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The science-practice interface of connectivity in England

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Response to Reviewers:	We have added the requested paragraph, see lines 653-664.

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Abstract

Context

A disconnect has been identified at the interface between landscape science and practice. More commonly, it is assumed that better or more targeted science would lead to better practice. Others argue that such a view is partial, and propose an understanding that foregrounds how social and political factors shape the science-practice interface.

Objectives

In this study we explore how (the combination of) different conceptualisations, novel governance architectures, and political-economic conditions shape the science-practice interface between landscape ecology and practice, using connectivity conservation and enhancement initiatives in England as a case study.

Methods

We conducted interviews (n=36) with practitioners involved in connectivity-related projects (predominantly Nature Improvement Areas and Green Infrastructure initiatives). We transcribed and analysed the interviews using standard methods of qualitative analysis. We also conducted a desk study of green infrastructure strategies (n=58 documents).

Results

Enhancing or maintaining connectivity is perceived positively by conservation and planning practitioners in England. Considering both planning and ecological contexts, quantitative assessments are rare on the ground. Conceptual ambiguity, lack of resources (time, personnel, software and hardware), novel governance architectures, and changing economic and political conditions are implicated.

Conclusions

We find that the co-articulation of conceptual ambiguity and resource issues with novel forms of governance in changing economies is diminishing opportunities and creating challenges for (ecological) connectivity conservation. This is particularly true in relation to large scale operationalisation that requires multi-scale and multi-partner coordination.

1. Introduction

1.1. The science practice interface in ecology and conservation

It is widely recognised that there is a disconnect between the science and practice of ecology and conservation (Pullin and Knight 2005; Beunen and Opdam 2011; Salomaa et al. 2016; Opdam 2018). More commonly, it is considered that there is a "gap" between science and implementation because the former "*has a poor record of translating research into action*" and the latter is not utilising lessons derived from research (Knight et al. 2008:602). Particularly in conservation (Bertuol-Garcia et al. 2018), the onus for forging better connections between science and practice falls on enhancing knowledge production, exchange and use through evidence-based science, ensuring the practical and societal relevance of science and engaging with other forms knowledge, e.g. qualitative and local (Knight et al. 2008; Opdam et al. 2013; Castella et al. 2014). This linear model of expertise of the science-practice interface (henceforth "the linear model") is built on the (explicit or implicit) assumption that if "*people just knew, they would of course do something – and since they are not, there is a need for policies that influence attitudes, behaviours and choices*" (O'Brien 2013:588). According to this model, the responsibility for this disconnect is placed primarily on knowledge-transfer bottlenecks (Bertuol-Garcia et al. 2018).

Studies critical of the linear model of the science-practice interface have emerged from a variety of theoretical and empirical angles. The field is large enough to preclude detailed description here, but some of the main points of criticism (based on Cash et al. 2003; Nowotny et al. 2003; Harding 2006; Görg 2007; Wyborn 2015b; Toomey et al. 2017; Bertuol-Garcia et al. 2018) revolve around: a) the repositioning of practitioners from mere recipients of "facts" to "judges" of scientific claims; b) the basis of their "judgments" (which is not necessarily scientific but can be influenced by cultural, political and economic factors); c) the inseparability of sciences and society; d) the challenge of the universality of Western positivist science and; f) a move towards transdisciplinary research involving a diverse set of institutions (not only universities and research centres).

1.2. The science practice interface in landscape ecology

Within landscape ecology, several authors have highlighted the need for a transformed understanding of the science-practice interface. Opdam et al. (2013) and Pinto-Correia and Kristensen (2013) for example, argue that the landscape as a material and immaterial entity can be the "medium and the method" for a new transdisciplinary union of research and practice in urban and rural planning and design, and sustainability science. Nassauer and Opdam (2008) and Nassauer (2012) argue that in landscape ecology the concept of landscape "design" can work as the missing link or boundary concept that could bring science and practice closer. Others stress the merits of collaborative research or the adaptive co-production of knowledge (Wyborn 2015a, 2015b) as ways to overcome disconnects in the science-practice interface.

A research lacuna remains regarding the interplay between science, practice and governance in landscapes that have shifted to "governance-beyond-the-state" and "adaptive governance" models (Swyngedouw 2005; Wyborn 2015a), especially when large-scale strategic land-use coordination is required (Adams et al. 2016). Considering that what we call landscape "practice" nowadays has evolved to include a constellation of actors beyond landowners and the various arms of the local/national state, and now includes consultants, community groups, NGOs, activists, businesses, quasi-public institutions, universities, usually in some form of organised partnership. This research gap is particularly acute in the context of unstable economic (e.g. post-financial crisis) or rapidly changing political (e.g. Brexit in the United Kingdom) conditions that suddenly alter financial, governance or legal architectures. Our study is an attempt to explore the science-practice under such conditions using the lens connectivity conservation and enhancement.

Connectivity conservation could be a fertile ground for empirically informing this knowledge gap. Most pertinently, connectivity is interesting from a science-practice interface perspective because it can have multiple meanings due to the different scale-, site-, species- or landscape-dependent definitions and concepts that abound. For landscape ecologists, connectivity is predominantly a referent for two related concepts: structural connectivity, which could be defined as the extent to which different "habitat types" are linked; and functional connectivity, which is related to movement and responses of individuals and/or species across the landscape an (including habitat patches and a permeable matrix) (see Crooks and Sanjayan 2006). For planners, connectivity has additional meanings, such as footpath connectivity (Ellis et al. 2016), or cultural heritage connectivity (Antonson et al. 2010). As Hodgetts (2018) argues, connectivity has also been implicated in facilitating and furthering particular types of spatial planning that favour powerful interests, as well as to signify the connection people and nature.

Secondly, particularly in its large-scale implementation, e.g. at landscape, regional or even national scales, connectivity conservation requires coordinated operationalisation across jurisdictions and organisations. New governing architectures, such as "governance-beyond-the-state" (Swyngedouw 2005), provide opportunities and barriers for coordination which remain worthy of further investigation if their potential for partnership, knowledge-production and adaptation is to be realised (Beunen and Opdam 2011; Wyborn 2015a). Additional reasons that make connectivity an interesting case study of the science practice interface include: a) conceptually and empirically, its efficacy is still a focus of scientific debate, generating “friction” (*sensu* Tsing 2005) between different scientific schools (Hodgson et al. 2011; Moilanen 2011; Fahrig 2013), including the well-known habitat loss versus fragmentation debate (Villard and Metzger 2014) ; b) connectivity has become one of the cornerstones of conservation and landscape planning (Crooks and Sanjayan 2006; Wu, 2013), especially as an adaptation strategy for climate change (Vos et al. 2008); c) connectivity assessments often require expertise in mathematical or computational methods (Termorshuizen et al. 2007), especially as scientific legitimacy increases; d) connectivity can sometimes have negative consequences, such as promoting fire, spread of invasive species or disease.

As a result of this complexity, concepts that are related to connectivity conservation have provided several case studies for exploring the science-practice interface in landscape ecology. Beunen and Hagens (2009) found that while ecological networks were popular in the Netherlands, they were still rarely implemented in spatial planning practice as a result of the ambiguity of the concept. Nassauer and Opdam (2008) explored the design method for robust ecological corridors in the Netherlands to suggest new ways of linking science and practice in landscape ecology. Von Haaren and Reich (2006) in their study of connectivity conservation in Germany found that scientific findings play a minor role in establishing ecological networks. However, more recent studies about the German-wide Ecological Network show that more robust quantitative methodologies are indeed employed, although “stronger link[s] between the scientific and conceptual basis of habitat networks is needed” (Schweiger 2015: 298). Termorshuizen et al. (2007) in their study of planning documents in the Netherlands found that while the spatial conditions for maintaining sustainability were recognised, the use of quantitative assessments and strategies was limited, as they can be data hungry, time consuming and require expert knowledge. While Termorshuizen et al. (2007) recognised the shifting governance architectures of landscape management, considering them empirically was outside the scope of their study. Finally, in a major recent study drawing on a literature review, interviews and focus groups, Keeley et al. (2018) list the challenges and opportunities for implementing corridors, albeit without taking into account how governance and political economic complexities can affect the science-practice interface.

Nevertheless, so far, limited attention has been paid to the science-practice in connectivity *per se*. Wyborn in a series of papers (2015a, 2015b, 2015c) has delved in depth in two case studies (in Australia and USA), showing how a complex function of material (including resources), cognitive and social capacities shape the interactions between connectivity science and practice. Bergsten and Zetterberg (2013) discovered that lack of data and the choice of focal species were the main barriers for planners adopting a particular method for connectivity assessments in Swedish planning departments. Hodgetts (2018:83), in a conceptual study identifies five “types” of connectivity, and argues that the differences are indeed problematic because these different types of connectivity are considered separate: “sharing a coincidental terminology, but pertaining to different things.”

In this context, we can argue that there is a need for further studies of both the on-the-ground utilisation of scientific knowledge and methods in general, and of connectivity analyses in particular. The main aim of this study is to fill a gap in how the combination of different conceptualisations, novel governance architectures, and political-economic conditions shape the science-practice interface between landscape ecology and practice, using connectivity conservation and enhancement initiatives in England as a case study. To achieve this we answer the following research questions:

a) Which are the various connectivity-related concepts and methods employed in conservation and landscape planning practice?
b) What are the criteria for method choice to assess connectivity?
c) How has connectivity and the science-practice interface of landscape ecology more broadly been affected by recent changes in conservation and landscape governance?

2. Methods

2.1. Case study

England can act as solid ground for empirically investigating the science-practice nexus and connectivity conservation in particular. England and the United Kingdom are home to top-level research and scientific organisations (e.g. British Ecological Society) and national environmental NGOs are among the most productive research-wise and popular in terms of membership and volunteers (e.g. the Royal Society for the Protection of Birds is the oldest and among the largest conservation NGOs in Europe). Also, England is unique in the sense that connectivity conservation has rocketed to the mainstream of conservation and planning, and the urge for "more, bigger, better and joined" (Lawton et al. 2010) protected areas forms one the backbones of English conservation (Isaac et al. 2018). A case in point are the 12 Nature Improvement Areas (NIAs), launched by the Department for Environment, Food and Rural Affairs (Defra) in 2011 and operating since 2012, aiming at creating more and better-connected habitats at the landscape scale. NIAs were funded as a competitive funding scheme operating in rural and urban areas all over England. They were presented as a "bottom-up" policy that allows diverse partnerships to "lead" conservation on the ground, "based on the recommendations of local people" (Defra 2011). 76 partnerships applied for the £7.5 million available and after a process similar to a research or art grant proposal including evaluation in stages, business plans and interviews, 12 areas were selected in 2012. Moreover, landscape ecology-influenced concepts such as wildlife corridors, landscape permeability or stepping stones have also interpenetrated land-use planning. Green Infrastructure (GI), a concept and policy mainly coming from a planning perspective, has incorporated connectivity at its core not only in the United Kingdom, but in Europe and across the world (Garmendia et al. 2016), and according to recent reports, it seems to be a "good example" of "successful transfer of connectivity research to practice" (Žlender and Thompson 2017).

2.2. Data collection and analysis

In order to explore the science-practice interface of landscape ecology through the lenses of connectivity, we focused on gaining information from initiatives that have connectivity as a central element of their remit. The main country-wide connectivity-related initiatives in England are the aforementioned NIAs and GI initiatives and partnerships; thus we chose respondents that are active within them.

To answer questions related to connectivity conceptualisation and methodological application, we interviewed 14 representatives from nine (out of 12 in total) NIA partnerships and 13 from eight GI partnerships and organisations. Preparatory desk studies revealed that there are additional organisations related to connectivity, such as NGOs, public sector organisations, consultants, even academics. Thus, to have a wider sample and information from other projects or organisations that are involved with connectivity conservation, we also talked with three representatives from organisations or projects that deal with connectivity of specific genera (or focal species) and six respondents involved in connectivity assessments in a professional capacity (consultants, university staff, and NGO and public sector employees). In total 36 open-ended interviews were conducted in 2012-2015 with a range of practitioners including consultants, state officials and scientists, local government officials and NGO staff. The geographical spread of the NIA and GI partnerships and projects we interviewed cover the breadth of England, with a slight bias towards the South East. The themes around which the interviews were based upon were: how do they understand connectivity; whether they measure connectivity or not; which method or metric they use; which criteria do they use for choosing a method; how is connectivity conservation operationalised. It is important to note that in our discussions with respondents we never initiated discussions around resources. Furthermore, since we identified the theme early on in our interview schedule we explicitly choose not to introduce resources-related themes ourselves to avoid biasing data collection.

We recorded and transcribed the interviews for qualitative analysis, which has been shown to be a suitable way to explore individual's perceptions of knowledge-practice processes (Denzin and Lincoln 2011; Moon et al 2016). We first induced codes, i.e. quotation categories that are identical or similar in some way. Then, after the coding phase, we created themes which according to our research questions and desk study better represented the relations between codes and reflected the opinions of our interviewees (Table 1). As is common practice, we use interviewee quotes to illustrate key themes in the results section. Analysis was conducted using a combination of qualitative analysis software (NVivo 10) and hand drawn graphs and notes. All interviewee quotes are anonymised. Ethical approval was obtained from the School of Anthropology and Conservation, University of Kent.

The empirical data from the interviews were complemented by a desk study of all strategies and plans for GI we could find online using Google searches, supplemented by searching through the recovered documents for extra links to older documents (see Termorshuizen et al. 2007 for a similar methodology). In total, 58 documents were recovered as of December 2015 (see supporting material Table 1 for details and links, and a Google Earth file for the geographical cover). They ranged from local scale to city scale or even regional level plans and strategies. The GI-related documents were closely studied and the following information was recorded: who developed the plan or strategy (e.g. a local council's planning division, or a consulting firm); whether connectivity was assessed or not (yes/no); methodology for connectivity assessment (specific methodology); connectivity concepts.

To investigate how connectivity has been affected by changes in conservation governance and landscape-scale planning in England, we relied on public data on government spending and human resources, the aforementioned interviews and desk study, as well literature on the subject (including own work, see Apostolopoulou et al. 2014).

3. Results

The 36 respondents (16 female and 20 male) had a variety of backgrounds (ecology, biology, planning, physical and human geography). 66.6% have postgraduate degrees (11 have MSc degrees, 11 PhD degrees, and two are professors), while 12 have BSc or BA degrees.

Connectivity assessments in England are made by a variety of institutions and partnerships, and involve a plethora of actors from the public, private and voluntary sectors. There are several tools and methods devised, used and promoted mainly by Non-Departmental Public Bodies such as Natural England and Forest Science, large NGOs, universities and private consultants. Commonly this is done within specific projects by conservation partnerships (e.g. NIAs, European Union LIFE projects, National Parks).

(Insert Table 1 here) Themes used in the analysis and examples of codes.

3.1. Connectivity: concepts and methods

Several connectivity concepts were articulated by the interviewees. The most significant division was between connectivity as a landscape/ecological concept and connectivity from a planning perspective. The former, mainly articulated by respondents who are involved in projects or organisations dealing with nature conservation (14, 35% of the sample), involved a continuum of connectivity concepts. These concepts ranged from the structural to the specifically species-based and functional.

> *I normally say that there is structural connectivity going to functional connectivity, so these are the ends of this continuum. Some of that can be quite abstract and quite pattern based e.g. structural measures for some of our work we may assess whether this one particular* [withheld] *grant scheme changes the structural connectivity of landscape … The other end of the continuum is more about functional connectivity, which is very* [species] *specific… So some of our work will be very much species-based, how they move and interact with the matrix and quite a sort of complex understanding, while others will be very abstract and very simple* (R32, public sector scientist).

The movement of individuals across landscapes, or genetic material. It's basically the flow of individuals or genes between different areas and I leave it fairly open (R11, NIA representative).

Planning conceptualisations, articulated by the majority (60%, 8 out of 13) of GI practitioners, stress its multifunctional character, for example "*connecting green space through a footpath network*" (R18, GI partnership representative), i.e. combining urban habitat connectivity with transport connectivity and peoples connections to nature. Note that this type of conceptualisation did not only prevail among planners in our sample. For example, a NIA representative noted that connectivity in their case also means more community connections such as "*community gatherings*", arguing that if "*we just make our* [connectivity concept] *only ecological, we don't make ourselves relevant to the people making a living in the area.*"

The desk study of GI initiatives revealed that in this context, which is more related to urban and urban fringe planning, connectivity is also conceptualised in a variegated way. In contrast though to most ecologically-minded respondents and organisations, the analysis of GI strategies revealed that almost 80% (46) of the documents articulated diverse articulations of connectivity – *even in the same document.* Thus, for example, in a single document (Swindon Borough Council 2011) one can find the following: "*inter-connected 'park belt'*" (p. 19); "*River Ray and River Cole corridors with connections to Coate Water*" (p. 19); "*connectivity between existing neighbourhood, borough-wide and strategic scale recreational open spaces*" (p. 33); "*enhancing and improving connectivity within existing wildlife 'hot-spots*'" (p. 35); "[c]*onnecting people and place*" (p. 55).

Similarly to concepts, connectivity assessment methods used lie on a continuum from structural pattern-based to functional and species-based. Pattern-based methods include patch-based assessments e.g. nearest neighbour distance, patch size and shape. The middle ground is occupied by models that use a particular species and habitat, often using a focal-species approach (e.g. Watts et al. 2010). This approach is one of the most common, as it utilizes expert opinion and is not data hungry, often feasible using already available data. It is actually an approach used by several organisations in England, e.g. Forest Research, Natural England and several consultants working on connectivity.

Interviewees with an ecological background or within ecologically-minded organisations stressed the importance of actually assessing connectivity from a landscape ecology perspective (70% of the NIA representatives). A minority (two) also criticised the influence of planning concepts in habitat network design. For example, a consultant (R03), with experience in the NGO and public sectors argued:

> *"There's very few landscape ecologists and spatial ecologists in conservation and that really does worry me especially with what I have seen in ecological network definition and green infrastructure modelling – well I wouldn't actually even call it modelling, it's so simplistic and a lot of local authorities are confusing ecological networks with GI and they think that GI will provide an ecological network, it's a completely different thing. They do it mostly through overlay analysis, and accessible greens and maybe putting a few arrows on the map. I have seen some really shocking ecological networks as well which have been just arrows on a map."*

Nevertheless, the most scientifically robust methods, like individual based models, graph-based models or metapopulation approaches are the rarest on-the-ground and are usually related to discreet projects. Exceptions include: the BEETLE least-cost path based connectivity model developed by Forest Research (Watts et al. 2010) which is used by several organisations across the UK (e.g. Somerset Wildlife Trust 2016); the Condatis software Hodgson et al. (2012) which implements a conductivity-based connectivity model (used by e.g. Buglife projects in Kent and Sussex and the Northern Forest tree planting initiative in Liverpool); Natural England's National Biodiversity Climate Change Vulnerability Model (NBCCVM) which includes a module on habitat fragmentation and is used by many organisations and partnerships (Adaptation Sub-Committee 2013). Furthermore, when these types of sophisticated approaches are employed, model development and application is usually – but not always, see Northern Forest Condatis application at https://iale.uk/northern-forest-thinking-about-landscape – outsourced either to the particular model developer (e.g. Forest Research, Natural England) or experienced private consultants. Further evidence of such approaches was found in European Union and Defra funded projects, such as the Cheshire Econet project (http://maps.cheshire.gov.uk/econet/about.asp) or the Dorset AONB habitat connectivity mapping under the EU Interreg Cordiale project (http://www.southdevonaonb.org.uk/our-work/active-projects/completed-projects/cordiale), and some species-specific graph-theoretic applications (e.g. Bormpoudakis et al. 2016, on great crested newts and its application in compensation schemes). Notably, the deployment of quantitative methods for modelling connectivity is almost exclusively related to ecological/conservation rather than planning contexts.

In fact, few of the interviewees mentioned the use of such an approach. NIA representatives were the most aware and during the interviews mentioned several of these methods. Furthermore, NIAs took part in workshops and collaborative interactions where concepts and methods of connectivity assessment and measurement were presented and debated. Each NIA used a simple scoring system to calculate a "*comparative indicator of habitat connectivity*" (*ibid*) which is "*a proxy measure of connectivity based on the contribution of actions to improve connectivity*" (Collingwood Environmental Planning 2014: 60), and different local indices of habitat connectivity ranging from technically complex to simple (e.g. the ratio of the area (ha) of a particular protected habitat patch to the distance to its nearest neighbour (m) or the number of weirs removed or lowered along a river as an indicator of connectivity for anadromous fish) (Collingwood Environmental Planning 2015).

Confirming our interview results regarding the approach to connectivity from a planning perspective, the desk study of GI strategies revealed that only 6.7 % (four) of the GI documents analysed incorporated a systematic method for assigning corridors. 94% (56) simply overlaid maps within a GIS to allocate GI areas (Snäll et al. (2016) highlight the limits of such an approach), while a limited number (9.7%, six) incorporated some form of previous connectivity-related work (usually as maps in an overlay GIS exercise).

Despite the different approaches to connectivity, interviewees were definitely positive about the role connectivity could play in the landscape, place or species their organisations are working on. Although it was to be expected based on our sample, circa 90% of the respondents agree that the issue of connectivity "*is fundamental*" for managing rural and urban landscapes.

3.2. Criteria for method choice and implementation

The main outcome regarding the method choice when assessing connectivity is that there is neither a single specific method nor a particular scale that are suitable for connectivity analyses. 80% of the respondents note though that *"having a unique approach to connectivity is wrong*" (R28, NIA representative) and the way it is measured should be case-dependent (or site- and problem-specific). Our result is confirmed by the findings of the NIA final evaluation report, released 1.5 years after the completion of our NIA interviews, which notes that "[h]*abitat connectivity may be best considered and measured at the local level … targeted at particular species/habitats*" (Collingwood Environmental Planning 2015:69) and that it "*is questionable whether habitat connectivity in an abstract sense means very much because it is place and species specific*" (*ibid*: 83).

Moreover, as indicated above, there is clear evidence of disconnect when it comes to methods that are endorsed by the ecological scientific community and what is actually used on-the-ground. On the one hand, there is some worry that methods developed in academia are not suited to the actual needs of practitioners (30% of interviewees). As two interviewees told us (R01 and R05, a consultant and NIA representative respectively):

> *"I think the methods that are used in academia are largely unsuitable for use outside research projects because it simply takes too long, they are too complicated to use and they cost too much."*

On the other, in our case, most practitioners were not looking down on science, but were looking to inform and better their practice through the use of science. That was also true for organisations and projects that were not explicitly related to connectivity conservation.

> *"The result* [of previous connectivity analyses] *were tens and tens of GIS layers, but it needs to be more digestible and simple for the people, e.g. for local plan consultations … Now I am more informed about the direction but for someone who is not an academic it is difficult to keep up … Connectivity is a useful method for targeting our effort in an era of limited resources and personnel."* (R27, National park employee)

Finally, we also came across a few cases (4, 10% of the interviewees) where practitioners on the ground felt that connectivity conservation or enhancement is fairly straightforward even without the use of purely scientific methods, i.e. "*it is not rocket science*" (R30, NIA representative). As a local planning officer told us (R17):

> *To a degree it's going to be based on the ranger's gut feeling. Considering the ranger's experience and knowledge of the area, it's not that difficult.*

Moreover, the influence of resources (Table 2) on the choice of methods to assess and implement connectivity was strongly argued by several interviewees (23 out of 36, 64.8%), including NIA representatives (9 out of 14, 64.2%). Many NIA representatives (7 out of 14, 50%) were familiar with a host of connectivity metrics and methodologies, while all of them had clear ideas about the available methodologies. Despite that, some NIA partnerships were having difficulties in calculating structural connectivity indices themselves or were unable to give us a clear-cut answer on the method they would be using. After the completion of the NIA-related interviews the 2nd year monitoring report for the NIAs was published and only 2 of the 12 NIAs managed to quantitatively assess connectivity (Collingwood Environmental Planning 2013). As our interviewees told and as was later revealed by the publication of the monitoring and evaluation of the NIAs project, measuring connectivity "*remained a challenge*" for NIAs (Collingwood Environmental Planning 2015: 83).

Overall, the themes around which organisations' resource-related issues were grouped were mainly centred on software, personnel, time and budget restrictions (See Table 2). We recorded organisations: (a) with no access to GIS when most connectivity analyses require it (or computers powerful/new enough to run GIS analyses); (b) personnel without GIS capabilities; (c) limited funds for hiring skilled personnel; (d) experts that could not fund the application of their knowledge; (e) no time for sophisticated analyses; (f) project-based exercises that were rarely taken further or incorporated in organisational or institutional workflows. This element of our findings is confirmed by the results of a survey published in van Dijk et al. (2013: 23), which found that 8 out of 17 (47%) NIA representatives found "*local GIS expertise / resource*" would be a barrier to the use of Natural England's NBCCVM model.

(Insert Table 2 here)

This is particularly revealing in the case of a large NGO, which is quite sophisticated in their understanding of connectivity concepts and methods. According to their own words (R21, NGO representative):

> *We translate [scientific] theory into practice … We pride ourselves as we try to look at what we do from a scientific perspective. We do make an effort to explain in a quasi-scientific way population ecology to our volunteers…* [However] *the only way we measured connectivity is mean distance between occupied patches ... We don't have the resources to do more than that ... I describe it as a crude measure of connectivity, but we have the distance between sites and that says quite a lot.*

A desk study revealed similar cases, such as the Kent Wildlife Trust's Living Landscape project (a landscape-scale conservation initiative) which was not "*at present in a position to carry … least-cost analysis*" (Moyse and Rowsell, 2007:121); the Conservation Target Areas mapping project in Oxfordshire "*explored the possibility of using a detailed scoring system to decide which areas should be included in the target area mapping. This was not feasible in the limited time available.*" (Hawker and Burrell 2006:3).

3.3. Governing conservation and landscape-scale planning in England

Significant changes have occurred in English spatial governance in the last 20 years. For our study, the most significant would be the move away from the "strong state" paradigm to a form of governance that empowers a new and growing host of actors independent from the local or national state. This trend, tied to neoliberal conservation and environmental governance (Castree 2008; Apostolopoulou et al 2014), is especially evident in landscape-scale conservation and planning (Adams et al. 2014), but also clear in the type of organisation that was involved in producing GI strategies and plans as revealed by our analysis (Table 3; see also Table 2 in supplementary material for a list of actors involved in each NIA). NGOs, consultants, local community groups and private companies have all seen their governance roles and powers enhanced during the last two decades, resembling what Erik Swyngedouw (2005) termed "*governance-beyond-the-state*".

(Insert Table 3 here)

A second and related key change in English conservation, and one that directly links with both our case study initiatives (NIA and GI), has been the steady increase in large-scale conservation projects. As Adams et al. (2014:585) note, the fundamental feature of these projects is that "*they are an attempt to coordinate land use and conservation management over a larger extent than can typically be maintained by a single conservation landholder*", requiring hybrid forms of governance, partnerships, and coordination between state and non-state actors.

The rise and implementation of large-scale or landscape scale conservation coincided with the financial crisis of 2008-2009 which resulted in significant cuts that have affected both public spending on biodiversity and Natural England staff (Fig. 1). Furthermore, while the interviews were conducted before the Brexit referendum (June 2015), several of our interviewees were worried that post-crisis funding and staff cuts along with cuts in Common Agricultural Policy funding are sure to affect not only connectivity conservation, but nature conservation in general.

> *"There is one issue I wanted to flag up today, the issue of the new Common Agricultural Policy … There is no doubt, I would say at least 90% of the work that we can achieve ecologically depends on grants for farmers that are available through the* [Common Agricultural Policy]*".* (R28, NIA representative)

Staff number reduction in Natural England, the public body responsible for nature conservation in England, was also highlighted by the interviewees. An experienced private consultant confirmed that he is facing difficulties as "*more and more* [Natural England] *senior staff with a lot of experience and scientific knowledge are leaving and are not replaced*" (R01).

(Insert Figure 1 here)

The effects of resources on the interface between science and practice have been highlighted above. Some interviewees, however, also noted that the way these limited resources are allocated in competitive funding, limited-time projects like the NIAs is having an additional effect on the strategic and cooperative character of connectivity and landscape scale conservation. It is particularly interesting to note that while interviewees highlighted the powerful potentials of partnership-based and bottom-up projects, they noted how the current governance architecture of NIAs and other initiatives is hindering this potential.

> *“*[T]*hese NIAs that haven’t got GIS, why not find another that has got GIS, and work together; if you can do this for us, we will help you do something else … I think a lot of this is because the funds are competitive, they are often working against each other rather that with each other.”* (R32, public sector scientist)

> *Ideally you need some kind of national plan, to know that you are looking at a coherent network along the lines of the Lawton report… So a lot of action at the local level helps, you know, doing better conservation is going to help, but we need to be a bit more targeted and strategic about that kind of thing.”* (R15, public sector employee)

Note that competitive funding for conservation is relatively recent phenomenon in English conservation, which according to our data is to some extent responsible for the turn of several organisations towards connectivity conservation.

> *“Funding is limited so you have to focus your efforts in particular areas* [and] *funders are interested in projects which take a landscape scale approach … When Landfill tax started you could only apply for funding on one site, not for taking a landscape approach. In the last five years this has changed and they are interested more in a landscape scale approach … In the last ten years everyone is gradually moving toward thinking about larger scales”* (R21, NGO representative).

The concerns of the respondents highlight the interplay between novel forms of governance in large-scale scale conservation with the market logics of funding instruments such as competitive bidding.

4. Discussion

Opdam (2018:7) argues that a central challenge for landscape ecology is “bridging the gap between science and practice”, and that understanding the way “scientific information interacts with social processes” is fundamental to that goal. Our paper is a contribution towards resolving that challenge, looking at the science-practice interface through the lens of connectivity conservation.

4.1. Connectivity as a scientific object

The conceptualisations of connectivity underpin the way it is assessed in England. First, whether it is quantified or not depends on the understanding of what connectivity actually is: when the idea is that it is “*not rocket science*”, professional or experiential ranger knowledge may be used; or when the concept comes from a planning background, it is usually equated with corridors, footpaths or “*nodes in a network of green spaces*”. Second, when connectivity is considered a central component of conservation, it is usually seen as a continuum of approaches, from the structural and pattern-based to the functional and biological.

However, as the diversification of actors involved in contemporary environmental governance continues (Apostolopoulou et al. 2014; see Table 2 in the Supplementary Materials for a list of the actors involved in the NIAs scheme), so are the conceptualisations of connectivity diverging according to different positionalities within the science-practice space. In our case, actors from a planning perspective usually understood connectivity entirely differently from actors coming from an ecological perspective (e.g. connectivity as better footpath links between green areas versus connectivity as species dispersal least-cost paths). As a result, and particularly for GI-related initiatives that usually arise from planning frameworks, landscape connectivity assessments are rare on the ground and often do not meet the needs of nature conservation (see Termorshuizen et al. 2007 for a similar assessment for the Netherlands).

The diverse conceptualisations of connectivity we uncovered also partly reflect Hodgetts' (2018) reading of connectivity as "plural". We discovered elements of the diversity he documents in the workings of landscape and conservation planning, in both rural and urban areas (see map of GI strategies in Supplementary Material). Hodgett's argues that we should view connectivity as "multiple", meaning that we should holistically embrace the diversity of its "plural types" without reducing the concept to just one type (e.g. ecological connectivity). His understanding resonates with Tsing (2005) who posits that "friction" between knowledge claims is actually *creative* – provided it is recognised that it exists. Read in this context, our data indicates that while a scientific concept (like connectivity) can be universally lauded, if most practitioners are faithful to their "own connectivity", ignoring, dismissing or even suppressing different approaches, then the productive "friction" that Tsing (2005) argues can reshape the divides between science and practice cannot do its work. On the other hand, considering that most GI strategies we read did indeed employ multiple types of connectivity and that very few actually used quantitative assessments limits Tsing's (2005) and Hodgett's (2018) "creative friction" interpretation and adds further complexity to the understanding of the science-practice interface of connectivity conservation.

Although further work would be required, perhaps a starting point would be to accept that connectivity, like other ambiguous concepts like resilience, is Janus-faced (Brand and Jax 2007) in terms of science implementation. On the one hand they may have positive aspects, for example in promoting connectivity operationalisation in diverse landscapes. On the other hand they may also have negative aspects, for example in diluting certain aspects of connectivity conservation, as our findings regarding GI initiatives and the lack of ecological/quantitative assessments indicate.

Nevertheless, it seems that if landscape ecology is to become a scientific field which can influence practical application of its concepts, it has to accept and embrace this multiplicity. Considering that landscape planning is inherently a large-scale, regional, national or even international endeavour, this could pose new challenges. Particularly as novel governance architectures characterised by decentralisation and rescaling are solidified, landscape approaches such as ecological networks which require coordination between different groups or some form of standardisation (e.g. methodological) could face barriers to implementation. As we showed in the case of NIA's, the different approaches to connectivity create a geographically and organisationally anarchic (not in the political sense) science-practice interface, with different approaches, conceptualisations, methodologies, data, etc. employed to operationalise (supposedly) the same concept. This ostensibly bottom-up implementation of landscape science can result in uncoordinated land use allocations that do not do justice to any of the different types of connectivity (or corridors, or ecological networks, etc.). Thus, letting a thousand types of connectivity to bloom may be a productive – and in fact necessary step for landscape ecology, but could come with a price to pay: the "*price of anarchy*" for the lack of coordination among the different partnerships, NGOs, land owners, public institutions, and all the actors involved in spatial planning (Youn et al. 2008). Finding a way to balance between connectivity-as-multiple and connectivity-as-single (e.g. ecological) is perhaps the way forward (Hodgetts 2018).

That is not to say that some types of connectivity, e.g. ecological connectivity, are better or preferable than others, but to underline that sometimes policy tools that are designed to enhance and maintain a particular type of connectivity (e.g. NIAs for landscape/ecological connectivity) can fail to do so as a result of the multiplicity of the concept.

4.2. Recourses as a complex governance and political-economic issue

As our data reveals, the connectivity assessment method used by NIA and GI partnerships depends on the problem at hand and a combination of institutional experience and background, data available and resources at hand. The latter proved to be a very significant determinant of the method used for measuring connectivity in England. Tools, funding, personnel and time available for each organisation or partnership attempting to undertake connectivity measurements were limiting factors in the choice of methods and metrics used.

Therefore, while the matter of relevant research and informed practitioners is crucial, the research-to-practice punctuated continuum is not *just* a matter of knowledge exchange, but based on our findings, it is *also* a matter of resources. Considering the diverse set of resource-related constrains put upon organisations (hardware and software; experienced or skilled personnel; time; project-based funding; staffing problems), it is understandable that the work is often either "*crude*" (R32) or outsourced (e.g. to consultancies or state organisations such as Natural England), reducing the capacity for experimental learning that forms part of adaptive management that comes with in-house production (Plummer et al. 2013). Indicative of the situation in England, especially for local governance, only 1/3 of local authorities employ in-house ecologists (Defra 2012), and post-financial crisis some UK cities have been forced to let go of 90% of parks and countryside staff (Douglas 2014).

While the issue of insufficient resources is often included as one of the constituents of particular science-practice architectures, often it is not discussed further (Pullin and Knight 2005), or even dismissed as beyond the competence of "*practitioners and scientists*" (Arlettaz et al. 2010:836). As our results and other reports indicate (see Figure 1; Eggermont et al. 2013), in the post-financial crisis climate of tight state budgets (almost globally) this is no longer the case (see also Adams et al. 2016) and it is a fact that should be considered when proposing evidence-based science and the systematic review as the main remedy.

The dwindling public resources for conservation, and the way these are dispersed to conservation and other actors are tied to the novel forms of land-use governance that emerged in England in the last two decades and to the way science and scientific concepts are used in practice. As mentioned above, financial and other resources have been repeatedly implicated in the implementation gap in landscape ecology and conservation (e.g. Termorshuizen et al. 2007; Keeley et al. 2018). The novelty of our findings is that they indicate that resources are not a static, constant, and identical concern for conservation practitioners. Resources are influenced by and co-implicated with governance, funding architectures and national (economic and political) policies in determining how science is used in practice. Furthermore, because this articulation is determined by multiple factors that often vary in space it creates *geographies of the science-practice interface*, which so far have been neglected in the literature (Eden 2016) with most studies assuming a geographically homogeneous science-practice interface.

Our results also resonate with Adams et al. (2014) who identify a paradox between the doctrine of governance-beyond-the-state and scientific paradigms such as large-scale conservation or systematic spatial planning that require the state "*in full command of both its territory and its extractive sectors*" (Sandberg 2007, cited by Adams et al. 2014:583). In the English case, our results echo the findings of Lockhart (2015:341), who in the context of biodiversity offsetting identified a contradiction between rolling out a "*mandatory offsetting system with the sufficient resources to deliver meaningful outcomes*" and the de-regulation and austerity agendas of the 2010-2015 UK government.

Our results regarding competitive funding in a period of diminishing public expenditures for the environment are also salient. First, in an era of severe cuts to the environment sector, organisations that supply public benefits and goods increasingly have to conform to specific criteria to acquire funding. Second, the findings also highlight the Janus face of partnership working and the need for more nuanced approaches to the study of partnerships, especially in cases that require extra-local multi-partner coordination like connectivity conservation. As the NIAs case shows (see also Collingwood Environmental Planning 2015), partnership can be a very efficient way of achieving agreements and providing space for deliberation, a way to tackle larger projects and maybe even are required for achieving ambitious targets. Nevertheless, when these partnerships are competitively funded, there are at least two inherent dangers: conservation on-the-ground being dictated by the funders; and driving up competition among partners and reducing the inherent benefits to be gained from fruitful collaboration. Furthermore, considering that agri-environmental schemes embedded in the Common Agricultural Policy were the main source of funding for a significant amount of actions (see also Adams et al. 2016 who make a similar case), the post-Brexit situation in England becomes crucial. How agri-environmental funding gets directed will play a role in the ability of organisations and partnerships not only to measure and enhance connectivity, but also make good use of the science that they are familiar with and underpins their actions.

5. Conclusion

The disconnect between science and practice in ecology and conservation is related to knowledge bottlenecks, but such an explanation on its own is partial and there are other significant factors that have to be included in any model of the science-practice space. Firstly, the plasticity and ambiguity of connectivity concepts creates potential barriers to implementation. The issue is confounded by the proliferation of actors that are involved with conservation on-the-ground that is in turn causing an explosion of different concepts and approaches on an already debated (Fahrig 2013) subject such as connectivity. If our findings hold, the positive aspects of more diverse actors and publics (Eden 2016) being involved with practical conservation may result in ambiguities in the use of scientific concepts, leading to coordination issues and dilution in the application of certain scientific concepts or advances. The challenge is how not to erase this emerging plurality, but to find scientific and practical ways to work around the inherent strategic coordination risks such a condition entails.

Secondly, the availability of resources seems to be a very important and material issue, especially if we consider that funding issues are complex and interrelated and influence available personnel, infrastructure (software and hardware) and time. While the issue of resources comes up repeatedly in the literature, it is mostly confounded with funding, and there is little research on what it means on the ground, nor any substantial interrogation of how political-economic changes affect conservation on-the-ground. While this article did not aim to identify solutions, there are some practical and relatively fast – but definitely *not* problem-resolving – measures that could be taken. For example, more well-paid internships for young scientists could provide both well-educated staff for conservation organisations and allow conservation to learn a lot from on-the-ground conservation in a collaborative framework. Furthermore, more investment in open-source software would make running quantitative connectivity analyses less costly; for example, Natural England is writing some connectivity software using open source software libraries that can be extended or added to any GIS. More broadly, moving away from project-based conservation into longer term engagements that can be adaptive and continuous would allow for better resource planning.

Third, the governance, political and economic drivers of knowledge utilisation are always present, co-producing the science-practice nexus, in co-articulation resource issues. Hence, there is no easy solution to the resource-related problems of the science-policy interface – certainly as Wyborn (2015b:11) notes, more "*funding is not a panacea*". To paraphrase Lockhart (2015:342), there is an irreducible and understudied relationship between the successful roll-out of large-scale strategic planning and restoration initiatives, and their articulation with broader political and economic paradigms, such as the UK variants of post-2008 neoliberalism.

To sum up, firstly, we have uncovered the divergent conceptualisation of connectivity and how these conceptualisations influence if and how connectivity is assessed in conservation and planning. Secondly, we documented the central role diverse resources play in the utilisation of scientific methods by practitioners. Thirdly, we saw how governance-beyond-the-state is implicated in shaping the science-practice interface of conservation in particular ways that are essentially ambivalent. Fourthly, we showed how novel forms of governance, and particularly competitive funding/bidding, can diminish the potential for fruitful partnership working.

In closing, we would like to flag up the generalisability of our results and discussion, acknowledging that they are drawn from a UK context and certain limitations do apply. Regarding conceptual “plurality”, our findings should be applicable widely, considering connectivity is a global concept, and its diversity of conceptualisation does not reflect a UK peculiarity but has been well documented across countries (Crooks and Sanjayan 2006; Hodgetts 2018). Regarding the role of diverse resources in driving the practical implementation of scientific concepts, we argue again that our findings are applicable in non-UK contexts, since they are more often than not country or culture independent. Finally, while the particular interplay between novel forms of governance, changing economies and large scale conservation and planning may be unique to the UK or Europe (Apostolopoulou et al. 2014), we argue that our findings allow for limited and careful interpolation since such changes have been, in variegated form and to a certain extent, global (Brenner et al. 2010).

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List of table captions

Table 1. Themes used in the analysis and examples of codes.

Table 2 A selection of quotes from conservationists pointing to the resources issues they have grouped according to resource type.

Table 3 Actors involved in preparing GI strategies, frameworks and plans in England, 2005-2015. Data compiled by the authors from a list of 58 documents available online (see supplementary material Table 1)

Table 1

Theme	Codes in theme (examples)
Concepts of connectivity	Functional connectivity; structural connectivity; planning concepts of connectivity (e.g. footpaths, cyclepaths)
Methods of connectivity assessment	Ecology based; planning based; graph-based methods; Fragstats; GIS-based; systematic methods
Criteria for method choice	Scientific legitimacy; resources; understanding of the method; connectivity analysis is simple
Implementation barriers	Resources, irrelevance of science

Table 2

Resource	Quote
Equipment (including software)	*We don't have access to GIS.* *Some of them* [NIAs] *are very capable, or others don't have any GIS capabilities.*
Personnel	*If this was done 10 years ago, I am sure I would have a team of 5 people, he would have a team of 5 people … now we don't do in depth analysis, we do it quite broad brush.* *We lost Ranger's Services … from 11 staff now it's only 2*
Time	*We might be using a Fragstats approach, but no time for now.* *The timescales were so quick and we were so pressurised so we had to be based on expert knowledge.* *In two years you cannot do more than the baseline.*
Budget	*The only way we measured connectivity is mean distance between occupied patches … We don't have the resources to do more than that.*

Table 3

Type of organisation	Number of GI documents
Consultants	21
Consultants with business partnership	6
Consultants with district, local or county council	6
Consultants in a multi-stakeholder partnership*	6
County/District/Local Councils	10
Third sector	1
University	2
Community Forest	2
Partnership	1
Unknown	3

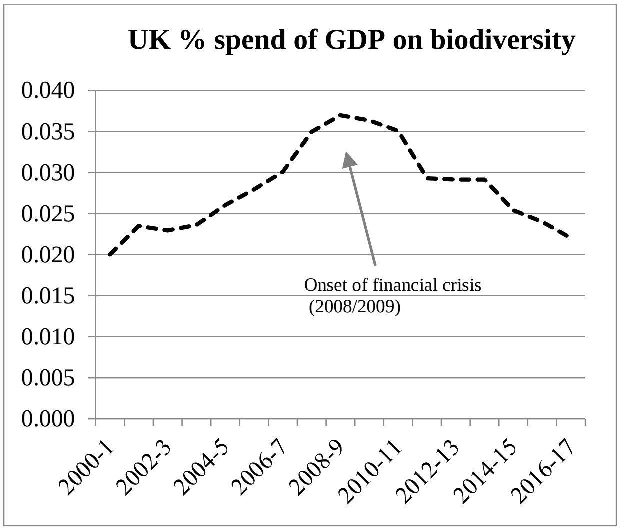
*** Typically these multi-stakeholder partnerships are very diverse and include governmental or quasi-governmental organisations (e.g. Natural England), NGOs, local councils, development agencies, or even other partnerships.**

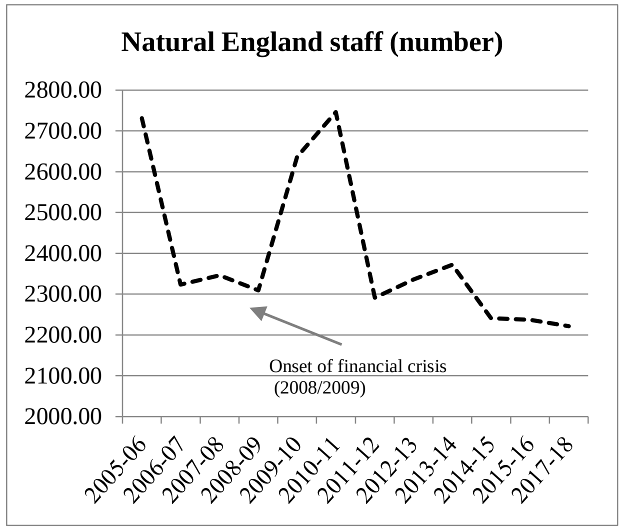
List of figures

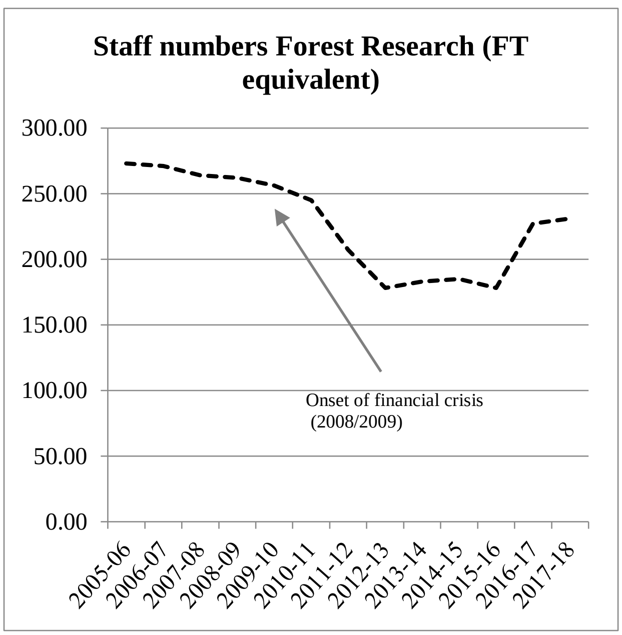
Figure 1. *Top Left*: Public spending in biodiversity as percentage of GDP, from http://jncc.defra.gov.uk/page-4251.*Top Right*: Absolute number of Natural England staff from the years leading up to the crisis up to now. Data compiled by the authors from Natural England annual reports and accounts, available at: https://www.gov.uk/government/collections/natural-england-annual-reports-and-accounts. *Bottom*: Full-time equivalent number of Forest Research staff from the years leading up to the crisis up to now. Data compiled by the authors from Forest Science annual reports and accounts, available at https://www.gov.uk/government/collections/forestry-commission-annual-reports. Increase of staff between 2016 and 2017 due to the "internal" move of 44 FT-equivalent staff from the Forestry Commission to Forest Research.

Figures

Figure 1







Figure

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