. 226).

We apply a second-generation psycho-social mobilisation approach to adaptive capacity (Mortreux and Barnett, 2017) and establish its relation to an extended framework of phosphorus stewardship action (Withers et al., 2015), using Structural Equation Modelling (SEM). We focus on perceived adaptive capacity, rather than objective measures of adaptive capacity, due to its pivotal importance. Objective capacity only partly determines whether an actor will take adaptive responses, and perceived capability has been found to account for a greater proportion of variance in adaptive action rather than objective factors such as income, age or homeownership (Grothmann and Reusswig, 2006). Because perceived ability can be very different from objective ability and humans are not always aware of their objective action scope and can over or underestimate their ability to adapt (Elrick-Barr et al., 2017) we discuss our results in light of the implications that perceived capacity can have for actual action.

This research builds on a qualitative study in two catchments in the UK (Lyon et al., 2022). That study exposed the inertia of established practices, and it critically confirmed the pivotal role of farmers in the overall system's transition to a changed phosphorus regime. Here, we introduce a step-change in this understanding through a quantitative adaptive capacity assessment using a national farmers' survey. Although unique in some respects, the UK reflects a widespread global situation of 'chaotic' phosphorus governance with high external supply dependency (Withers et al., 2020), high levels of phosphorus pollution in waters (Environment Agency, 2019a; Lyon et al., 2022) and accumulation in soils (Rothwell et al., 2022). Following departure from the EU, UK agricultural policy finds itself in a transitional period fraught with uncertainty. This uncertainty provides, on the one hand, a credible context to phosphorus supply shocks and disruptions for eliciting farmers' responses, and, on the other hand, an opportunity for questioning current practices.

2. Conceptual basis

2.1. A dynamic understanding of adaptive capacity

Research has traditionally approached generic adaptive capacity through the assessment of 'assets', often conceptualised as the five capitals (natural, physical, financial, social, human) (e.g., Nelson et al., 2010). The underpinning idea is that if one had sufficient assets, one could adapt, and hence that adaptation could be approached via addressing the deficit of such assets. The five capitals conceptualisation is rooted in livelihoods research and has been referred to as a 'first-generation' approach. This approach has been recently criticised for assuming that capacity translates into action (Mortreux and Barnett 2017; Elrick-Barr et al., 2022). Critics argue that there is evidence to believe that adaptation practices arise from more nuanced and relational processes in which "stocks of assets are not the only or the most important explanatory variable" (Mortreux and Barnett, p.13). Using findings from the disaster risk reduction and behavioural science literatures, Mortreux and Barnett outline a 'second-generation' approach. This approach, referred to as psycho-social mobilisation, is thought to better explain how capacity is translated and mobilised into action through factors such as risk attitudes, personal experience, trust in and expectations of authorities, place attachment, competing concerns, and household composition and dynamics (Table 1). These factors reflect enabling capacities (Patterson et al., 2015) and relate to the dynamics and agency for adaptation (Jacobs and Brown, 2014).

Here, we adapt Mortreux and Barnett (2017)'s second-generation approach to farmers' perceived adaptive capacity to phosphorus challenges and explore how it relates to phosphorus stewardship action. We do so by also testing how the five capitals of the first-generation approach interact with the mobilisation factors of the second-generation approach. Results are further discussed in relation to relational aspects that account for transference of capacity among individuals and groups, in what Elrick-Barr et al. (2022) refer to as the 'third generation' approach, which encompasses the dynamic processes across scales by which collective capacity is enhanced or diminished through social interactions enabling (or constraining) transference. We contribute in this way to an evolving understanding of adaptive capacity.

2.2. Phosphorus stewardship action

In an attempt to propose solutions to Europe's high dependency on phosphorus imports and widespread inefficient use in the food system, Withers et al. (2015) conceptualised a stewardship framework based on five key *R* strategies for sustainability: *Re-align* resources, *Reduce* phosphorus losses to water, *Recycle* phosphorus in bio-resources, *Recover* phosphorus in wastes, and *Re-design* phosphorus in the food chain. This framework (Table 2) helps identify a range of integrated innovations to improve phosphorus use efficiency in society. Their combined adoption could maximise the resource and environmental benefits and help deliver a more circular and sustainable use of the resource (Withers, 2019).

Technical measures toward resilient phosphorus management in the 5-Rs framework, however, miss the relationships between stakeholders that permit these other Rs to occur. Earlier qualitative work in phosphorus adaptive capacity (Lyon et al., 2022) revealed the importance of these stakeholder relational aspects, for example, stakeholder cooperation and synergy, and stakeholders' and farmers' shared commitments. Other empirical work in the context of transformative use of phosphorus in food systems indeed has shown how barriers to transition are more related to governance and collaboration aspects rather than technological ones (Macintosh et al., 2019; Martin-Ortega et al., 2022). While the

Table 1
Second-generation factors of adaptive capacity that can mobilise action.

Factors	Description
Personal experience	• Personal experience of risks and hazards is a significant factor shaping individual risk perception, although the nature of that influence is contested. • Some studies demonstrate that previous experience of a hazard increases people's preparations; other research suggests that experience decreases preparations. • It is therefore difficult to conclude what influence previous experience has on adaptation; however, it is clear that in some cases it can impede adaptation. • Personal experiences are more likely to become a barrier to adaptation where the experience was not very intense, where the experience was a number of years in the past, and where the experience was so intense that people felt they had little or no control over the situation. • People's capacity may remain fairly static over time, however their commitment to adaptation might change substantially depending on their changing experiences and interpretations of risks.
Place attachment	• Place attachment describes the emotional ties individuals have to specific places. Time spent living in that place, identification with the broader community, and dependence on natural resources found in that place are several factors seen to influence emotional ties to place. • The economic and social factors that 'root' someone to a particular place are also important. • The adaptation literature has tended to frame place attachment as 'inherently positive'. • The literature has examined risks to communities that are emotionally tied to specific places and the importance that risk is made relevant to people in the places they value rather than being perceived with moral and psychological distance. • Elsewhere the adaptation literature suggests that place attachment may play an important role in motivating people to act. • In contrast, the disaster risk reduction literature demonstrates that attachment can act as a barrier to household preparation for known hazards.
Competing concerns	• The presence of competing concerns can be a major barrier to adaptation. In the psychology literature, people are described to have a limited capacity to worry such that increases in worry about one issue in life will lead to a decrease in worry about other issues. • The literature suggests then that the presence of competing concerns significantly constrains adaptation, even where households may have relatively high adaptive capacity.
Household Composition and Dynamics	• Household composition and dynamics have not been considered as a possible barrier in the adaptation literature, however, there are disaster risk reduction studies suggesting that the dynamics within a household—how decisions are made, and adaptation actions performed or carried out—can to some extent explain household adaptation. • Household composition and dynamics can, in some cases, act as a barrier to adaptation. Differences of opinion within and between households about how to manage known climate risks may constrain adaptation by delaying or preventing important decisions.
Risk attitude	• Risk attitudes consist of the ways in which individuals perceive the probability and severity of risk (risk appraisal), the way in which they perceive their capacity to perform options (self-efficacy), the perceived costs and benefits associated with adapting (adaptation appraisal), and cognitive biases such as wishful thinking, denial, and fatalism (avoidant maladaptation). • Perceptions of risk and self-efficacy play an important role in shaping individuals' engagement with adaptation and disaster risk reduction.
Trust and expectations in authorities	• A lack of trust in authorities has been associated with low levels of household adherence to advice from authorities regarding basic preparations for known hazards. • Conversely, high levels of expectations of institutions and a belief in the capacity and responsibility of authorities to protect properties have been found to result in lower levels of household adaptation.

Source: summarised from Mortreux and Barnett (2017).

Table 2
6-Rs Phosphorus (P) stewardship strategies with examples of actions.

Strategy	Examples of actions
Re-align resources	• Remove non-essential P inputs • Match P inputs to P requirements more closely • Utilise P legacies
Reduce P losses to water	• Optimise P input management • Minimise P loss in runoff and erosion • Deploy strategic land-based P retentions
Recycle P in bio-resources	• Avoid wastage of P in the whole food chain • Improve P utilisation efficiency • Integrate crop and livestock systems
Recover P in wastes	• Recover and reuse P in societies' waste • Produce P fertiliser from phosphate-rock substitutes • Improve manure management and nutrient recycling
Redesign P in the food chain	• Influence dietary choice • Define end-user P requirements • Reduce P requirements
Relationships for alignment of P action	• Enhance stakeholder collaboration • Promote shared visions and goals • Knowledge building and brokerage

Source: expanded from Withers et al. (2015) *and as per* Lyon et al. (2022).

existence of such relationships forms part of actors' adaptive capacity (Patterson et al., 2015), it is key - if we are to place the focus on the mobilisation of such capacity into action (Elrick-Barr et al., 2022) - to test whether farmers are likely to take specific action to develop such relationships. We therefore add a sixth R to the framework, that of *Relationships*, referring then to 6-Rs phosphorus stewardship strategies.

2.3. Testing the relationship between adaptive capacity and phosphorus stewardship action

The hypothesis underpinning this research is that farmers perceived adaptive capacity, as defined by the factors forming the psycho-social mobilisation conceptual framework (Table 1), determines (at least in part) farmers' predisposition to taking phosphorus stewardship action (in relation to the 6-Rs, Table 2) (Fig. 1). The premise is that possession of assets (capitals) does not equate to adaptation action. Nelson et al. (2007) argued that adaptive capacity must be 'activated' through 'triggers' so, to overcome the limitations of the first generation approach, the focus should be on the factors that mobilise capacity such that change is enacted, i.e. on attributes that enable social systems or actors to adapt. The array of evidence collected by (Mortreux and Barnett, 2017) from the disaster risk reduction and behavioural science literatures (Table 1), supports that certain psycho-social factors may act as mobilisers of such capacity for action. Such are the factors that we test in our hypothesis. We still include assets-based elements (five capitals), so that we can explore the interaction between the first and second-generation approaches.

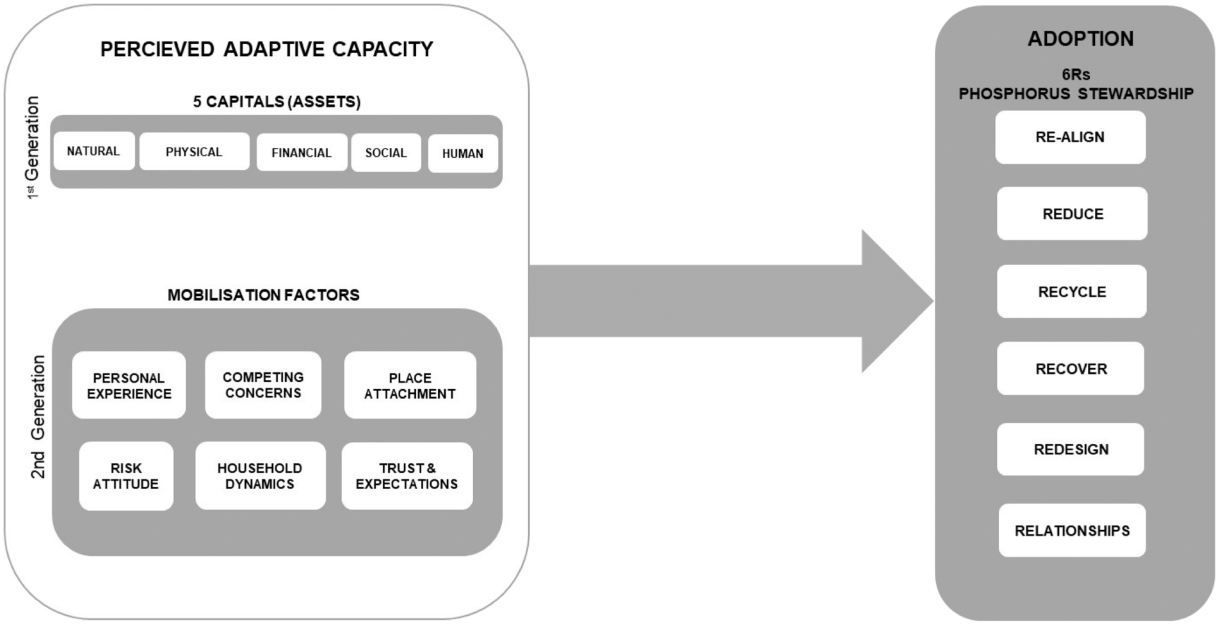

Fig. 1. Tested hypothesis on the relationship between perceived adaptive capacity and adoption of phosphorus action.

3. Methodology

3.1. Case study: phosphorus use and pollution in the UK

As in many developed countries dominated by livestock farming, phosphorus use in the UK is very inefficient. Only 43 % of phosphorus imports end up in usable products, resulting in a large annual agricultural surplus of 89 kilotonnes phosphorus/year, and a high risk of loss to water (Rothwell et al., 2022). Coupled with continuing inputs from wastewater pollution from agriculture, losses continue to be a major cause of water quality failure for rivers and lakes despite some progress in phosphorus mitigation (Environment Agency, 2019a; Whelan et al., 2022). With no phosphate rock reserves of its own, the UK is also heavily dependent on phosphorus in fertiliser imports, with prices (as of July 2022) nearly four-fold the average of the previous five years (AHDB, 2022). The UK National Phosphorus Transformation Strategy clearly highlights the need for action at the farm level (Cordell et al., 2022).

3.2. Survey design

The questionnaire (Supplement 1), starts with a profiling section eliciting farmer and farm characteristics such as farm size, ownership, type of farm activity, share of income dependant on farming, and type of phosphate products used on the farm.

Each of the second-generation factors of adaptive capacity are assessed using responses to a set of Likert scale questions from 1 (completely agree) to 7 (completely disagree; Table 3). These adapt Mortreux and Barnett's (2017) framework for application to phosphorus and farming. For the risk attitude and trust factors,[1] a scenario of change was presented whereby respondents were faced with the possibility of new legislation coming into force introducing a permanent cap to total phosphorus applications on farmland. This hypothetical scenario was 'brought home' to farmers by stating it would be similar to the one that had previously been introduced for nitrogen under the Nitrates Directive in the early 2000s (EU Commission, 1991). For credibility, respondents were informed that this has already been implemented in other countries, like Germany, the Netherlands, and Denmark (Barreau et al., 2018). This was followed by a set of questions assessing the (first--generation) five capitals factors using the context of the hypothesised cap on phosphorus use (Table 3).

The questionnaire also included questions on phosphorus awareness. We checked farmers' knowledge of the relationship between phosphorus use and diffuse pollution, economic and productivity inefficiencies in phosphorus use, and vulnerabilities to the phosphorus supply, also elicited via a Likert scale of agreement/disagreement with a set of statements (Q25 - Q30).

A series of questions on land management practices corresponding to the 6-Rs actions on phosphorus stewardship followed (Table 4). Each of the stewardship strategies was composed of three different actions (Ra, Rb, Rc). The three actions were conceived as being progressively more challenging to adopt by the farmers. That is, we would expect farmers to be able to reasonably adopt the first action in each of the Rs, with the other two actions representing step-change challenges (i.e., Ra<Rb<Rc in terms of challenge to adopt). As explained in Section 2.2., *Relationships* refers to whether farmers are likely to take specific action to develop relationships that are thought to support a transition to more sustainable and efficient phosphorus use (with the aspects of relationships that form part of *existing* capacity being captured previously in the social capital of the first-generation framework, as per Table 3).

It was important to distinguish between current adoption and likelihood of adoption, and to identify the farmers who are already taking action.[2] Current adoption was scored as a binary variable ("I currently apply" =1, other = 0). Likelihood of adoption was indicated on a scale from 1 ("I am not likely to apply in the future") to 4 ("I am very likely to apply in the future"). Acknowledging the key effect that financial constraints can place on adoption of best management practices generally (Pe'er et al., 2020; Tyllianakis and Martin-Ortega, 2021) and phosphorus stewardship specifically (Lyon et al., 2022), we asked whether respondents would change their answer on likelihood of adoption if financial aid was available. Farmers (and their representatives)

[1] Note that in Mortreux and Barret (2017)'s the trust and expectations factors relate to 'authorities', here we expand also to other institutions, such as advisory services and farmers' representative organisations in recognition of relational dimensions of adaptive capacity important for transference of capacity.

[2] while also allowing for "non-applicable" answers since some of the actions only apply to livestock or arable farming.

Table 3
Adaptive capacity questionnaire questions. See supplement 1 for the full questionnaire.

Factor	Questionnaire question	Label in SEM*
Second-generation Adaptive Capacity factors		
Personal experience	Q13 Were you affected by the capping of the nitrogen applications brought by the EU Nitrogen Vulnerable Zones regulations in 2000?	Pers Exp1
	Q14 Have you been affected in the past by other environmental regulations that made significant changes to your farming practices? (for example, regulations related to sensitive habitats, ammonia emissions, pesticide management, water pollution, soil quality, climate change)	Pers Exp2
	Q15 Have you been affected in the past by any other disruption that made significant changes to your farming practices? For example, related to Brexit, Covid−19, the 2008 price hike in phosphate fertilisers, foot and mouth diseases, BSE, market collapse, etc.	Pers Exp3
	How much do you agree / disagree with the following statements:	
Place attachment	Q16 I have a strong emotional connection to the land where my farm holding is	Place Att1
	Q17 Where my farm holding is, is part of who I am as a person	Place Att2
	Q18 I see the land where my farm holding is as part of the heritage/legacy I will leave to my children and their children (regardless of whether they continue farming after me)	Place Att3
Competing concerns	Q19 How worried are you about the uncertainties that Brexit can bring to the future of your farming activity?	Comp Con1
	Q20 How worried are you about declining farm productivity/bad crops in the future for reasons outside your control (for example, climate change, diseases, etc.)	Comp Con2
	Q21 How worried are you about declining prices of farm produce	Comp Con3
Household Dynamics	Q22 How much do you agree or disagree with the following statements: We (my family or partners) all tend to agree on most decisions regarding the management of the land holding	House Dyn1
	Q23 Me (my family or partners) we all share a common vision on what the future holds	House Dyn2
	Q24 Me (my family or partners) we all take relevant decisions together	House Dyn3
Risk Attitudes	Q44 How concerned are you about the possibility that such permanent cap could come into force?	Risk1
	Q45 If there was a permanent cap to phosphate applications in farmland, how likely is it that it would negatively affect your own farming activity?	Risk2
	Q46 How severe do you think this would be for your own farming activity?	Risk3
Trust and expectations	Q47 If there was a permanent cap to total phosphate applications to farmland: I trust the government to set up appropriate means for me to adapt to it	Trust1
	Q48 I trust my advisory services or levy boards to provide effective advice on how to adapt to it	Trust2
	Q49 I trust I can count on the help of the Farmers Union or similar associations to help me adapt to it	Trust3
First-generation adaptive capacity (five capitals)		
	How much do you agree or disagree with the following statements: If there was a permanent cap to total phosphate applications to farmland,	
Financial capital	Q50 My current financial situation would allow me to adapt	Financial
Social capital	Q51 My support networks (family, other farmers, advisors) would help me to adapt	Social
Natural capital	Q52 The natural soil fertility on my farm holding would allow me to adapt	Natural
Human capital	Q53 I have access to information/knowledge/expertise to help me adapt	Human
Physical capital	Q54 I would be able to access technology to allow me to adapt to it	Physical

* These labels become relevant for reading SEM figures in Section 4.3.

Table 4
Phosphorus (P) stewardship questions.

P Strategy	Questionnaire question	Label in SEM
Re-align Q31–32	Adopt a farm nutrient management plan including regular soil/crop/feed/manure analysis	R1a
	Adopt precision farming technologies, including GPS soil nutrient mapping, variable rate application and precision placement (e.g., manure injection, combine drilling)	R1b
	Meet a phosphate use efficiency target for the farm (producing more with less)	R1c
Reduce Q33–34	Reduce stock numbers in areas of your farm vulnerable to phosphate loss based on run off risk maps	R2a
	Adopt targeted nature-based solutions to reduce run off and erosion (e.g., cover crops, riparian buffer strips, wetlands, woodland)	R2b
	Meet a farm gate phosphate surplus target of zero	R2c
Recycle Q35–36	Replace chemical fertiliser with livestock manure or alternative (secondary) sources of phosphate (e.g., biosolids, AD, compost)	R3a
	Produce more feed on livestock farms and rely less on imported grains	R3b
	Diversify cropping patterns, use green manures and adopt intercropping practices	R3c
Recover Q37–38	Adopt manure separation technologies to aid transportability of manures	R4a
	Join co-operative, centralised manure management and nutrient recovery plants to deal with localised excess manure	R4b
	Use on farm technologies to remove and recover phosphate from drain/yard runoff water	R4c
Redesign Q39–40	Adopt mixed farming (e.g., introduce livestock system to arable farms)	R5a
	Adopt low input farming and agro-ecological principles	R5b
	Take land out of production and/or reduce livestock numbers	R5c
Relationships Q41–42	Join farmer discussion groups and networks to achieve common land management and environmental goals	R6a
	Work more closely with extension services (e.g., farm advisors)	R6b
	Work more closely with relevant bodies (e.g., government agencies, environmental organisations, catchment partnerships)	R6c

routinely cite financial constraints and need for financial support as a limiting factor to change (Prager and Posthumus, 2010; Tyllianakis et al., 2023). Furthermore, historically, when it relates to addressing a systemic complex environmental problem, interventions in agriculture overwhelmingly take the form of financial incentives even when there is variation in the governance structure (Wiering et al., 2023). It is therefore appropriate to test specifically the impact of this specific intervention, because (a) farmers can draw on their previous experience of engaging with subsidies instead of a purely hypothetical intervention, and (b) there is a very good chance this will be the first and dominant tool policymakers will deploy.

The response scales of all items above were coded such that higher scores reflect greater agreement (e.g., with adaptive capacity factor), and greater likelihood of adoption (of phosphorus stewardship actions).

A final set of questions asked for respondents' socio-demographic characteristics.

3.3. Survey implementation and data

Survey dissemination took place online. Responses were procured through two means: a whole UK sample from the online survey panel provider Qualtrics and dissemination via farmer networks available to the authors across the UK. Qualtrics applies several quality control measures to ensure validity and consistency of responses through incentivising participation while offering compensation only if responses are considered to be of suitable quality. Additional quality control measures regarding time of completion of surveys and geolocation of respondents were also employed.[3] Data collection took place from end of 2021 to beginning of 2022. Final sample included 251 farmers.

Table 5 presents key summary statistics of our sample. The sample spreads across the four regions of the UK, with Scotland and Wales somewhat less represented. It is composed of slightly younger, more educated participants than the official statistics for the farming population. This is common in online surveys (Olsen, 2009; Windle and Rolfe, 2011), and also because official statistics often report on the registered owner, who tends to be the eldest generation involved with the farm, while relatively (younger) family members may actively manage the land, and, therefore, are relevant to this research. Female respondents are over-represented, which aligns with research indicating female members of farm households often take on administrative tasks (Kallioniemi and Kymäläinen, 2012) such as survey participation. Average farm size is larger in our sample than the average in the UK, and the sample is also over-represented for dairy and mixed farms.

Sampling farmers is notoriously difficult (Polain et al., 2011), and overall this sample is considered to be reasonably representative in the context of the farm surveying literature in the UK (e.g. Daxini et al., 2018; May et al., 2021). In any case, implications of sample characteristics on the results are discussed where relevant.

Table 5
Sample's summary statistics and comparison with UK's farming population.

Characteristics	Sample	UK farming population
England	79 %	61 %
Scotland	5 %	14 %
Wales	6 %	12 %
Northern Ireland	11 %	13 %
Average in years	*41(st.dev=12)*	59*
Average gross farm income in £/year	*£46,293 (st.dev=24,548)*	£51,900*
Average hectares	*246.8 (st.dev=1709)*	159.9 (Total Utilised Agricultural Area)*
Gender	*Male= 67 %*	Male = 85 %*
Education	No formal qualifications = 4 % Secondary school = 20 % Vocational/professional agricultural education = 24 % College education = 51 %	n.d. Vocational/professional agricultural education = 17 %** College education = 45 %**
Farm type (% number of farms)	Arable = 11 % Dairy = 22 % Lowland livestock = 16 % Upland livestock = 8 % Mixed (arable and livestock) =28 % Other = 7 %	Arable = 28 %* Dairy = 6 %* Lowland livestock = 21 %* Upland livestock = 33 %* Mixed (arable and livestock) =8 %* Other = 5 %*
Full time employment	49 %	41 %*
Owner	80 %	86 %*

Sources:* Defra (2020); ** Eurostat, 2020; Defra, (2021)c.

3.4. Analysis

Principal components analyses (PCA) were conducted to verify that the adaptive capacity items gathered in the questionnaire (Table 3) inter-correlated as expected to form the six second-generation factors and constitute robust metrics of the psycho-social mobilisation framework (Table 1). Next, we tested whether the means of each of the six adaptive capacity second-generation factors were significantly higher than the mid-point of the seven-point scales (i.e., higher than 4) using one-sample t-tests. This allowed us to establish average levels of farmer's perceived adaptive capacity for each factor. The five capitals items (second half of Table 3) were tested using the same approach, to check that we could compute a first-generation composite score (in a PCA) and whether this score was significantly higher than the mid-point of the scale (in a one-sample t-test).

PCA was also used to verify the validity of the 6-Rs phosphorus stewardship items (Table 2). These, combined with descriptive statistics (frequencies), allowed us to establish the current levels of adoption and likelihood of future adoption of the phosphorus stewardship actions and whether this changed in the presence of subsidies.

Structural Equation Modelling (SEM) was then used to examine the extent to which adaptive capacity components accounted for the likelihood of adopting phosphorus stewardship actions. SEM is an established method to understand attitudes and behavioural intentions in the context of applied social and environmental psychological studies (Schulz et al., 2019), allowing the analysis of complex relationships between latent constructs such as adaptive capacity. SEM typically combines path analysis (to test hypothesised relationships between variables) and confirmatory factor analysis (to measure latent variables using several observed indicators). SEM has been applied in other studies of adaptive capacity (e.g., Le Dang et al., 2014; Bui Phong et al., 2020; Lockwood et al., 2015; Mercado, 2016; Luu et al., 2019; Dressel et al., 2020) but, to our knowledge, this is the first study to use a second-generation approach and to focus on explaining phosphorus stewardship action. In our study, the hypothesised relationship is that a farmer's level of adaptive capacity predicts, in part, whether they will likely take phosphorus stewardship action. Presence of higher levels of the psycho-social mobilisation factors for adaptive capacity are expected to be linked with higher predisposition to phosphorus action.

4. Results

4.1. Farmers' perceived adaptive capacity

The PCA confirmed all expected second-generation adaptive capacity factors: personal experience (Cronbach's $\alpha = 0.82$), place attachment ($\alpha = 0.79$), competing concerns ($\alpha = 0.79$), household dynamics ($\alpha = 0.78$), risk attitude ($\alpha = 0.78$), and trust ($\alpha = 0.75$) (see Table S1 in Supplement 2 for the PCA diagram and further information).

The one-sample *t*-tests showed that participants display on average relatively high scores on each of the adaptive capacity components (with respect to the mid-point 4): personal experience with similar risks and hazards (*Mean (M)* = 4.81; *Standard Deviation* (*SD*) = 1.47), place attachment ($M = 6.01$, $SD = 0.98$), competing concerns ($M = 5.33$, $SD = 1.09$), collective decision-making in the household dynamics ($M = 5.74$, $SD = 0.91$), risk attitudes ($M = 5.24$, $SD = 1.04$), and levels of trust ($M = 5.15$, $SD = 1.16$). All one-sample t-tests were significant at $p < 0.001$.

An additional PCA showed that the five first-generation adaptive capacity items loaded onto one factor, allowing us to compute a first-generation composite score ($\alpha = 0.87$; see Table S2 in Supplement 2). Again, respondents scored on average significantly higher than the mid-

[3] This included identifying as 'speeders' as those taking below the quarter of the median completion time, and ensuring responses came from within the UK.

point of the composite first-generation scale ($M = 5.17$, $SD = 1.10$; $p < 0.001$).

4.2. *Phosphorus awareness, current action and likelihood of adoption of phosphorus stewardship*

A PCA with varimax rotation of awareness items allowed us to consider a 'phosphorus awareness' factor (see Table S3 in Supplement 2). One sample *t*-tests showed relative high scores for awareness measured in this way ($M = 5.58$, $SD = 0.93$; $p < 0.001$). This shows farmers' relatively high levels of awareness about phosphorus use and diffuse pollution, economic and productivity inefficiencies in phosphorus use, and vulnerabilities to the phosphorus supply.

Slightly more than half of respondents indicated they apply at least some 6-Rspractices (Table 4S in Supplement 2). As explained, the actions within each of the R strategies were assumed to be progressively more challenging for the farmers to adopt. We do observe that there is a higher level of current adoption for the first action for each of the Rs (R1a, R2a, etc.) relative to the second and third actions (see Figure S1 in the Supplement 2). However, we do not observe a similar 'drop' in the likelihood of adoption items (Figure S2 in the Supplement 2).

Regarding likelihood of adoption, six PCAs confirmed the expected *Realign* (Cronbach's $\alpha = 0.73$), *Reduce* ($\alpha = 0.73$), *Recycle* ($\alpha = 0.78$), *Recover* ($\alpha = 0.82$), *Redesign* ($\alpha = 0.79$), and *Relationships* ($\alpha = 0.81$) factors, with acceptable to good internal consistencies. The likelihood of adoption items hence reliably measure the expected factors, allowing us to compute composite scores to use in the SEM.

We also examined how many respondents indicated that they would or would not change their answer to likelihood of adoption if financial aid was provided (Table S5 in Supplement 2). As expected, likelihood of adoption increases dramatically upon the offer of financial support, but it is still interesting to see non-negligible percentages of respondents who would not change their answers (over 10 % in each case, with *Redesign* being high at 27 %).

4.3. *Effects of adaptive capacity in stewardship action*

Table 6 shows how all six components of the second-generation perceived adaptive capacity framework generally correlate positively with all of the 6-Rs strategies – i.e., likelihood of adoption of phosphorus stewardship action is associated with all components of psycho-social mobilisation. The positive signs indicate that higher engagement with the component is linked with a higher likelihood of adoption. That is, higher levels of previous self-reported personal experience, competing concerns, collective decision-making in household dynamics, risk attitudes and trust, are associated with higher likelihood of adoption. Only place attachment displays non-significant correlation with three of the types of strategies (i.e., *Recycle, Reduce, Recover*), but it does positively correlate with the other types of strategies.

The first-generation adaptive capacity factor (composite of all five capitals) is also correlated with all phosphate stewardship strategies, reinforcing the finding that presence of these assets is indeed associated with predisposition to stewardship action. Most correlations point in the same direction and show comparable strengths in their association with likelihood of adoption, suggesting that the adaptive capacity components together have a shared role in explaining likelihood of adoption.

To disentangle the contribution of the adaptive capacity components, we next present two SEMs that can filter out the shared variance among the adaptive capacity factors and examine their unique role in predicting likelihood of adoption of the 6-Rs strategies. We first tested a model in which the first-generation composite factor was included (Fig. 2). This factor came up non-significant (p=0.814), meaning that the first-generation factor does not explain any variance *beyond* the second-generation adaptive capacity factors. While it should be noted that the first-generation factor on its own does relate to stewardship action (as shown in Table 6), its explanatory power is embedded in the second-generation factors. We next re-ran the analysis without the first-generation composite factor in order to better disentangle the contribution of the second-generation factors, leading to the second SEM model shown in Fig. 3. This model shows that the likelihood of adopting phosphorus stewardship actions is uniquely predicted by higher personal experience (p=.011), more collective decision-making in the household dynamics (p=.006), higher levels of trust (p<.001), and lower place attachment (p=.045). It is to be noted that while place attachment showed positive or non-significant correlation to likelihood of action (Table 6), the SEM model (Fig. 2) indicates that, when controlling for the rest of the factors, the contribution of place attachment to likelihood of adoption is negative ($\beta = -0.30$). The risk attitude (p=.061) and competing demands (p=.681) factors did not significantly contribute to the prediction of stewardship action.

5. Discussion

5.1. *A dynamic understanding of adaptive capacity*

Our analysis allowed interrelations among attributes of adaptive capacity and potential responses to the phosphorus challenge by farmers to be explored. Results indicate that, consistent with critiques of asset deficit (first-generation) approaches (e.g., Elrick-Barr et al., 2022), the second-generation approach provides a more nuanced conceptual approximation through which transitions by farmers to sustainable phosphorus management can be understood. In our analysis, while the five capitals remain embedded as a foundation (Fig. 2), the attributes associated with a second-generation approach, i.e., personal experience, place attachment, competing concerns, household dynamics, and risk attitude, provide a robust framework for capacity assessment. Adopting this framework, we established that our study participants display, on average, relatively high levels for each of the psycho-social mobilisation factors.

5.2. *Phosphorus stewardship action*

Regarding phosphorus stewardship action, our results indicate that UK farmers generally display predisposition (intention) for the adoption of phosphorus stewardship action. The most frequent responses related to a stated high likelihood of adoption for the various Rs, with only *Reduce* and *Redesign* strategies showing a more nuanced picture, but still representing clear inclination for adoption. As expected, likelihood of adoption increased with the offer of financial support. However, at least 10 % of respondents indicated that they would not adopt more sustainable practices across the Rs (up to 27 % for *Redesign*), despite financial support being offered. This 'resistance' to change indicates some strongly anchored practices, due to individual attitudes and structural inertia. For example, participants in the Lyon et al. study (2022, p.230) raised concerns that some farmers are "too wedded" to established practices (e.g., fertiliser-intensive farming methods) to change. This is especially the case if adoption of actions is perceived to alter their farming system fundamentally, such as adopting different types of farming (Martin-Ortega et al., 2022). Here, the *Reduce* and *Redesign* categories include reducing animal numbers, a switch to arable from livestock, or taking land out of production which can indeed represent major alterations of the farming system at the individual level (and is possibly also feared as un-economical, Franks, 2022). In fact, the *Redesign* actions may be seen as transformational (rather than incremental) change (Rickards and Howden, 2012; Bene et al., 2018). Despite this selective resistance, the overall picture is promising in terms of willingness to adopt phosphorus action in the sampled population. This is in agreement with observations that experimentation with some stewardship practices is already occurring in some catchments in the UK (Withers et al., 2015; Cordell et al., 2022, Lyon et al., 2022).

Table 6
Zero-order correlations between adaptive capacity factors and likelihood of adoption of the 6-Rs strategies.

AC factors	Realign	Reduce	Recycle	Recover	Redesign	Relationships
Personal experience	0.38***	0.33***	0.28***	0.30***	0.30***	0.17*
Place attachment	0.28***	0.15*	0.11	0.10	0.02	0.19**
Competing demands	0.32***	0.27***	0.25***	0.22**	0.15*	0.27***
Household dynamics	0.33***	0.31***	0.21**	0.23***	0.18*	0.22**
Risk attitude	0.37***	0.29***	0.28***	0.28***	0.19**	0.27***
Trust	0.38***	0.35***	0.20**	0.39***	0.41***	0.29***
First-generation adaptive capacity (five capitals)	0.35***	0.40***	0.25***	0.39***	0.41***	0.25***

Note: * significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.

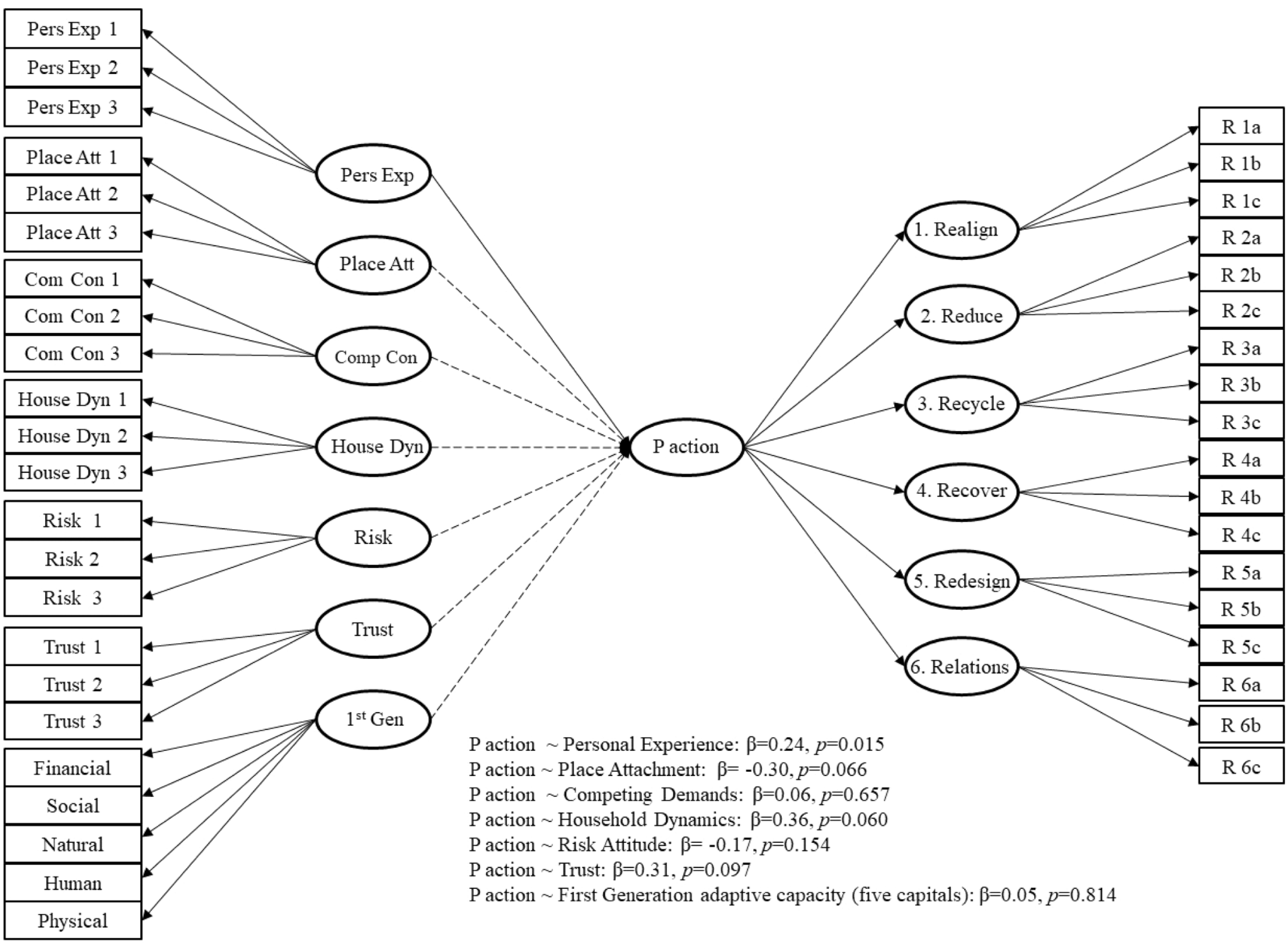

Fig. 2. Structural model of adaptive capacity for phosphorus stewardship action, including first-generation adaptive capacity factor Labels on the left correspond to each of the questions conforming each of the adaptive capacity factors as per Table 3 (i.e. personal experience, place attachment, etc.). Labels on the right correspond to actions under each of the phosphorus stewardship action as per Table 4. Dashed lines represent non-significant relationships.

5.3. *The relationship between perceived adaptive capacity and phosphorus stewardship action*

SEM allowed us to identify which of the socio-mobilisation factors significantly affected likelihood of stewardship actions and can be used to inform efforts to promote them. Those factors are: personal experience, place attachment, household dynamics, and trust (Fig. 3). Our results suggest that previous experience of hazards can trigger phosphorus adaptation in line with some of the adaptation literature (Mortreux and Barnett, 2017; Thompson and Dezzani, 2021). This can be related to the precedent of the 2008 phosphorus fertiliser price spike, when global fertiliser prices rose by 800 % (Spears et al., 2022). In response, UK farmers coped by reducing application of phosphorus fertiliser that year (Defra, 2021). Using reference to those past experiences in communicating to farmers the need for changing phosphorus practices would therefore be useful in stimulating action, although it should be noted that it matters whether personal experience is direct or indirect (Wachinger et al., 2013). Direct experiences are more likely to drive farmers towards adaptive action (Hamilton-Webb et al., 2017) and have a stronger effect on risk belief than indirect experiences (Viscusi and Zeckhauser, 2015). It is therefore important to combine reference to those past experiences with a focus on current and future threats; for example, highlighting the impacts on fertiliser price and/or availability following the Russian invasion of Ukraine (World Bank, 2022).

Regarding place attachment, while it shows either positive or non-significant correlations with most of the 6-R strategies (Table 6), it

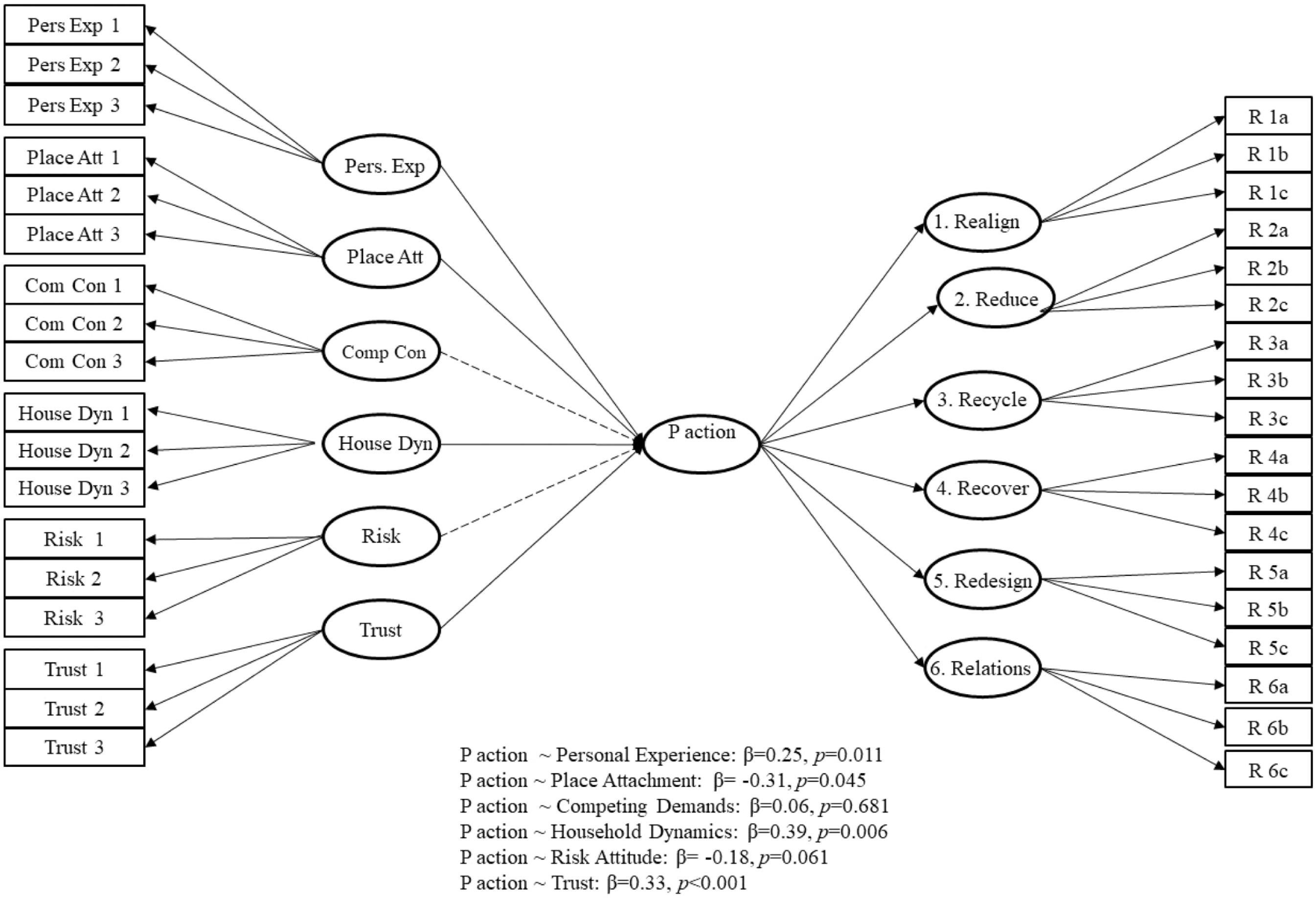

Fig. 3. Structural model of adaptive capacity for P stewardship action, without first-generation adaptive capacity factor. Labels on the left correspond to each of the questions conforming each of the adaptive capacity factors as per Table 3 (i.e. personal experience, place attachment, etc.). Labels on the right correspond to actions under each of the phosphorus stewardship action as per Table 4. Dashed lines represent non-significant relationships.

appears as a negative predictor in the SEM model when the other components are considered (Fig. 3). The adaptation literature suggests that place attachment may play an important role in motivating people to act, while the disaster risk reduction literature demonstrates that attachment can act as a barrier to household preparation (Mortreux and Barnett, 2017). Our results are therefore in agreement with the latter, where we report a negative effect of place attachment on phosphorus stewardship action. It is important to contextualise this finding with respect to how place attachment was addressed here. Our questions on place attachment related to the connection between the respondent and the farm holding specifically, and not generically to the area or its environment (or 'natural attachment' as conceived in e.g., Wang et al. 2021). In our context, many farmers have the attitude that the land is there to be farmed (they will keep farming even if only breaking even, according to Lyon et al., 2022). Farmers' attachment to their holding may be therefore associated with tradition, for example, in farming practices conducted by their ancestors. That is, their attachment to their farm results from it being the place where their 'farm identity' has been formed. This historical context is important as it may prevent changes in practices. Overcoming such barriers, requires a paradigmatic cultural shift amongst the farming community, promoting a change in their self-identification from 'just' food producers to environmental stewards, as it has been suggested, for example, regarding adoption of nature-based solutions (Bark et al., 2021).

Differences of opinion within households about how to manage risks may constrain adaptation by delaying or preventing important decisions (Mortreux and Barnett, 2017). Our respondents reported high levels of collaborative household decision making, and this is confirmed to positively predict phosphorus stewardship action (i.e. household dynamics is significant and positive in the SEM, Fig. 3). Similarly, our participants displayed relatively high levels of trust (in the government, advisory services and farmers unions) in that they would be supported in the adoption of phosphorus actions, which translates into a positive effect on the likelihood of adoption (Pannell and Vanclay, 2011). While the high levels of expectations and belief in the capacity and responsibility of authorities for protection have been found to result in lower levels of household adaptation (Wachinger et al., 2013), here we framed trust as 'being assisted' rather than as delegation of the action. Promoting a supportive farming environment by building that trust through those various strands (government, advisory services, and farmers' union) should pay off in terms of further phosphorus action.

The fact that competing concerns did not relate significantly to phosphorus action could be related to the "finite pool of worry" hypothesis (Weber, 2015), by which concerns diminish as other worries rise in prominence. Our survey took place during the Covid-19 pandemic, and unlike e.g. climate change (Evensen et al., 2021), it is unlikely that phosphorus vulnerabilities have become a "member" of people's "pool of worry" (ibid. p2). This could also explain the non-significant effect of risk attitudes in the SEM (Fig. 3), i.e. the phosphorus risk is possibly not perceived subjectively as high enough to trigger action. This align with other (qualitative) findings regarding phosphorus risk perception in the UK (Lyon et al., 2022).

Lyon et al. (2020) proposed the addition of *Relationships* to the original five Rs framework (Withers et al., 2015) to incorporate the need for enhanced social capital in support of knowledge exchange among farmers and institutions during the transition to improved phosphorus sustainability. Our study also suggests that its inclusion as a sixth R was useful in explaining the association between elements of adaptive capacity and action on phosphorus management (i.e. the sixth R showed a similar pattern of correlations with the components of the second-generation adaptive capacity as the other five Rs (see Table 6), suggesting it fits neatly with the other five and supporting the idea that relationships are an integral part of phosphorus action). Landscape-scale improvements in phosphorus sustainability that move beyond practice change on individual farms require social learning and collective action among stakeholders (e.g., Cordell et al., 2022; Okumah et al., 2020; Mills et al., 2011). Grothmann and Patt (2005) argued that adaptation to climate change by private actors (like farmers or homeowners) is not the same as adaptation to the global, long-term phenomenon of climate change but is rather adaptation related to regional and short-term impacts of climate change. This contrast between local-regional scale change and national transformation relates to phosphorus as well. The first requires vertical and horizontal links to support local adaptation by individual or small groups of farmers (e.g. catchment based) and the latter requires broad-scale systemic change (beyond the scope of the individual). System transformation at the national scale requires collective action and knowledge sharing among the population of farmers and other institutions (gathered in our sixth R) to transfer capacity system-wide. This is another argument in support of more dynamic understandings of adaptive capacity, centred on the transference of capacity among individuals and groups to facilitate building capacity across scales for systemic transformation (Elrick-Barr et al., 2022).

It is also important to consider the implications of having analysed perceived adaptive capacity rather than objective measures, such as income, age or homeownership. Perceived ability can be very different from objective ability (Grothmann and Reusswig, 2006)[4] and humans are not always aware of their objective action scope and can over or underestimate their ability to adapt (Elrick-Barr et al., 2017). Our results show relatively high levels of perceived adaptive capacity and self-reported likelihood of action. While this can be seen in principle as promising, it has been shown (Elrick-Barr et al., 2017) that a dominant narrative of capability (i.e. actors believing they have the capacity to adapt) might actually prevent investment in adaptive action. Simply because our sampled farmers report relatively high levels of adaptive capacity, it does not mean that they will act un-aided or un-prompted. Similarly, the fact that farmers display relatively high levels of awareness of phosphorus issues does not mean that is sufficient for them to act if these issues are not seen as a sufficient personal threat to function as precursors of adaptation action (Pelling, 2010).[5] Activating farmers' adaptive capacity to address phosphorus vulnerability requires subjective risk appraisal (perceived probability and severity), subjective adaptation appraisal (perceived efficacy of action, perceived self-efficacy and perceived costs of action) and objective availability of resources (such as time, money, entitlements and institutional support) (Grothmann and Patt, 2005). With respect to diffuse pollution and productivity inefficiencies derived from excessive fertilizer use, existing literature shows that awareness is not sufficient to promote adoption of best land management practices if it is not part of a process of experiential learning (Okumah et al., 2020). With respect to fertiliser supply disruption, previous research also shows how farmers in the UK are largely unconcerned (Lyon et al., 2022), i.e. while they might be aware of these problems they do not necessarily see them as a significant personal challenge. This means, while relatively high levels of awareness, adaptive capacity and reported likelihood to take action lay a positive foundation, it would be a mistake to rely solely on this for a transition of the farming community to sustainable phosphorus use.

5.4. Study limitations

While relatively small samples like ours are not unusual in SEM studies (Bunkus et al., 2020, Lockwood et al., 2015), we were not able to conduct deeper analysis of some elements. These include assessing the moderating effects of factors known to affect farmers' behaviours with respect to best land management practices (e.g., farm size and type and socio-demographic characteristics (Okumah et al., 2018, 2020)), or making a comparative analysis between models of perceived adaptive capacity versus models of objective (socio-demographic) measures. Similarly, differentiation of results across different geographies is limited, and so the extent to which adaptive capacity varies across geographies or populations (Thomalla et al., 2006) is not explored here. Another limitation is related to sample composition: larger farms, particularly dairy farms (slightly overrepresented in our sample) may have a higher annual phosphorus input compared to smaller beef/sheep farms and therefore may be more able/likely to adapt. This may skew results in a positive way, leading to overestimation of the likelihood of adoption for some of the proposed actions. Actions associated with *Redesign*, in particular, could be hardest for smaller beef/sheep farms (Franks, 2022). Finally, as with any quantitative research, our results are shaped by the standardisation of what are, in effect, complex multi-dimensional concepts, such are trust, risk attitude, place attachment, etc. These needed to be narrowly set in the survey questions, which limits the interpretation of the construct by survey respondents and necessarily mediates the interpretation of the results. Further qualitative research into the complexity of such constructs and their effects on adaptive capacity should be welcomed.

Despite these limitations, the study provides valuable insights. While it is generally understood that all key stakeholders in the phosphorus value chain need to play a role in transforming a country's food system (Cordell et al., 2022; Macintosh et al., 2019, Jacobs et al., 2017), there is often an erroneous perception that farmers are largely to blame for poor phosphorus management rather than being 'locked-in' to unsustainable practices through path dependency and institutional arrangements (Iles, 2021). This study demonstrates in a far more nuanced way, how farmers can be (and in some cases are) motivated to adapt or are hindered from doing so. This understanding goes beyond the financial barriers facing farmers as price-takers and business-owners operating with small margins, and involves other barriers (such as the traditional farm identity as 'just' food producers) and enablers (such as tapping into past experiences, supporting collaborative household dynamics in decision-making and building trust in other actors).

6. Conclusions

As a key component of fertilizers for which there is no substitute, phosphorus is central to the fundamental challenge of ensuring global food security while halting ecosystem degradation and biodiversity loss. Regional food production systems are critically vulnerable to phosphorus supply disruptions and price spikes, while high phosphorus-inefficiencies drive the greatest global threat to inland and coastal waters through diffuse pollution. Transformation to a more phosphorus sustainable and efficient system inevitably necessitates transition at the farm level, leading to the critical question of whether farmers are ready to undertake the necessary changes. This paper has addressed this question by examining the relationship between the farmers' perceived adaptive capacity and farm level actions that can enable a positive phosphorus transition, using a national UK survey.

Our results confirm that the second-generation approach provides a more nuanced approximation to the understanding of the capacity of farmers. While the first-generation (five capitals) remain embedded as a

[4] We indeed find weak to non-significant correlation between perceived adaptive capacity and the sample's socio-demographic characteristics (Table S6 in Supplement 2).

[5] We tested whether the awareness factor acts as a mediating factor in the relationship between adaptive capacity and action in the SEM and found non-significant results, i.e. those more aware of such specific phosphorus issues are not more likely to take the stewardship actions.

foundation, these stocks of assets are not the only, or most important, explanatory variable to explain action. The psycho-social mobilisation factors (personal experience, place attachment, competing concerns, household dynamics, and risk attitudes), represent a more dynamic understanding of adaptive capacity, and our research has shown how it can be robustly measured and related to predisposition to positive phosphorus stewardship action. Additionally, our research also shows how the transfer of capacity from individuals to the system through relationships will likely prove essential for national scale transformation in phosphorus sustainability.

According to our survey, UK farmers seem to have relatively high levels of perceived adaptive capacity. While this might be seen as promising, it actually provides further arguments for explicitly supporting farmers in taking phosphorus stewardship action, to avoid a dominant narrative of capability preventing them from investing, particularly while phosphorus issues are not seen by farmers as a direct threat. This will not be simply solved by subsiding phosphorus positive action. Our results indicate that whilst financial support may increase uptake of stewardship actions, in isolation subsidies would be insufficient to change behaviours embedded within context specific attachments with historical farming practices and place. Support is required to affect a paradigmatic change in the relationship between farmers' identity and land and environmental practices. This could include experiential learning activating association to personal experiences, supporting collaborative household dynamics in decision-making over land management, and, reinforcing trust in multiple institutions relevant to farmers. Whilst challenging, this should be designed to promote the identity of farmers as environmental stewards, as well as food producers. This paradigmatic change needs to include a change of narrative that promotes a transdisciplinary and collaborative elucidation of transformative action across stakeholders along the whole supply change, rather than a 'blame game' across actors.[6]

Beyond the UK, agriculture worldwide is facing increasing uncertainty. Embedded within impacts of climate change, escalating energy and fertiliser costs and disruption of global supply chains associated with long-term impacts of the COVID-19 pandemic and Russian's invasion of Ukraine, makes the question of farmers' adaptive capacity in the face of such uncertainty even more critical globally. The framework tested here can support the development of such understanding. As demonstrated in this research, this understanding can be used to identify priority actions to enhance uptake of phosphorus stewardship actions within the farming community.

CRediT authorship contribution statement

Aine Anderson: Writing – original draft, Investigation. **Brent Jacobs:** Writing – original draft, Investigation, Conceptualization. **Paul J. A. Withers:** Writing – original draft, Project administration, Funding acquisition. **Emmanouil Tyllianakis:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Bryan M. Spears:** Writing – original draft. **Lukas J. Wolf:** Writing – original draft, Methodology, Investigation, Formal analysis. **Erin Sherry:** Writing – original draft, Investigation. **Julia Martin-Ortega:** Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Shervin Shahvi:** Investigation, Data curation. **Shane A. Rothwell:** Investigation. **Kirsty J. Ross:** Investigation. **Donacha Doody:** Writing – original draft, Project administration, Investigation, Funding acquisition. **Dana Cordell:** Writing – original draft. **Miller Alonso Camargo-Valero:** Investigation.

[6] This is what the Rephokus project (which funded this research) sought via catchment and national level stakeholder engagement. Such alternative narrative is illustrated in the UK National Transformation Strategy produced in consultation (Cordell et al. 2022) and is reflected for example in this animation: https://www.youtube.com/watch?v=YdbHIxdo9sw

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2024.103930.

Data availability

Data will be made available on request.

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