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1. Introduction

It is widely accepted that resource use is exceeding the planet's replacement capacity (Melkert & Vos, 2008; WHO, 2013) with anthropogenic, global environmental change problems threatening human needs. Associated, complex social-environmental issues have, in many cases, been classified as 'wicked problems' following Rittel and Webber (1973). This term denotes problems for which it is impossible to define optimal solutions because of both uncertainty about future environmental conditions and intractable differences in social values (Shindler & Cramer, 1999). Environmental, wicked problems are particularly challenging for policy makers. Policy initiatives aiming to address complex social-environmental issues are perennially difficult to implement because of a host of circumstances including when associated knowledge bases are divergent and incomplete, when short-term interests conflict with long-term benefits, and when ambiguous boundaries prevent universally agreed problem formulation or assignation of responsibilities for resource allocation (Head, 2014).

This paper re-evaluates what makes problems wicked, reflecting upon the nature of the 'untameable beast' to which wicked problems have been likened (Xiang, 2013, see also Churchman, 1967) and assesses the theoretical and pragmatic approaches that have been advanced to 'tame the beast' through a literature review. We begin by revisiting Rittel and Webber's (1973) despondent analysis in which they set out a series of insoluble conundrums for would-be problem solvers. We see despondency in the superlative negativity of the language repeated throughout the seminal article: wicked problems are not merely difficult to manage but "incorrigible" (Rittel and Webber, 1973). We then move on to critique the discourse that has emerged which promotes more optimistic strategies to

tackle wicked problems (for example, ASPC, 2007; Brown et al., 2010; Termeer et al., 2013) and qualitatively review the presence of corresponding strategic initiatives in actual practices of environmental problem management and the surrounding policy discourse in Scotland. Specifically, we address the following research questions:

> What strategies to tackle wicked environmental problems are prominent in the literature and to what extent do they address or provide pathways for tackling the defining characteristics of wicked problems?
>
> How are these strategies, suggested by the literature, reflected in examples of practice in Scotland?

Our analysis seeks out emergent themes in the literature on wicked environmental problems to help us to understand how far both theory and practice have come since the original problem formulation by Rittel and Webber (1973) and how this has percolated, implicitly or explicitly in the policy discourse, using the Scottish example. In Scotland, policy is responding to address wicked environmental problems with a range of instruments including legislation, strategies, programmes and frameworks, and in some cases implementing European directives (e.g. The Water Framework Directive). Encouragement for bottom-up individual or community led approaches and the use of market mechanisms is also present in the Scottish policy discourse. Given this diversity of policy initiatives and with respect to wider interest in all aspects of environmental governance there is a pressing need to leave no stone unturned in exploring the available methods for understanding and responding to wicked environmental problems.

2. Methodology

To address our research questions, the paper conducts a three-step analysis. First, based on Rittel and Webber's (1973) original representation and subsequent formulations (for example, Conklin, 2003; Horn & Weber, 2007; Levin et al., 2009), we present a consolidated set of characteristics of wicked problems (see Table 1). Second, we map 'strategies to tackle wicked problems' proposed in the literature onto the particular elements of wicked problems which each strategy claims to tackle, grouping them thematically. Third, we search for evidence that the grouped strategies are reflected in Scottish policy responses to four wicked environmental problems, namely: securing the sustainability and resilience of landscape and land-use systems through spatial planning; addressing population health through the control of livestock diseases; mitigating climate change through woodland planting; and mitigating rural diffuse pollution in freshwater systems.

2.1. Characterizing wicked problems

Table 1 is a novel reformulation of wicked problem characteristics, starting from Rittel and Webber's 1973 article, in which they detailed ten defining characteristics, and developed by collapsing and condensing ten into six descriptive categories. We aim to comprehensively but more concisely capture the original ideas augmented with some of our own insights informed by other literature in the field. Our categories are: 1. Indefinable; 2. Ambiguously bounded; 3. Temporally exacting; 4. Repercussive; 5. Doubly hermeneutic; and 6. Morally consequential. The objective was to develop an instrument that eliminated repetition in the original yet remained true to Rittel and Webber's conceptual construct, and furthermore worked on a pragmatic level within the scope of this paper. In doing so, we acknowledge Conklin (2005) who presents a different, condensed set of defining characteristics.

2.2. Identifying and mapping strategies from the literature

The second step of the analysis maps various proposed strategies to tackle wicked problems onto the six defining categories (Table 1). The objective is to identify the specific characteristic of wickedness purportedly being tackled. Strategies were identified using the ScienceDirect and Google Scholar search engines. The titles of articles and reports identified through keyword searching were reviewed, and articles best matching the search criteria were studied in greater detail. Reference lists from reviewed articles were scanned for other relevant articles. Material was chosen at first for a good match with the 'wicked environmental problem' topic, but later, as strategies began to be repeated with only minor variations, we purposely searched for more novel strategies. We stopped searching the literature following the principle of theoretical saturation, that is; no new concepts were emerging regarding the development of our categorization thereby demonstrating that our overall structure had sufficient variation to enable categorization of all new proposals appearing in the literature; and we had become reasonably confident that relationships among categories were well established and validated, and that further discoveries would add little to the model (Glaser & Strauss, 1967, pp.61-62, 11-112). A caveat to the search is however, that while based on an extensive review of the literature, our evaluation is not an inventory of all published papers on the topic of wicked problems, but rather the result of a systematic exercise to identify strategies to tackle wicked environmental problems in the literature.

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Mapping the strategies to the six defining characteristics was accomplished qualitatively through an 'analytical matrix' in which we plotted how each identified tackling strategy might best correspond to a specific wicked characteristic. This was sometimes straightforward where, as in many cases, there were explicit claims attached to the strategies. At other times the process of drawing linkages was more interpretive. A qualitative, thematic analysis drawing on aspects of Grounded Theory (Corbin & Strauss, 2008; Glaser & Strauss, 1967) was applied revealing a number of common themes. Based on this analysis we identified a set of mitigation approaches taking the most distinct elements from the matrix. Tackling strategies, as proposed by the literature, were consolidated on the basis of having strong similarity or common authorship. Many studies only allowed a partial mapping because all six characteristics (Table 1) were not necessarily tackled thus leaving gaps in the matrix. Furthermore, we recognise that thematically clustering and condensing common ideas inevitably loses some of the nuances in the original papers. However, our review covers a substantial body of literature and what is gained is the degree of generality our research question requires. We also acknowledge applying subjective judgements to the analysis, assigning strategies to categories on the basis of our reading of the text. This is integral to our methodology. We situate this study within the tradition of qualitative research and hold that the derivation of meaning from text as an interpretive practice is a valid exercise for the social sciences.

2.3. Identifying tackling strategies in four case studies

In the third step we examined four cases of wicked environmental problems found in Scotland in the light of the tackling strategies that we have identified: Our four cases were as follows: i) securing the sustainability and resilience of landscape and land-use systems through spatial planning; ii) addressing population health and infectious diseases through livestock disease control; iii) climate change mitigation with woodland planting; iv) mitigation of freshwater diffuse pollution. All four cases are high on Scotland's environmental policy agenda and are part of the Scottish Government's Rural Affairs and the Environment Portfolio Strategic Research Programme 2011-2016.

3. Findings from the mapping process

The decades since Rittel and Webber defined wicked problems have seen a wealth of material proposing strategies to tackle wicked environmental problems (for example, Balint et al., 2011; Brown et al., 2010). Post-normal science (Sardar, 2010; Healy, 2011; Ravetz, 2011) and other mixed methods approaches that incorporate adaptive, participatory and transdisciplinary (APT) elements have been proposed and in various cases applied to wicked problems (O'Connor, 1999; Frame & Brown, 2007; Innes & Booher, 2010). For example, there are claims that scenario planning techniques can open up problem solving possibilities through more creative, inclusive and ongoing engagement processes, such as participatory back-casting, in contrast to normal science-based approaches (Carlsson-Kanyama et al., 2008).

Figure 1 summarizes the results of the analysis and the options identified in the process of mapping the tackling strategies against the six defining characteristics.

[INSERT FIGURE HERE]

Figure 1. The wicked wheel: strategies to tackle wicked problems mapped to consolidated characteristics of wickedness proposed in the searched literature

3.1. Tackling Indefinability

To address the indefinable nature of wicked problems, a strand of the literature proposes changing the problem solving paradigm or theoretical framework. For example, Batie (2008) suggests that post-normal science and its epistemic assumptions can generate a more powerful conceptual framework to deal with wicked problems. Berkes (2011) proposes framing problems under the socio-ecological systems paradigm. Other authors go further, advocating methods beyond rationality (Coyne, 2005) and the use of philosophical inputs enlisting environmental philosophers in collaborative reimagining of engineering and technology practices particularly in relation to sustainability problems (Whyte & Thompson, 2012). We label this group of ideas as the theoretical approach (strategy 1a, Fig. 1).

Other proposals in the literature are, what can be understood as, pragmatic (strategy 1b, Fig. 1). Two pragmatic sub themes are identified: firstly, those that advance specific analytical tools or methodological approaches to help cope with uncertainty (for example, modelling tools, scenario planning and non-deterministic participatory approaches (see Batie, 2008; Grootjans in Brown et al., 2010); and secondly, those favouring deconstructing the problem into sub-problems, for example, the translation of complex problems into more recognizable, smaller problems (Shindler & Cramer, 1999); locking the down the problem definition (Conklin, 2010) ‘sticking’ to purposes and goals (Lazarus,

150 2009) and assessing competences (Mascarenhas, 2009). These deconstructive approaches
151 are further referred to in our analysis as atomistic. In another approach, Innes and Booher
152 (2010) have developed a framework they call 'collaborative rationality' that we consider
153 both theoretical and pragmatic. Their approach, explicitly based on Habermas' 'Theory of
154 Communicative Rationality' (Habermas, 1984), targets reframing the planning process in
155 the complex contexts in which wicked environmental problems arise. These authors
156 balance more abstract theorizing, for example, 'thinking differently in an age of
157 complexity' with practical application, for example 'stories from the field'.

158 A further theme accepts the indefinability of wicked problems offering no way around
159 (Sharman, 2009; van der Brugge et al., 2005; van Latesteijn & Rabbinge, 2012; Palmer,
160 2012). We denote this as the resignatory approach (strategy 1c, Fig 1). This neologism is
161 not intended to be a pejorative label but one very much in the spirit of Rittel and Webber's
162 delineation of the field. They explicitly state that, without severe qualifications there are no
163 solutions and emphasise that wicked problems are "incorrigible" (Rittel & Webber's 1973).
164 To a large extent their seminal paper implies a resignatory approach from the outset and
165 this important idea will be revisited in the conclusion.

166 It is worth noting at this point, that for the defining characteristic of indefinability, many
167 studies in our review do not propose any kind of solution, but we make a clear distinction
168 between omissions for which any interpretation would be highly speculative and the
169 resignatory approach (strategy 1c, Fig. 1) which explicitly recognises that little can be done
170 about indefinability and the associated non-generalizability beyond informed acceptance.

3.2. Tackling Boundary ambiguity

Regarding the boundary ambiguity of many wicked problems (2, Table 1), three strategic options emerged from the analysis; although it should be noted that they are not necessarily mutually exclusive. Some authors propose an explicitly interdisciplinary or transdisciplinary approach (strategy 2a, Fig 1): the distinction being that an interdisciplinary approach entails integration across different scientific disciplines whereas transdisciplinary entails the incorporation of other strands of knowledge including non-academic knowledge (Tress et al., 2004). For example, Batie (2008) uses the example of ecological economics and sustainability sciences as examples of interdisciplinarity to address wicked problems, whereas Conklin (2010) and Palmer (2012) advocate transdisciplinary approaches in which science is integrated with management. A variation, for Innes and Booher (2010) proposes transdisciplinarity with a particular emphasis on the generation of rational knowledge and discussion through permanent collaboration between public and private decision makers, enrolling scientists as informants and facilitators.

Systems thinking (strategy 2b, Fig. 1) following Bertalanffy (1968) also features in some approaches such as the one inherent to the socio-ecological framework (Berkes, 2011) and underpinning the proposals by Shindler and Cramer (1999), Chapin et al. (2008) and Sharman (2009). Beyond transdisciplinary planning processes, Innes and Booher (2010) propose a complexity-based approach to tackle wicked problems that also appears to favour looking at wicked problems through the lens of systems thinking but using softer tools that recognise different world views and local knowledge (see also Checkland, 1981 and 2000). The ‘collaborative rationality’ proposed by Innes and Booher (2010) draws upon Habermas (1984) and emphasises the importance of levelling power imbalances in order to reach

194 genuine consensus. We distinguish a final approach in response to this defining
195 characteristic, which we call boundary spanning (strategy 2c, Fig. 1). This refers to
196 bridging levels or institutional boundaries within organizations and across functional scales
197 (van der Brugge et al., 2005; van Latesteijn & Rabbinge, 2012; Whyte & Thompson,
198 2012).

199 **3.3. Tackling Exacting temporality**

200 Several approaches have also been proposed to deal with the temporally exacting
201 characteristic evident in many wicked environmental problems. Different forms of scenario
202 building, fore-sighting and envisioning (strategy 3a, Fig. 1) are advanced for imagining
203 plausible futures and preparing solutions for them (e.g., Batie, 2008; Whyte & Thompson,
204 2012; Griffith in Brown et al., 2010). Not mutually exclusive to envisioning is the
205 opportunity-driven approach (strategy 3b, Fig. 1), by which several authors propose
206 grasping the opportunity or seizing the moment, to establish dynamic and temporary goals
207 and intermediate solutions (Lazarus, 2009; van Latesteijn & Rabbinge, 2012). Mascarenhas
208 (2009) expresses this in terms of concentrating on possibility rather than probability.
209 Following their practice based approach to planning and decision-making, Innes and
210 Booher (2010) propose an opportunity-driven approach with (rational) communication
211 taking place amongst different stakeholders as the key tool to adaptive mitigation of wicked
212 problems possessing contingent and ever-changing characteristics. Within the socio-
213 ecological framework, resilience (strategy 3c, Fig. 1) is proposed as the key variable that
214 determines the limits and thresholds that ought not to be passed, thus attempting to
215 determine the point at which the system is destabilized to such an extent that alternative,
216 beneficial courses of action are no longer available (Berkes, 2011).

3.4. Tackling Repercursiveness

The most frequently recurring suggestion addressing the repercusiveness characteristic of wicked environmental problems (within the searched literature) is to use different participatory approaches (strategy 4a Fig. 1). This is formulated, variously, as effective engagement (Batie, 2008), integration of knowledges, social learning, accommodation of multiple alternatives, group exploration (Mascarenhas, 2009), dialogue mapping and deliberation (Conklin, 2010). Suggestions also include some more concrete frameworks such as adaptive co-management (Berkes, 2011), and collaborative rationality (Innes & Booher, 2010), both of which explicitly prescribe the necessity to go beyond participation and towards active collaboration throughout the whole planning and decision-making process.

3.5. Tackling the Double hermeneutic characteristic

The notion of a double hermeneutic (5, Fig. 1) draws on Giddens' (1987) idea that there is a two-way relationship between reflection upon and participation in the social world. This can be particularly frustrating when tackling wicked environmental problems in which social context and proposed solutions are mutually and constantly reshaping one another. In response, some of the reviewed literature refers to a participatory re-framing of the problem through iterative processes (strategy 5a, Fig. 1) that is, sharing views at different stages of the process to reframe the problem. This includes the proposals by van Bueren et al. (2003), Coyne (2005), Batie (2008), Conklin (2010), Palmer (2012), van Latesteijn and Rabbinge (2012) and Schooneveldt (in Brown et al. (2010)). Alternatively, by placing wicked environmental problems in the context of complexity, Innes and Booher suggest

239 going beyond participation through iterative dialogues, and promote instead "a democratic
240 governance for a resilient society" (2010, p. 196). Their idea of resilience envisages public
241 rationality and adaptiveness spontaneously arising from the communicative processes
242 taking place within and between local communities, scientists, planners and politicians.
243 According to these authors, rational processes of communication will allow communities to
244 constantly adapt to any new circumstances, and be empowered to take full responsibility for
245 common, agreed actions and decisions.

246 A second strand aiming to tackle the double hermeneutic problem characteristic can be
247 classified as a holistic approach (strategy 5b, Fig. 1) that emphasises connectedness.
248 Mascarenhas (2009) argues for a focus on the relationships between discrete alternatives
249 rather than continuous variables for a better understanding of the systemic nature of wicked
250 problems (see also Sharman (2009)). Waddock (2012) conceives of a holistic shift through
251 which agents of change stand outside the detailed interactions at the operational level and
252 take a bigger-picture view with democratically agreed objectives. According to the APSC
253 (2007) thinking inclusively to tackle wicked problems also belongs to the holistic approach.

254 We also find an atomistic (strategy 5c, Fig 1) proposal in relation to the double hermeneutic
255 in Chapin et al. (2008) who recommend pursuing simple solutions at an appropriate scale
256 (e.g., local or regional), thereby capturing problem definitions at the actor level. This two-
257 way dynamic is treated ambivalently under asymmetric pre-commitment strategy (Lazarus,
258 2009), an approach which deliberately makes it hard to roll-back laws established to deliver
259 environmental goods, while simultaneously allowing advances that are consistent with the
260 established law's objectives. The pre-commitment rationale recognises that actors, over

time, will sometimes subvert less rigid arrangements in the pursuit of self-interest therefore it promotes seizing moments of opportunity to pre-empt this.

3.6. Tackling Moral consequentiality

We found a consensus, where the issue arises, that the morally consequential nature of wicked problems can be addressed through public participation (6a, Fig 1). Authors refer variously to collective deliberation (Coyne, 2005); citizens at the core of the problems (Sharman, 2009); equal empowerment of everyone (Aslin & Blackstock in Brown et al., 2010); increasing ownership through transparency and participation (Mascarenhas, 2009); comparing different perspectives and incentivizing continuous debate (Whyte & Thompson, 2012); and of going beyond public participation and into rational collaboration (Innes & Booher, 2010). In places this participatory theme evokes a Habermasian view of governance (Habermas, 1984), presupposing that the generation of permanent platforms for discussion and collaboration are the key to overcoming barriers to progressive decision-making (for example, differences in status, power, etc.) and facilitating rational decisions. There are notes of caution however. Participation ought to take proper account of the socio-ecological contingencies of any given moment for Innes and Booher (2010). Head and Alford (2015) agree that collaboration offers one way of recognizing the complexity of problems but point to the difficulty of establishing and sustaining robust collaboration particularly in a public-sector context subject to turbulence and strict accountability rules. Van Bueren et al. (2003) identify risks involved in over-reliance on citizen engagement citing ethical dilemmas associated with public participation. One example, are the tensions created trying to maintain scientific credibility while engaging in adaptive management (Griffith in Brown et al., 2010). In addition, the APSC (2007) cautions that lack of understanding of the wicked

environmental problem can result in different stakeholders being confident that their version of the problem is correct. To the list of logistical challenges Sharman (2009) adds the need to re-think the scale of moral values, with citizens at the core of the process, an idea echoed throughout the literature. Finally, Huxham and Vangen (2005), advise that seeking collaborative advantage is a seriously resource-consuming activity that practitioners and policy makers should not undertake lightly.

4. Case study analysis

There follow four separate case studies undertaken by sector specialists (the four named authors). A personal perspective is presented regarding the influences of the wicked problem discourse within the field of each of these four cases. We were inspired to develop this paper and drawn together through our encounters with the 'wicked problem' discourse in the course of our separate programs of research. These four cases have not been selected necessarily because they feature prominently in the 'wicked problems' discourse, although some of them (e.g. the mitigation of diffuse pollution in freshwater systems) have been identified as such (Patterson et al., 2013). For the most part however, they are not exemplars or archetypes long established as wicked problems by scholars. For us 'wickedness' is not a fixed academic label but an analytical category and we have selected the four cases to show that they variously share the characteristics of wicked problems as defined in this paper. More importantly, they allow us to present ideas to address or 'tackle' wicked problems in the context of real-world environmental challenges that bear the hallmarks of incorrigibility and intractability that first drew the attention of Rittel and Webber (1973). Whether or not wicked problems are either explicitly referred to in the respective policy frames or generally in the measures adopted to manage the challenges is

not germane to our analysis and we fully accept that other discourses may have influenced the development of the policies that are in place.

We proceed systematically, case by case, firstly presenting the policy frame, secondly supporting our assertion that the case is a wicked environmental problem. We do so in a narrative way, highlighting elements of the problem that link to the defining characteristics established in this paper. Thirdly, we explore the tackling strategies that we see in evidence and critique them in light of the literature presented above.

4.1. Securing the sustainability and resilience of landscape and land-use systems through spatial planning

What is the policy frame? Following political devolution from the UK more than a decade ago, the Scottish Government assumed full competence in Spatial Planning. The resulting political and planning framework is fragmented (Campbell et al., 2012; Sugden et al., 2012). It comprises independent regimes for urban, rural and semi-natural land-use systems. This might hamper the achievability of generic political goals for Scotland's land systems, including achieving sustainable multi-functionality and increasing resilience (Scottish Government, 2011a). Relevant examples of regulations and planning tools that concern the built environment include the National Planning Framework 2 (Scottish Government, 2009b), the National Planning Framework 3 (Scottish Government, 2014a), the Scottish Planning Policy (Scottish Government, 2014b) and Local Development Plans for local planning authorities. Meanwhile Scotland's Land Use Strategy (Scottish Government, 2011a), local Forest Indicative Strategies, regional Forest District Strategies, and Rural Development Programmes are all concerned with the planning and regulation of

328 rural areas, whilst the Nature Conservation (Act) Scotland (Scottish Government, 2004)
329 and the Local Biodiversity Action Plans regulate natural resources. Landscape-oriented
330 policies include: National Scenic Areas and National Parks; Local and Regional Landscape
331 Designations; and Landscape Character Assessment and Supplementary Planning
332 Guidelines underpinning local plans and strategies. Additionally, some other regulatory
333 instruments have been recently approved that strongly influence the direction of spatial
334 planning, including; the Land Reform (Scotland) Act 2003, and (Modification) Order 2013
335 (Scottish Government, 2013), and the Climate Change (Scotland) Act (Scottish
336 Government, 2009a). Clearly therefore, there is a diversity of very specialized regulatory
337 and planning instruments influencing change in land-use (Campbell et al., 2012). This
338 results in a highly fragmented spatial planning framework. Such fragmentation is therefore
339 unfit to address the fact that the diverse components of land-use systems are, in reality,
340 strongly interconnected and mutually dependant, for example, urbanization and its effects
341 on landscape protection, or conflicts amongst forestry and wind-energy expansion.

342 **What is the wicked environmental problem?** Spatial planning is a an area of public
343 policy that is defined at diverse levels of public administration, ranging from the National
344 to the Local levels, and across areas of policy that jointly encompass the natural, rural and
345 urban components of land-use systems. It is basically aimed at securing the sustainability
346 and multi-functionality and at increasing the resilience of land-use systems. It is the site of
347 a wicked environmental problem because it operates within cross-cutting socio-political
348 jurisdictions and established institutional, administrative and socio-political structures.
349 Furthermore, it addresses territorial processes that are mutually nested, and hence
350 ambiguously bounded (2, Table 1) across spatial-temporal institutional scales (from the

national to the local), forming complex patterns, making it both spatially and temporally exacting (3, Fig. 1). Ultimately it is subject to huge uncertainty associated with the definition of permanent, concrete targets and objectives (1, Fig. 1). This problem is exacerbated by the lack of stopping rules concerning the definition of targets for change in land-use systems, especially surrounding defining attributes such as resilience and sustainable multi-functionality. Additional complexity arises where outcomes can be determined by the attribution of roles and responsibilities in the decision-making process. This results in the process of spatial planning being characterized by a double-hermeneutic nature (5, Fig 1). Furthermore, even the conceptualisation of spatial planning tools to tackle the wicked problems of resilience and multi-functionality of land-use systems can defy rational formulation (1, Fig, 1), as the domain itself is simultaneously defined as a scientific field of study, an administrative technique and a socio-political praxis (European Regional/Spatial Planning Charter, 1983). Consequently it confounds rules that may be separately applicable to the political, social and scientific spheres of human knowledge and action.

How are the strategies to tackle wicked problems being reflected in practice? The indefinability that is inherent in the complex nature of land-use systems (Rindfuss et al., 2008; Dearing et al., 2010) and the landscapes that are representative of these (Pedroli et al., 2006; Selman, 2008; Dramstad & Fjellstad, 2011) is currently being tackled in Scotland through the fragmentation of policy and planning frameworks and regimes. This is a pragmatic (strategy 1b, Fig. 1) and atomistic (strategy 5c, Fig. 1) approach. In order to tackle the ambiguous boundaries (2, Table 1) of problems associated with landscapes and land-use systems, the present Scottish planning regime has opted to operate in a systemic

374 mode (strategy 2b, Fig. 1). This is clearly reflected in strategic documents such as
375 Scotland's Land Use Strategy (Scottish Government, 2011a) and Scottish Planning Policy
376 (Scottish Government, 2014b) and National Planning Framework 3 (2014a). These
377 documents are reflective of the Scottish Government's intention to embed spatial planning
378 policy in a wider and more holistic understanding of land-use systems, by adopting an
379 ecosystem approach (Scottish Government, 2011b). Regarding the temporally exacting (3,
380 Table 1) nature of changes in landscapes and land-use systems, it is clear from major
381 policies and their recent evolution that the approach undertaken by the spatial planning
382 system in Scotland is opportunity driven (strategy 3b, Fig. 1). This is well reflected by the
383 recent changes in the definition of targets for issues as important for land-use change as
384 forestry expansion (Scottish Executive, 2006; WEAG, 2012).

385 In essence, most efforts to cope with the wickedness of land-use systems in the planning
386 and policy framework in Scotland to date have been concentrated through strategic
387 instruments that operate at the national and regional levels. Paradoxically, there is a clear
388 tendency in the Scottish territorial political discourse to favour bottom-up approaches
389 underpinned by the principle of subsidiarity that favour decisions at the local level (Scott &
390 Shannon, 2007), and that are backed by a strong emphasis on promoting public and
391 stakeholder participation in the planning process (strategies 4a and 6a, Fig. 1). Whilst
392 recognising these competing strategies, it is too soon to evaluate their effects on shaping
393 novel planning models that are capable of coping with wicked environmental problems
394 associated with defining targets for planning the sustainable multi-functionality and
395 resilience of land-use systems and associated landscapes. Nevertheless, a joint effort by
396 political authorities, local agents and experts is clearly underway.

4.2. Addressing population health through the control of livestock diseases

What is the policy frame? Balancing ecological and agricultural objectives under conditions of climate change whilst competing in globalised food and energy markets severely tests collective approaches and encompasses a number of policy areas impacting on the control of livestock disease. The Wildlife and Natural Environment (Scotland) Act 2011 attempts to harmonise policy outcomes with those of the Scottish Rural Development Program (Scottish Government, 2014c) which in turn are subject to the European Rural Development programme. The monolithic Common Agricultural Policy, currently in the midst of profound and politically charged reform, overarches all of these. Environmental management is further subject to European directives (for example the Habitats Directive, 1992) and UK law (for example, The Protection of Badgers Act (1992)) as livestock intersects with wild nature. At European Union, UK and devolved Scottish scales there are complex, nested and overlapping constraints on control policies. More widely, Scotland's disease control strategy must co-exist in a minefield of international obligations in a dynamic environment where diseases are both uncertain and emerging, and in which human values are inextricably bound-up. Animal disease is regulated through The World Organization for Animal Health (OIE); trade in livestock through The World Trade Organization; and zoonotic disease through The World Health Organization.

What is the wicked environmental problem? Few issues attract the polarity of ethical contestation than that of the human, animal interface. Our attitudes to the other sentient creatures that share our planet, with animal rights agendas and animal welfare regimes literally changing the landscape, and our responsibilities to our fellow humans in terms of food security and moral obligations towards the hungry, create incommensurate priorities

(Food and Agriculture Organization (FAO), 1996). Controlling livestock disease directly encounters all of these contested areas as evidenced by the furore surrounding the funeral pyres of cattle seen throughout the UK in 2001 (Convery et al., 2005) or accompanying the ongoing failures to effectively manage bovine tuberculosis (bTB) through culling (or killing) wild badgers (Cassidy, 2012) and during 'mad cow disease' (Murphy-Lawless, 2014) that led to a crisis of confidence in British beef of global proportions. In these recent cases, market pressures, trade arrangements, food safety concerns, food security issues, animal rights and animal welfare agendas, indeed the lives and livelihoods of entire communities, have all been entangled in disputes about science and social justice, constraining proposed interventions. In the case of bTB scientists, farmers, policy makers and non-farming citizens continue to argue amongst and between themselves about the aetiology of the disease and both the efficacy and the ethics of trialled control measures (Cassidy, 2012) making a wicked problem with indefinability and moral consequences (1 and 6, Table 1) as characteristics.

Livestock disease is, in certain cases, exacerbated by particular modes of production, e.g., intensification, that can constitute new epidemiological risk in terms of diseases associated with livestock production (for example, Arnold, 2013), yet are advanced as a solution to food scarcity. Intensiveness and veterinary interventions create new problems in terms of disease susceptible and drug resistant animals. Highly efficient farms can experience drastic interventions such as mass culling following a disease outbreak that have led to severe social and economic problems, for example, following a Foot and Mouth Disease (FMD) outbreak in 2001. Vaccination strategies are often influenced by trade implications; for example, when a country's disease-free status is compromised by false-positive test results

443 from vaccinated animals. Conservation measures may produce wildlife disease reservoirs,
444 such as the protection of badgers that farmers associate with increasing bovine TB. These
445 various effects and interrelationships are open to interpretation as ambiguously bounded
446 and repercussive problem characteristics (2 and 4, Table 1).

447 Growing global food requirements add further moral and ethical dimensions to already
448 complex issues with ever increasing requirements for highly productive systems, including
449 stock bred for production rather than health. Agricultural pressures on wildlife reservoirs
450 can be intolerant of 'wild nature' seeing in it disease risks including vectors and
451 opportunities such as land resources for additional pasture. Globalisation of trade in animal
452 produce and live animals is ever increasing. The problems are getting worse in various
453 ways as the human population grows and any stopping rule appears unlikely. Zoonotic
454 disease is partly a product of interactions between human and animal systems, and human
455 populations are encroaching on wild spaces evermore (3, Fig. 1). Social impacts of zoonotic
456 pathogens can be significant while the variety of competing economic interests frustrate
457 preparedness initiatives (Miller & Parent, 2012). Drug resistance and disease vulnerable
458 production units may be products of earlier problem framings that sought to address animal
459 welfare or human food requirements thereby revealing both a doubly hermeneutic and an
460 ambiguously bounded pattern (5 and 2, Table 1). Rational demands for food self-
461 sufficiency post World War II have in part driven intensification for which adverse animal
462 welfare side effects are an unintended consequence; another repercussive effect. Culling
463 may be too traumatic to be repeatable in political terms (Convery et al., 2005) with the
464 potential to stigmatise production systems and become politically problematic for would-be
465 decision makers. Outbreaks demand action yet all available actions can be unpalatable.

Finally, public responses to livestock disease risk are intersubjective, drawing on earlier experiences, media coverage and other dynamic socio-economic and socio-cultural contingencies (Duckett & Busby, 2013; Busby & Duckett, 2012) making response to outbreaks a highly charged political exercise (6, Table 1).

How are the strategies to tackle wicked problems reflected in practice? Across the panoply of recent crises besetting the United Kingdom in the area of livestock disease the available toolbox has been extensively and variously called into service. Recent experiences of FMD have, for example, resulted in the formation of public participatory exercises (strategy 6a, Fig. 1) considering, for example, issues of access to the countryside during livestock disease outbreaks. Recently, interdisciplinary and participatory initiatives (strategies 2a and 4a, Fig. 1) have been deployed by Scottish Government through its Centre for Excellence in Livestock Disease Outbreaks (www.epicscotland.org), including scenario planning exercises (strategy 3a, Fig. 1) looking at the future of the Scottish cattle sector (EPIC, 2014) and the sheep sector (EPIC, 2015). The work within the centre is interdisciplinary and transdisciplinary where social scientists, veterinary scientists and other disciples based across Scotland's major research providers work together to design a holistic approach (strategy 5b, Fig 1) in a one-stop scientific advice centre for policy makers.

The establishment of structures, like EPIC, that are willing to implement a range of strategies broadly in-line with those promoted in the literature on tackling wicked environmental problems, does appear to make Scotland better prepared to meet challenges like those first encountered in 1986 with bovine spongiform encephalopathy (BSE) and in 2001with foot and mouth disease (FMD). Stakeholders are more engaged; scientists are

working in new partnerships, and these developments alone seem reason for optimism. With diseases however, unlike the other cases under discussion here, progress in tackling outbreaks defines success and it is tempting fate to suggest that novel approaches will deliver significantly better outcomes in the future especially given that traditional responses may have weakened with the reduction in front-line veterinary staff and state veterinary services across the UK including Scotland (Lowe, 2009). It is also worth reflecting that diseases appear as adaptive as any mitigation so far developed which is yet another reason why novel and emerging pathogens are such a wicked adversary.

4.3. Mitigating climate change through woodland planting

What is the policy frame? Scotland's targets to mitigate greenhouse gas (GHG) emissions were set in the Climate Change (Scotland) Act in 2009 by the Scottish Government. These targets are 80% GHG emission reduction by 2050 and 42% (interim target) reduction by 2020 (Scottish Government, 2009a). This Act presents a stern challenge to the rural land use sector which is expected to mitigate its own GHG emissions and also to offset GHG emissions from other sectors that are not expected to achieve such substantial reductions (for example, transport and industry). One of the Scottish Government policies to achieve the necessary GHG emission reductions is the creation of 10,000 hectares of new woodland annually until 2022 (Scottish Government, 2011a). To support woodland creation and management, the Scottish Rural Development Programme 2014–2020 (Scottish Government, 2014c) has made £252 million available through the Forestry Grant Scheme (Forestry Commission Scotland, 2015). Farmers can apply for support under eight categories, two for the creation of woodland and six for management of existing woodland. The most recent discourse points out that apart from climate change mitigation benefits, the Scottish Government also aims at promoting

512 other environmental benefits as well as economic and social benefits, ensuring that new
513 woodlands are created by multiple landowners and across holdings.
514
515 **What is the wicked environmental problem?** Climate change, perhaps more than any other
516 area, has been conceptualized as a set of wicked environmental problems. It defies resolution
517 due to enormous uncertainties, circularities and conflicting stakeholder interests that become
518 enmeshed in efforts to develop solutions (Lazarus, 2009). Woodland planting has been
519 considered an essential strategy to mitigate GHG emissions due to its capacity to sequester
520 CO2 from the atmosphere. However, in Scotland, this strategy is difficult to implement due
521 to conflicting food and climate change policy goals (Feliciano et al., 2013, Munoz-Rojas
522 Morenes et al., 2015), low acceptability of woodland planting schemes among Scottish
523 farmers (Crabtree et al., 2001; WEAG, 2012) and volatile stakeholder perceptions about the
524 consequences of climate change (Barnes & Toma, 2012; Feliciano et al., 2014). Therefore,
525 the strategy to mitigate the climate change problem is itself a wicked problem and because
526 of that it engenders slow progress in addressing the main problem. Meanwhile, the rate of
527 GHG emissions is increasing and time seems to be running out for communities and
528 ecosystems both in Scotland and around the world. In short, the problem is temporally
529 exacting (3, Table 1). Furthermore, while neither woodland planting nor any single
530 intervention can change such a complex nexus, every individual effort can foster negative
531 repercussions (4, Table 1). For example, reducing available arable land or pasture through
532 woodland planting may promote more intensive farming through demand-side pressure or
533 competing imports from other countries; a development laden with a further ambiguously
534 bounded set of wicked environmental problems (2, Table 1).
535

536 Those seeking to resolve the problem (for example, Scottish Government) are also
537 exacerbating it (5, Table 1). Political discourses are sometimes contradictory in relation to
538 the support of woodland planting to cut GHG emissions since by strengthening food policy
539 discourses, which accept the mantra of increasing food demand, they undermine the
540 aspiration to increase forest cover. Woodland planting is a morally consequential problem
541 (6, Table 1) because stakeholders have different perspectives and goals, both specifically in
542 relation to the successful implementation of woodland planting in Scotland, and in relation
543 to climate change in general. A report from the Woodland Expansion Advisory Group
544 (WEAG, 2012) admitted that there is a deep cultural divide between forestry and farming
545 strategy. A glance at the Food and Agriculture Rome declaration (FAO, 1996) highlights the
546 moral imperatives stacked-up on the food side of that divide.

547 **How are the strategies to tackle wicked problems being reflected in practice?**

548 Mitigating climate change through woodland planting requires the Scottish Government to
549 align its own policies, plans and strategies. We focus on the Land Use Strategy for Scotland
550 (Scottish Government, 2011a) and the Scottish Forestry Strategy discourses (Scottish
551 Executive, 2006). Through these instruments the Scottish Government recognises that
552 different individuals have different legitimate interests and priorities for the use of particular
553 areas of land and that the main factors influencing land use and land use choices can vary
554 considerably from area to area. There is recognition that decisions are generally best made
555 by those closest to the land, namely individuals, land managers, communities and businesses,
556 in order to reflect local needs and circumstances; a recognition partly emerging from and
557 partly creating a need for participatory processes (strategy 4a, Fig. 1). The Land Use Strategy
558 for Scotland (Scottish Government, 2011a) proposes a pragmatic approach (strategy 1b, Fig.
559 1) to inform these local processes.

560 The Scottish Government, working through its Forestry Strategy is cooperating with local
561 authorities and others to expand existing strategies beyond forestry issues. These multi-
562 agency strategies are expected to assist in decisions on grant funding, develop proposals and
563 other decisions relating to land use and land use change, thus embarking upon boundary
564 spanning collaborations (strategy 2b, Fig. 1). The APSC (2007) considers that improving the
565 public sector's capacity to work in a distributed way can help to better understand the causes
566 and solutions of a particular wicked problem among the organisations that are supposed to
567 deliver the services.
568 The Land Use Strategy for Scotland (Scottish Government, 2011a) enshrines values that land
569 use decisions should be informed by an understanding of the opportunities and threats,
570 brought about by the changing climate. In addition, it mentions that land should continue to
571 contribute to delivering climate change mitigation objectives in addition to reduced GHG
572 emissions associated to land use change (Scottish Government, 2011a). We interpret this
573 discourse as being an opportunity driven approach (strategy 3b, Fig. 1).
574 Mitigating climate change through woodland planting is entangled with value conflicts,
575 ideological and cultural constraints. The Scottish Government has set out principles to decide
576 how proposals within the Land Use Strategy for Scotland (Scottish Government, 2011a) will
577 be delivered, including a commitment that, "people should have opportunities to contribute
578 to debates and decisions about land use and management decisions which affect their lives
579 and their future" (Scottish Government, 2011a), an explicitly public participatory approach
580 (strategy 6a, Fig. 1).
581 The Land Use Strategy for Scotland (Scottish Government, 2011a) presents a set of ten
582 principles for sustainable land use that reflect Scottish Government policies on the priorities
583 which should inform national land use choices. These principles tacitly acknowledge the

584 doubly hermeneutic characteristics of wicked problem (5, Table 1), whereby contextual
585 factors, human and non-human are an on-going challenge varying in spatial and temporal
586 dimensions. The strategy asserts that it is not an option to look at a narrow range of interests
587 when making decisions about land and it particularly embraces regionalisation. It further
588 recommends an integrated approach and holistic action in decision-making about land use to
589 secure tangible benefits in practice (strategy 5b, Fig. 1).
590 Finally, the Forestry Commission Scotland suggests increasing awareness of the forestry
591 sector's contribution in climate change mitigation with Regional Forestry Forums and
592 assessing trends in public awareness through public opinion surveys. The Land Use Strategy
593 for Scotland (Scottish Government, 2011a) recognises that people should have opportunities
594 to contribute to debates and decisions about land use and management decisions that affect
595 their lives and their future (strategy 6a, Fig. 1).
596 In 2012, the Woodland Expansion Advisory Group wrote a report to the cabinet secretary for
597 rural affairs and environment with 24 recommendations to help achieving woodland creation.
598 Given the inclusive approach intended by both the Forestry Strategy and the Land Use
599 Strategy, it is expected that these recommendations will be taken forward for further
600 discussion.
601

602 **4.4. Mitigating rural diffuse pollution in freshwater systems**

603 **What is the policy frame?** The Scotland River Basin Management Plan, developed by the
604 Scottish Environmental Protection Agency (SEPA, 2009), requires programmes and
605 interventions that comply with the Water Framework (WFD) and Nitrates Directives. The
606 WFD (2000) sets the target for European water bodies to reach 'good ecological status',

607 prescribing the use of economic tools and principles and promoting public participation
608 (Martin-Ortega, 2012). The Nitrates Directive (1991) aims to protect water quality across
609 Europe by preventing nitrates from agricultural sources polluting ground and surface waters
610 and by promoting the use of good farming practices. In this context, the Rural Diffuse
611 Pollution Management Strategy for Scotland (SEPA, 2010) aims at improving water quality
612 through a combination of regulation, guidance and voluntary measures.

613 **What is the wicked environmental problem?** We focus on how best to mitigate pollution
614 of freshwater systems at the catchment scale in a cost-effective and socially acceptable
615 way. This is a problem tackled by Scottish Government (SEPA, 2010), and is also
616 recognized as a problem by a range of other stakeholders, however, land managers in
617 Scotland do not always necessarily see or recognize the link between their activities and
618 water quality (Martin-Ortega & Holstead, 2013, Christen et al, 2015).

619 Catchment management in general (von Korff et al., 2012) and diffuse pollution in
620 particular have been explicitly recognized to be wicked problems in the literature.
621 Addressing diffuse pollution requires implementation actions involving multiple actors
622 acting at multiple scales and influenced by a range of factors (Patterson et al., 2013; Smith
623 & Porter, 2010), making it ambiguously bounded (2, Table 1). It also commonly involves
624 tensions and mismatches between spatial and temporal scales relating to environmental
625 change, human behaviour and institutional processes (Patterson et al., 2013; Smith &
626 Porter, 2010), which are all riddled by uncertainty and affected by repercusiveness and the
627 double hermeneutic effect (4, 5 Table 1). For example, programmes to improve water
628 quality need to be assessed in terms of their economic efficiency at the catchment scale by
629 the regulator; while each specific intervention requires farmers' action at the field level.

630 Current hydro-chemical models are limited in their capacity to establish the association and
631 causation between land-management practices and ecological and geomorphological
632 consequences across the catchment and field scales (Slee et al., 2013). There are also
633 heterogeneous perceptions of what constitutes proper land-management and how it affects
634 water quality between different stakeholders (Martin-Ortega & Holstead, 2013, Christen et
635 al, 2015), making the problem indefinable (1, Table 1). Moreover, there is evidence that
636 mitigation programmes designed for current conditions might not be 'future-proofed'
637 against climate and land-use change (Jackson-Blake et al., 2013), contributing to a
638 temporally exacting dimension (3, Table 1). Finally, the ultimate aim, established by the
639 WFD, to achieve (close to) natural conditions in systems that are essentially
640 anthropogenized, poses a moral dilemma (6, Table 1) as to whether it is acceptable (and
641 ultimately possible) due to the unequal distribution of the costs of measures to improve
642 water quality and the benefits the good ecological status provides (Martin-Ortega et al.,
643 2015).

644 **How are the strategies to tackle wicked problems being reflected in practice?** We focus
645 on the approach followed by The Scottish Environmental Protection Agency, through the
646 analysis of its Rural Diffuse Pollution Plan (SEPA, 2010). The Plan is aimed at ensuring
647 'that the key stakeholders in Scotland work in a coordinated way to reduce diffuse
648 pollution, tacitly acknowledging the ambiguously bounded nature of this wicked
649 environmental problem (2, Table 1). There are some early signs of interdisciplinarity
650 (strategy 2a, Fig. 1) and the adopted catchment approach can to some extent be
651 approximated to systems thinking (strategy 2b, Fig. 1).

652 The Scottish Environmental protection Agency acknowledges the fact that 'there is no
653 single solution to problems of diffuse pollution and it adopts a pragmatic approach
654 (strategy 1b, Fig. 1) by endorsing best management practices, which rely on a range of
655 measures to reduce and alleviate diffuse pollution impacts, and by offering a number of
656 planning tools and in-field measures. Through the creation of a Diffuse Pollution
657 Management Advisory Group (DPMAG) involving a range of stakeholders and aimed at
658 'helping create robust governance, decision-making and a coordination framework' and
659 'ensuring input from a cross-section of rural, environmental and biodiversity interests', the
660 Scottish Environmental Protection Agency has adopted an explicitly participatory approach
661 (strategy 4a, Fig. 1). It is too early to observe whether the advisory group is also an
662 instrument for iterative participatory re-framing (strategy 5a, Fig. 1), which could address
663 the double hermeneutic issue. The Diffuse Pollution Management Advisory Group's
664 'Priority Catchment Strategy' where areas significantly failing water quality standards are
665 prioritized, could be approximated to a certain extent to the threshold delimitation approach
666 (strategy 3c, Fig. 1).

667 The national awareness raising and one-to-one farm visit campaigns, that are at the core of
668 the Rural Diffuse Pollution Plan and by which the Scottish Environmental Protection
669 Agency has moved from a punitive approach to a supportive one, could be interpreted as
670 the regulator's strategy towards tackling the morally consequential aspect of diffuse
671 pollution's wickedness (6, Table 1), by increasing transparency and participation
672 (strategies 6a and 6b, Fig. 1). While there has been no formal evaluation of the overall
673 effectiveness of the Rural Diffuse Pollution Plan in mitigating diffuse pollution, the Diffuse
674 Pollution Management Advisory Group is observing positive progress. Compliance with

675 General Binding Rules in six of the priority catchments has risen from 26% to 51%, with
676 88% compliant or working towards compliance, as evidence by field visits (SEPA, 2015).

5. Discussion

677 Numerous difficulties remain, some of which we attempt to address below. However first
678 we can say positively that strategies identified in the selected literature are clearly evident
679 in practice in the Scottish cases we have featured. Given that cause and effect between
680 theory and practice is perennially difficult to establish we have at least been able to draw
681 some parallels between environmental management praxis and the 'tackling wicked
682 environmental problems' literature, finding clear correspondences in terms of theoretical
683 ideas that have practical counterparts. An exemplar of theoretical ideas resembling
684 elements in current practice is participation. Various participatory processes were
685 evidenced in all four case studies. In this regard, the analytical approach we adopted allows
686 us to offer a partial answer to the question, often raised in this context, regarding whether
687 the wicked problem discourse is any more than a descriptive commentary and is actually
688 grounded in practices, (for example, Xiang, 2013). We have shown that, within the Scottish
689 context at least, socio-ecological challenges are sites where approaches consistent with
690 those advocated in the wicked problem literature are being practiced. In all four of our case
691 studies notable parallels are evident. With regard to securing the sustainability and
692 resilience of landscape and land-use through spatial planning, we have identified in-use
693 tackling strategies, such as the ecosystems approach, (the primary framework for action
694 under the Convention on Biological Diversity, 1992) that evoke the systemic approaches
695 common in the discourse. Scottish Government have also embraced scenario exercises and
696 appear committed to interdisciplinary science to tackle the thorny issues involved in

addressing population health through the control of livestock diseases. When it comes to mitigating climate change through woodland planting, there is further evidence that multi-scale approaches have been deployed in response to the ambiguously bounded nature of the challenges faced. In our fourth case study, mitigating rural diffuse pollution in freshwater systems, it also seems reasonable to argue for the existence of holistic, participatory, interdisciplinary and systemic approaches evoking similar ideas from the literature.

The extent to which the 'strategies to tackle wicked environmental problems' discourse has actually influenced these practices is more difficult to determine. All of the options (strategies 1a to 6b) are not only present as strategies to tackle wicked problems but are also aligned to prevailing ideas in wider research beyond any necessary association with wicked problems; examples include quests for transparency and systems thinking. The discourse, in many ways broadly reflects current methodologies, particularly in the social sciences, rather than offering a unique set of approaches tailored for a specifically 'wicked' problem. Other examples include the rubric of interdisciplinarity that pervades a great deal of research independently of the discourse of wicked environmental problems. Likewise, participatory approaches are de rigueur across social science with the idea of 'the stakeholder' a prerequisite for a great many problems that are not ostensively wicked (for example, Renn, 2003). Similarly both adaptive and holistic approaches within the socio-environmental problem sphere do not appear consistently differentiated in the searched literature from their more general usage.

This degree of generality does not invalidate the utility of any of the aforementioned approaches but does raise questions about the influence of the discourse especially given that it largely operates within an Anglophone diaspora (Xiang, 2013) whereas many of the

actual environmental problems and their management approaches appear ubiquitous. The question then arises, regarding whether these approaches are simply generally accepted as valid and useful for tame and wicked problems alike or whether they particularly offer something to wicked environmental problems. The evidence from our cases is mixed. Participation, for example, is often advanced uncritically as a universal panacea yet has obvious limitations including both potentially greater overheads than non-participatory approaches and variable outcomes. Other strategies to tackle wicked problems appear overly optimistic, for example overestimating the efficacy of interdisciplinary approaches; a familiar issue for many researchers. Other strategies to tackle wicked environmental problems appear to cherry-pick the least wicked parts of problems. Some of the strategies even appear to go against the foundational definition (contra-natura), for example, the atomization approaches. This reductionist strategy, breaking problems up into manageable components, aligns well with traditional ideas about complexity but is singled out for criticism by Rittel and Webber in their original formulation of wickedness. Wicked problems, they insist, are not supposed to be amenable to straightforward simplification. We are therefore keenly aware that wickedness, in its original formulation has a deeply problematic intractability to its nature and is different to complexity. The distinction is starkly evident in the explicitly negative prognosis running through the Rittel and Webber analysis. Those tasked with tackling wicked problems often have to contend with irreconcilable stakeholders, collateral environmental damage caused by previous and current interventions, policy failures, messy situations, conflict, temporary fudges, and paradoxical and morally objectionable outcomes – that's how wicked problems are defined and where such issues are avoided or resolved there was probably no wicked problem in the first place.

744 Complexity, by contrast, has long been ‘tackled’ in many ways in the social sciences for
745 example through Soft Systems Methodology (SSM) which proposes advanced problem
746 definition techniques, inclusive approaches to different worldviews and participatory
747 exercises with all kinds of stakeholders. This is not to say that SSM or other approaches
748 that have emerged independently are incompatible with tacking wicked environmental
749 problems, rather, that claims for their efficacy or indeed appropriateness probably need to
750 be considered on a case by case basis.

751 One approach that does appear incompatible and worth noting is precommitment strategy
752 (see section 3.5). Its notion of locked-in mitigation appears theoretically ill-equipped to
753 being an effective tackling strategy. In particular, given the general improvement in
754 scientific knowledge over time, privileging current assessments and goals over those that
755 may develop in the future and regarding current opportunities as inherently preferable to
756 those that may arise, seems flawed. Seeking to pin down mitigation when the problem itself
757 cannot be pinned down does not seem to be a sound principle. This is not to say that
758 binding targets, particularly in the sphere of emissions targets, do not have a constructive
759 role.

760 More broadly, it is far from clear how many of the proposed wicked environmental
761 problem fixes differ from parallel theoretical approaches, beyond belonging to a unique
762 discourse. That said, generality may well be a strength and the postmodern turn that social
763 science has made towards openness of method, inclusivity of stakeholders and rejection of
764 reductionism cannot be excluded from approaches to what may be the severest socio-
765 technical challenges of all. Furthermore, there is a pragmatic and a can-do tenor to most of
766 the literature excluding the original formulation. The idea of ‘tackling wickedness’ has, in

767 the most part, usefully moved away from idealistic notions about ‘solutions’. At the time of
768 publication Rittel and Webber were despondent about a failing planning system in which
769 ‘arrogant systems analysts’ falsely promised continual progress through outdated a nd
770 failing notions of ‘scientific management’. Most subsequent authors have been at pains to
771 reiterate a version of the wickedness conundrum before proposing their best-fit approach
772 and most, while determined that efforts must be made, are cautious and conservative in
773 their assessment of efficacy. For example, Head (2014) and Head and Alford (2015), argue
774 that while conclusive solutions are very uncommon, it is possible to frame partial,
775 provisional courses of action against wicked environmental problems. This is not without
776 risk. Addressing only some problem elements can spawn new problems just as the Lernean
777 hydra grew another two heads for each that was cut off. Therefore, it must be stressed that
778 what are considered in this study are explicitly tackling strategies not solutions. The
779 incorrigibility or otherwise of the wickedness bedevilling Scotland’s environmental
780 challenges demands our best efforts, however problematic the available options appear.

6. Conclusion

781 In closing, we believe it is important to reiterate the order of magnitude of the challenge
782 required in making useful progress with wicked environmental problems. Rittel and
783 Webber set us an extraordinary task, already anticipating some of the subsequent proposals
784 and ruling them out as inadequate. For example, they dismiss traditional, objectivist
785 systems approaches unequivocally stating that, “this type of scheme does not work” (Rittel
786 & Webber, 1973). In comparison to the ‘dodekathelon’ of challenges set for Hercules that
787 required only supreme effort, the decathlon of trials Rittel and Webber identified constitute
788 tasks for which even herculean effort is not enough. Unlike the slayer of the Nemean lion,

789 the would-be wicked problem tackler neither knows what the mission is, nor will it
790 necessarily ever be clear whether or not it has been accomplished. Rittel and Webber's lion
791 is not only "aggressive" but "tricky (like a leprechaun)" and "vicious (like a circle)" (Rittel
792 & Webber, 1973). It is to be expected then, given the scale of the challenges we have
793 investigated in our four cases that any positive impact resulting from strategies to tackle
794 wicked problems, even where it may exist, is extremely difficult to assess. Therefore, it is
795 with some trepidation, within this context of 'incorrigible' problems, that we offer this
796 research on small steps that are being taken within Scotland toward taming the untameable
797 beast.

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Table 1: Six consolidated characteristics of wicked problems

Short description	Long description
1.Indefinable (and non-generalizable)	The formulation of a wicked problem is the problem. Stakeholder contestation abounds s hampering all attempts to reach agreed or definitive problem formulations and making each wicked problem unique and resistant to general strategies of mitigation. This creates an immense problem for both analysts and would-be problem solvers. It undermines all the following definitions (2-6) just as it did for Rittel and Webber whose 10 characteristics were equally caught in this conundrum (of their own devising).
2.Ambigously bounded	Wicked problems can usually be considered as symptoms of another different problem often at a different scale. The resultant inter and intra-connectedness of issues problematizes the isolation of manageable components. Boundaries are hard to establish and unstable. There are problems within problems and strategies to address one can spawn other single or interlocking problems.
3.Temporally exacting	Time is often running out where wicked problems are concerned. There is generally no stopping rule. There are no ends to the causal chains linking open systems involved. Persistence and longevity confound intervention strategies and mitigation efforts often only cease because of the intervention project's own material limitations. System relationships are frequently nonlinear exhibiting disproportionate and unpredictable changes. Co-evolution occurs both in the overall system and the agents within it.
4.Repercussive	Proposed solutions to wicked problems are entangled with value conflicts and ideological/cultural constraints often with side effects that may themselves be profoundly problematic. They do not have an enumerable or an exhaustively describable set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into any plan. There is no ultimate validity test for solutions. A proposed solution to a wicked problem is often a 'one-shot operation' with the problem resisting a return to square one having often been transformed by attempts to tackle it.
5.Doubly hermeneutic	There is a two-way relationship between analysis and the social world. Understandings of wicked problems cannot be pinned-down but are constantly challenged by active subjects who, unlike rocks or chemicals under the gaze of the natural scientist, can change their practices just as understandings of those practices are developed condemning attempts to solve wicked problems based on a specific understanding of the behaviours involved to failure. The information needed to understand a wicked problem depends upon initial framing which itself is co-dependent on a wide range of contextual factors; human and non-human - adaptive agents react to the system and to each other. System behaviour is

	emergent from the interaction of the parts, such that the whole is different from the sum of the parts. The problem is not understood until after the formulation of a solution.
6.Morally consequential	Wicked problems demand action while displaying great resistance to change. They exist in social systems where mistakes are unacceptable not in controlled environments. This can create significant moral dilemmas that pose individual risks for would-be problem solvers who may be held to have no right to be wrong yet may be morally obligated to act. Outcomes can always be contested. Those seeking to solve the problem may also be causing it or inadvertently causing another wicked problem.

Appendix

Supplementary materials

Item	Label	File type
Table 1.	Six consolidated characteristics of wicked problems	Word Table on next page
Figure 1.	The wicked wheel: strategies to tackle wicked problems mapped to consolidated characteristics of wickedness proposed in the searched literature	Powerpoint figure as separate file attachment