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The land sparing – land sharing controversy: Tracing the politics of knowledge

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ABSTRACT

Feeding 9 billion people by 2050 on one hand, and preserving biodiversity on the other hand, are two shared policy goals at the global level. Yet while these goals are clear, they are to some extent in conflict, because agriculture is a major cause of biodiversity loss, and the path to achieve both of them is at the heart of a public controversy around 'productive' land use and biodiversity conservation. Over the years, the scientific, policy, civil society and agri-business communities have been engaged in producing evidence that can support a land sparing policy (separating intensive agricultural production from biodiversity conservation) or a land sharing policy (integrating the two in larger and more extensive landscapes). This paper contributes to this debate by analyzing land sparing and land sharing (LSS) as a socio-technical controversy. Through the analysis of large and small corpora of scientific, policy, corporate social responsibility and sustainability standards documents we explore the ethical underpinnings and social networks that support the opposing sides of this controversy. We explore these linkages in order to explain how the concept of land sparing achieved dominance in the scientific literature and how the concept has been taken up in international policy, business and civil society circles. We examine the convergences and divergences in alliances between actors in this controversy in order to map how specific actors have promoted the concept of land sparing as the best way to used land for biodiversity and food production.

1. Introduction

Feeding more than 9 billion people by 2050 and preserving biodiversity are two shared global policy goals (FAO, 2012; UN, 2015). Yet these goals are conflicting: agriculture is a major cause of biodiversity loss and the path to achieve both animates a public Land Sparing-Sharing (LSS) controversy over 'productive' land use and biodiversity conservation (Desquilbet et al., 2017; Goulart et al., 2016; Grau et al., 2013; Hertel et al., 2014; Lambin et al., 2001; Mertz and Mertens, 2017). Over the years, the scientific, practitioner and agri-business communities have been engaged in producing evidence that can support a "land sparing" policy (LSP: separating intensive agricultural land from biodiversity-rich wildlife spaces) or a "land sharing" policy (LSH: integrating biodiversity-rich practices into agriculture, but with lower yield per hectare hence *a priori* less 'pure' wildlife spaces left elsewhere). A pivotal year in the controversy was 2005, when influential articles were published in *Science* (Green et al., 2005a) and in *Global Change Biology* (Balmford et al., 2005). The authors presented a simple theoretical, ecological model of the relations between agricultural yields, land use and biodiversity. Based on this model and empirical evidence, they argued that LSP was more favourable for biodiversity preservation. Green et al.'s article immediately sparked debate as it seemingly confirmed, with a simple and easy to understand model, the LSP option that supported the dominant, yet contested, policy towards industrial input-intensive agriculture.

This article explores this debate as a socio-technical controversy (Lascoumes, 2002) so to reveal the points of tension where scientific uncertainty and private interests interact to contest or confirm the *status quo* (Bonneuil et al., 2008) in favour of 'agri-business as usual'. We respond to the question: *why has the concept of land sparing dominated the debate and how has this translated into practice*?

We analyse what type of evidence is presented, who presents it and how the actors of the debate are linked in the networks that sustain the controversy. We do this by mobilising bibliometric and lexical analysis

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of key documents from scientific, industry and civil society sources. We examine how the concept of LSP led to the emergence of an opposition concept of LSH. We explore the ethical roots of both concepts and show how they have travelled outside the scientific community. We follow their translations into the corporate social responsibility (CSR) claims used by agribusiness and sustainability standards, which turn discourse into action. We examine the convergences and divergences in the actor networks so to map how specific actors have promoted these concepts. Through this analysis we argue that the LSS controversy is partly a debate about two imaginaries (Jasanoff, 2015) of human-nature relationships. These imaginaries drive the assumptions of both the ecological models and analyses, and the social networks that enable their results to circulate from scientific journals into sustainability metrics.

We argue that the LSP approach has gained dominance not because the scientists have unequivocally proven that high-input industrial monocultures are more sustainable for biodiversity conservation, but because their models require inputs and provide outputs that are translated into simple metrics that are easily integrated into tools of the dominant paradigm. This contrasts with the LSH approaches that argue for integrated landscapes requiring varying degrees of collaboration and accountability between human and natural systems, which is more difficult to quantify and put into practice. Likewise, we find that the networks that have been built up to support the production and application of these imaginaries also demonstrate a less united front on the side of the LSH community, while the LSP network is more focused and integrated in their collaboration. These two elements – the type of knowledge and the type of network – demonstrate how the imaginary that farmland must be separated from and spared for nature still dominates public debate.

2. Tracing a controversy through text

Our conceptual framework relies upon a combination of two approaches, the tracing of controversies and the performativity of socio-technical objects. Together, they enable us to see how socio-technical objects can act upon the world with real consequences (Callon, 1992). We use them in combination to demonstrate how land-use models can be both instruments of knowledge and politics in public debates on agriculture and biodiversity.

2.1. Analytical methods

Emerging from the French school of the sociology of science and technology (Akrich et al., 2006), the 'study of controversies' is a methodological tool to understand new topics in science and technology that are not yet stabilised. It is an approach to understanding the dynamics of scientific expertise (Collins, 2014) that takes into consideration the contested nature of 'science in action' (Latour, 1987) from the vantage point of an analyst who can only see hypotheses that are partially tested and are still being discussed among peers (Pestre et al., 2015). The analysis goes beyond a literature review, to account for the fact that these controversies are not contained only in the pages of scientific journals, but have often moved into public debate (Bonneuil et al., 2008) – appearing in newspapers (e.g., The The Economist, 2013), CSR reports and even certifiable standards.

To study a controversy, it is important to observe from as many viewpoints as possible and to follow the actors' discourse (Venturini, 2010). Different actors rely upon interpretative tools – such as models or standards - to help advance their world-view. In this sense, we can identify a controversy by the forms of proof that are put forward by different actors to support their position and the language that is used by the actors to demonstrate their disaccord, to provoke or convince their opponents and to justify their arguments (Lemieux, 2007). In other words, we pay attention to how the proof is 'performed' (MacKenzie et al., 2007). This is done both through the modelling of the interaction of land use and biodiversity conservation and through the translation of this model into simplified indicators in sustainability standards and CSR reports. The latter metrics enable collective visions of desirable futures, what Jasanoff (2015) calls socio-technical imaginaries, to be put into practice (Busch, 2011).

To trace the LSS controversy, we relied upon a mix of social network analysis and lexical co-word analysis (Callon et al., 1983; Chavalarias and Cointet, 2013) to study scientific articles, CSR reports and sustainability standards. We constructed three separate corpora of documents and analysed them with the CorTexT platform.[1] This analytical method uses texts as objects of scientific and policy production and adopts a linguistic and semiotic analytic approach that is based on lexicometry (chi2 statistics and classification). It identifies recurring lexical combinations and counts the co-occurrence of words that have statistically significant relationships (Martinez, 2011). Additional social network analysis of relationships between actors was conducted based on metadata identified in bibliographic records and classic qualitative analysis and interviews with five key authors triangulated the results.

2.2. Scientific corpora

We constructed two corpora of scientific articles from bibliometric entries found in the Web of Science (WoS) database. WoS contains scientific articles considered to be at the top of their field, but has the important limitation of including mainly journal articles written in English. We selected articles that could be categorised either as promoting a LSP or a LSH approach. To do so, we developed sets of keywords and used them to identify LSS articles in the WoS database. Our first scientific corpus (i.e., 'small corpus'), gathers articles published in WoS through 2016 mentioning the exact phrases 'Land sparing' (168 results) or 'Land sharing' (128 results) in the WoS 'topic' field. We combined these two databases, cleaned the data,[2] and obtained the 'small corpus' with 200 articles. We used this small corpus to qualitatively analyse the content of controversy, identify its main actors (Section 2) and to quantitatively analyse its networks (Section 4).

Our second scientific corpus (i.e., 'large scientific corpus'), represents the broader literature feeding the LSS controversy. During an expert workshop in 2015, the authors and experts in ecology, economics, sociology and political science developed a binary list of keywords that described the agricultural approaches of the controversy. This list was re-reviewed by the authors to develop a definitive list of keywords (41 keywords for LSP, 56 keywords for LSH).[3]

We then created a discrete WoS query for each list of keywords. We only kept the results that also contained one of the three additional qualifiers 'land', 'agriculture' or 'biodiversity' so to avoid articles not related to the controversy. The resulting large scientific corpus consisted of 104,272 articles published between 1956 and 2016. It included 81,333 bibliographic records for LSP, and 35,545 for LSH, with 12,606 references in both sub-corpora (a 12 percent overlap). We adopted this much larger corpus for quantitative lexical analysis with the CorTexT algorithms to provide statistically significant results (Section 3).

From each corpus (LSP and LSH), we conducted an automatic multi-

[1] http://www.cortext.org

[2] We removed the repeated references and the few articles that related to the 'sharing of land' among people as part of land conflicts.

[3] The land sparing keywords were: land sparing; high yield; higher agricultural yield; conservation; production target; farming intensively; intensive management; agrochemical inputs; protected areas; pristine nature; land scarcity; mechanization; land use zoning; external inputs; big business; industrial agriculture; conventional; intensive farming; spare land for nature; large scale farming; monoculture; high input agriculture; pest control; green revolution; export-oriented agriculture; land for conservation; labor-and capital-intensive technologies; globalization; precision agriculture; intensification; agricultural technologies; Borlaug hypothesis; artificialisation; life-cycle analysis; wilderness; productionis*; irrigation scheme; simplified ecosystems; personal protective equipment; increasing yields; productivism.

Table 1
Term Lists for Land Sparing and Land Sharing used for analysis.

LAND SPARING		LAND SHARING	
Main term	C-value	Main term	C-value
conservation planning	4576	sustainable agriculture	5449
precision agriculture	4234	biological control	3485
genetic diversity	3924	agroforestry systems	2478
bird species	3443	environmental quality	1679
land management	3395	pest management	1627
nature conservation	3114	soil carbon	1619
habitat loss	2964	agricultural landscapes	1594
high levels	2857	natural enemies	1507
soil conservation	2750	land conversion	1458
habitat types	2747	integrated pest management	1437
conservation efforts	2703	management strategies	1430
natural resources	2550	ecosystem functions	1425
soil moisture	2522	smallholder farmers	1381
conservation value	2520	plant growth	1274
population size	2434	carbon stocks	1230
conventional tillage	2421	organic agriculture	1189
conservation practices	2420	carbon storage	1096
conservation status	2401	forest conversion	1003
conservation tillage	2354	soil samples	931
biodiversity hotspot	2347	land use types	923
conservation priorities	2347	provision of ecosystem services	875
sustainable development	2330	organic matter	871
habitat fragmentation	2297	agricultural soils	867
soil loss	2232	biodiversity and ecosystem services	855
tillage systems	2187	biodiversity loss	841
agricultural production	2154	carbon dioxide	838
water conservation	2119	biological control agents	833
conservation policy	2007	ecosystem functioning	832
conservation areas	1963	pesticide use	832
conservation measures	1896	weed control	830
objective study	1847	insect pests	819
bird communities	1779	natural forest	767
gene flow	1762	rural areas	760
soil water	1749	growth rate	720
land degradation	1716	heavy metals	709
geographic information system	1677	food systems	708
winter wheat	1627	microbial biomass	706
conservation actions	1597	bulk density	701
soil type	1583	payments for ecosystem services	683
negative effects	1578	ecosystem service value	671
plant species richness	1572	use efficiency	662
national parks	1537	life cycle assessment	653
local communities	1531	host plant	648
forest types	1502	soil management	648
habitat suitability	1487	positive effect	645

Note: These terms were extracted from the following fields of each document in the two sub-corpora of the Large Scientific Corpus: Abstract, Acknowledgement, Keywords, Title. CorText enables us to extract composite terms (n-grams) that better capture the meaning of the text. The c-value is the frequency indicator that is calculated at the level of each sentence in the document fields.

terms extraction (Kageura and Umino, 1996), which generated a list of the top 45 terms most frequently used (represented by their c-value, (Frantzi et al., 1998)) for LSP and LSH. We used these terms (and not the expert-developed keywords) to represent the concepts of LSP and LSH in our analysis as they best describe the content of these two sub-corpora of the large scientific corpus (Table 1).

2.3. CSR reporting (industry corpus)

For the industry corpus, we used the CSR or sustainability reports of the top agri-business multinational corporations in the world. These enterprises often carry first-mover's advantages in adopting sustainable practices and lead others in the industry to follow suit – thus holding political power in the field. To identify the organisations to be included, we first consulted the European Commission's ranking of top 2500 world enterprises investing in research and development in 2015,[4] and identified those in the food and beverages, agriculture or chemical sectors. We then examined the revenue for top global enterprises in food and agriculture based on the 2016 ranking on revenue and profit completed by Fortune 500.[5] These two rankings provided us with our sample of 20 'lead' enterprises for Agrochemicals, Food production, Food retailers and Food and beverages (Table 2). Their sustainability reports were found in the Sustainability Disclosure Database[6] maintained by the Global Reporting Initiative (GRI)[7], which is the data source for reporting on Sustainable Development Goal 12.1 (corporate reporting). Where available, we collected these reports from 2005 to 2014, to coincide with the date of the pivotal article in the LSS controversy. However, most reports in our corpus date from 2007 as sustainability reporting was not common beforehand.

2.4. NGO sustainability standards (standards corpus)

The final corpus provides insights into where visions of land use are being implemented. Since the late 1990s, there has been an explosion of sustainability standards developed by international NGOs that are implemented by farmers and multinational corporations, often with the support of UN and other public agencies (FAO, 2014). Therefore, the analysis of how the scientific controversy has translated into clear criteria that must be complied with by farmers and checked by third-party certification offers a strong case for the performative aspect of the LSS controversy. We created a corpus based on the standards included in the *State of Sustainability Initiatives (SSI)*,[8] which is an independent report that analyses the characteristics, performance and evolution of markets for certified products. We included the annual reports (available only from 2010 to 2016) of the 16 standards development organizations that focus on agriculture and land use, which are: The Global Coffee Platform (4C standard); Better Cotton Initiative (BCI); Bonsucro; Cotton made in Africa; Ethical Tea Partnership (ETP); Fairtrade International (FTI); Forest Stewardship Council (FSC); Global GAP; IFOAM Organics International; Programme for Forest Conservation (PEFC); ProTerra Foundation; Rainforest Alliance ; Roundtable on Sustainable Biofuels (RSB) ; Roundtable on Sustainable Palm Oil (RSPO); Roundtable on Responsible Soy (RTRS) ; UTZ Certified.[9] The majority of these standards are multi-stakeholder initiatives (Cheyns and Riisgaard, 2014), which means that some of the actors from our industry corpus (particularly the food and beverage and retailors) have also contributed to setting some of these standards. This influence is explored in our analysis.

3. What is controversial about land sparing?

The way in which agriculture uses land has significant effects on agricultural productivity, the environment, and the social organisation of agri-food systems. The point of underlying contention between LSP and LSH notions is how to find the 'best farming method' that can balance the trade-offs between agriculture and biodiversity.

The Green et al. (2005a) article serves as the critical junction for our analysis because it was the first to explicitly use the term 'land sparing'.

[4] *R&D* ranking *of the world top 2500,* 2015, http://iri.jrc.ec.europa.eu/scoreboard14.html

[5] http://fortune.com/global500, accessed 16/06/2016

[6] http://database.globalreporting.org/search, accessed 26/05/2018

[7] For more information on the GRI, see: http://www.novethic.fr/lexique/detail/gri.html

[8] https://www.iisd.org/ssi/, accessed 26/05/2018

[9] In 2017, UTZ certified and Rainforest Alliance – two standards with the highest number of certified producers – announced a merger and the creation of a harmonized standard.

Table 2
Sample of agri-business and agro-chemical firms in the industry corpus.
Source: Adapted from Fortune Global 500, 2016.

Sector	Agrochemicals[a]	Food and Beverage	Food Retailers	Food Production
Ranking 2014 revenue in millions of USD	Syngenta : 11.4 Bayer : 10.2 Basf : 7.2 Dow Chemical : 5.7 Monsanto : 5.1 DuPont : 3.7	Nestlé : 99.5 PepsiCo : 66.4 Unilever : 66.1 Coca Cola : 44.3 Danone : 28.3	Walmart[b] : 476.2 Cargill : 134.9 Tesco : 103.2 Carrefour : 101.7 Kroger : 98.3	ADM : 89.8 Bunge : 62.5 Wilmar : 44.1 JBS: 43

[a] These six enterprises sold, by themselves in 2007, 85% of the pesticides purchased in the world. Between 2015 and 2017 three megamergers were conducted consolidating this field into three new companies with a slightly higher percentage of global pesticide sales: ChemChina-Syngenta, Bayer-Monsanto-BASF and Dow Chemical-Dupont.

[b] Walmart is the top ranked enterprise in the world in terms of revenue.

The authors asked: "How should we best resolve the need for increased food production with the desire to minimize its impact on what remains of wild nature?" To answer their question, they developed a simple model based on the relationship between biodiversity and yield. They showed that, if this relationship is convex rather than concave, in a biodiversity-friendly but lower-yield agricultural system, the biodiversity gain on the already cultivated areas would be lower than the biodiversity loss on the new (wildlife) land that would need to be cultivated in order to meet the same production level of zero-biodiversity but higher-yield agriculture. They concluded that empirical evidence supported a convex relationship between biodiversity and yield and therefore a superiority of land sparing over wildlife-friendly farming.

'Land sparing' is so named as to 'spare' (wildlife) nature – in the sense of economising the use of land and saving 'natural' areas where biodiversity can be left intact. We trace the first mention of the concept of 'saving' land to a paper by Norman Borlaug (1987). In this paper, he titled a column of a table 'area saved by yield increase' (p. 392) and argued that the increased yields had resulted in a 'saving of 29.9 million hectares for other uses' (p. 393). Thus was born the 'Borlaug hypothesis' of land sparing (Angelsen and Kaimowitz, 2001; Pirard and Belna, 2012). The notion of 'sparing land for nature' was introduced later by Waggoner (1994), as pointed out by Hertel et al. (2014). Green et al., (2005b) quote both Borlaug (1987) and Waggoner (1994). This conceptualisation fits the 'productionist' argument (Fouilleux et al., 2017) where the question of global food security is reduced to the need to increase agricultural production. It leads to discrediting biodiversity-friendly farming and creates the imperative that the fewer hectares under agricultural production mean a greater conservation of 'nature'.

Since 2005, we observe an increase in the number of publications on LSP (Fig. 1). However, this 2005 publication immediately inspired two critiques, one as a response letter in *Science* (Vandermeer and Perfecto, 2005) and the other as a short article in *Conservation Biology* (Matson and Vitousek, 2006).[10] These critiques noted that the negative environmental impact of chemical fertilizers and pesticides were barely considered by Green et al., (2005b). Yet the controversy only emerged in 2008 and 2010, when strong retorts based on original data were published using the notion of the 'agroecological matrix' as a counterpoint to 'land sparing' (Perfecto and Vandermeer, 2008, 2010). The authors argued that the initial framing of the problem where agriculture must meet a given production target is problematic, as intensification is often accompanied by an expansion of markets – i.e. the 'rebound effect' or 'Jevons paradox' (Alcott, 2005; Desquilbet et al., 2017). Lastly, Perfecto and Vandermeer questioned the assumption that there necessarily be a trade-off between biodiversity and yield, as agroecological systems can be highly productive while maintaining and promoting biodiversity.

However, in their articles, Perfecto and Vandermeer did not employ the term 'land-sharing'. Neither did Foley and colleagues when they published in 2005. Nor did the historical body of literature that demonstrated, with data from the neo-tropics, that biodiversity and ecosystem services in farming areas (the 'countryside') were paramount to the future of biodiversity and that farming and biodiversity coexist (Foley et al., 2005). Indeed, at that time, the term 'land sharing' did not yet refer to the myriad practices used in extensive or ecologically intensive farming. The term 'land sharing', with its current meaning, was coined in 2011 by Green's group, who referred to a "lowest-yield land sharing strategy" (Phalan et al., 2011b). Their main argument was no longer centred on higher yields for a growing population, but shifted in focus towards biodiversity conservation and the possibility that land sparing could reduce deforestation and habitat degradation if it were truly accompanied by a policy of protected areas. The politics of consumption also began to enter the debate as the authors called upon consumers to reduce their meat consumption and proposed alternative hypotheses about the causes of food system inefficiencies (such as food waste and petroleum-based cultures) (Phalan et al., 2011a).

In the early 2010s, the argument for 'sustainable intensification' ushered in new terms for debate, focused on agronomic practices. Citing FAO and OECD documents, Tscharntke et al. (2012) argued that the LSP option was preferentially associated to the perverse effects of the diversion of food crops towards livestock feed and biofuel production, providing incentives for land grabbing, food losses and waste, and food price speculation. They also invoked the 'paradox of scale' claiming that LSH was preferentially associated to small-scale farmers, who are the backbone of global food security in the developing world. They argued that small-scale diversified production would be more productive than the large-scale monocultures associated with LSP, due to the possible beneficial effects of biodiversity within cultivated areas.

Following this period of hot debate in 2011-12, scholars continued to present evidence to support each opposing side. Scientific articles have focused on the LSS controversy itself, illustrating how there were problems with other assumptions in the original model (Desquilbet et al., 2017; Goulart et al., 2016; Hertel et al., 2014; Perfecto and Vandermeer, 2012). Recent work has uncovered political influences, citing that formal recognition of indigenous peoples' rights have played a role in reducing the market expansion effect of land sparing (Ceddia et al., 2015) and that nations often use contradictory policies that promote divergent incentives for intensive land use (Mertz and Mertens, 2017). Fischer et al. (2014) took a particularly political stance in their analysis of the controversy as they argued that the reduction of the terms of debate to a trade-off between biodiversity conservation and production required value judgements to be made and recognised by the scientists. Their article enlarged the scientific arena, suggesting that the 'real' causes of food insecurity within food systems, i.e., the politics of industry interests and access, must also be considered. In the follow sections, we pick up this latter point, but argue that there are more subtle politics of knowledge also at play in the LSS controversy.

4. Ethical underpinnings: conceptualising human-nature relations

In their retort to Green et al. (2005a), Vandermeer and Perfecto (2005, p. 1257) argued: "Most conservation biologists have gone beyond the simplistic idea that there is 'wild habitat' and 'agricultural land.' Most land is subjected to some sort of human interference." Green et al., (2005b) reply did not answer this particular statement. In this section, we argue that their lack of a dedicated response may be linked

[10] These articles do not appear in Fig. 1: the Vandermeer and Perfecto article is included in the WoS database but not selected by our keywords, while the Matson and Vitousek article is not included in the WoS database.

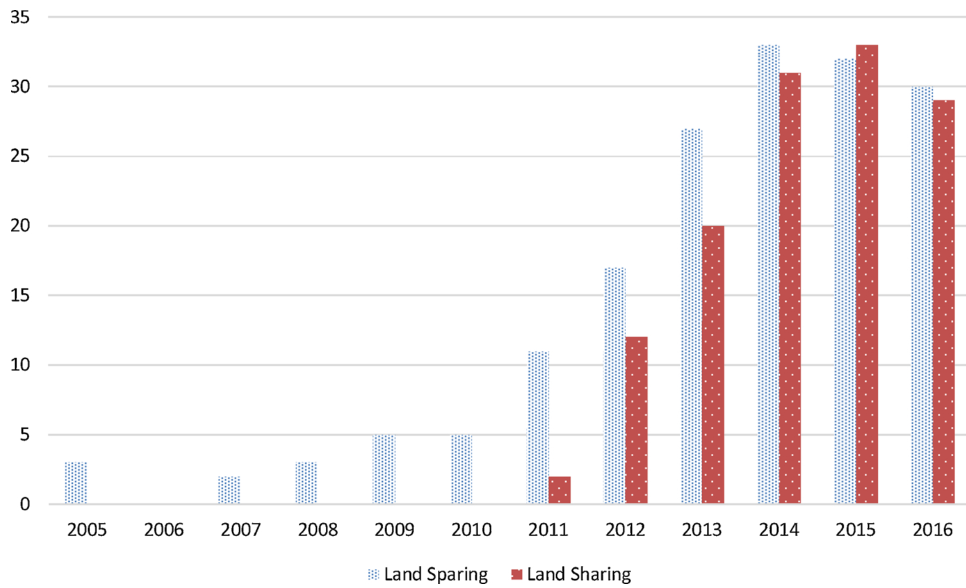

Fig. 1. Number of Publications in the LSS Controversy (2005–2016). NB: Small scientific corpus representing the LSS Controversy.

to a fundamental difference in the two opposing positions of scientists in the controversy about the fundamental relationship between humans and nature. These ethics can be differentiated as follows: on the one hand, nature and agriculture cannot cohabitate because they have opposing needs (ethics); while on the other, biodiversity and agriculture are thought of, planned and integrated as one system, considered as mutually interdependent. This observation is in line with the analysis of scholars who argue that opposing camps in environmental controversies hold fundamentally different visions of the relationship between humans and nature (De Witt et al., 2016; Díaz et al., 2018). Some propose that we block off nature from humans to create wild sanctuaries and in this way, maintain its perfect 'natural' integrity (i.e., humans are outside of nature). Others claim that nature and human societies must be integrated, in order to ensure their stability and integrity (i.e., humans are integrated within nature). We argue that unlike more obvious politics of interests (e.g., financial and political influences) that are also at play, these opposite world-views can provide an understanding of the science-practice alliances that feed the LSS controversy.

4.1. Compositionalism vs. functionalism

To clarify these world-views in LSS, we drew upon a classic text in conservation ethics to develop a set of terms that we searched for within our databases: the *Current Normative Concepts in Conservation* by Callicott et al. (1999). This seminal text introduced two notions to operationalize two poles of biodiversity conservation philosophy, what they called 'compositionalism' and 'functionalism'. For compositionalism, culture separates humans from nature and due to cultural practices, humans alter the wilderness and the pristineness of nature. The discipline of ecology that is affiliated with this philosophy is based on a biological hierarchy of organisms at the heart of species' populations that interact within biotic communities. The concept of conservation that is privileged is the preservation of biodiversity (or conservation biology), biological integrity and ecological restoration away from the pervasive effects of human actions. In functionalism, humans are a part of nature and this ethic is captured with the scientific discipline of ecosystem ecology, which studies the functioning of ecosystems. The conservation approaches linked to this philosophy focus on understanding ecosystem health, ecological services and adapting human economies to ecological exigencies. Table 3 shows the words used by Callicott et al. to explain both philosophies and our adaptation of them into the language of CorTexT. Callicott and colleagues classify these schools of thought as complementary and non-competitive, meaning that empirically some practices can bridge or combine the two ethics.

To identify affinities between compositionalism/functionalism and LSP/LSH approaches, we compared the co-occurrence of terms representing LSP and LSH (Table 1) with those of conservation ethics (Table 3). Our contingency matrix (Fig. 2) illustrates the correlations (measured through chi2) between the 12 conservation ethics terms and the 12 most frequently used terms for LSH/LSP in the large scientific database. This analysis tends to indicate cumulatively stronger co-occurrences between LSP terms and compositionalism terms (top left quadrant, Fig. 2), and between LSH terms and functionalism terms (bottom right quadrant, Fig. 2).

The positive association between the compositionalism ethic and LSP terms in this figure has three main sources. First, each compositionalism term has at least two positive correlations with LSP terms. Second, preservation of biological diversity (compositionalism) and genetic diversity, and nature conservation and bird species (LSP) are highly correlated. These LSP terms designate how to best preserve biodiversity, while the anti-correlation between the preservation of biological diversity and specific agricultural practices (e.g., precision agriculture, sustainable agriculture, agroforestry systems, pest management) confirms that the ethic of preserving biological diversity prioritizes saving land for nature. Third, there are positive correlations between ecological restoration (compositionalism) and soil conservation and precision agriculture (LSP), which are conservation agriculture practices that reduce tilling (and thus human interventions) and allow for the ecological restoration of intensively used agricultural land.

The positive association between the functionalism ethic and LSH approaches mainly arises from each functionalism term being positively correlated with at least two LSH terms, and strong positive correlations between ecosystem health (functionalism) and environmental quality (LSH) and between nutrient cycles (functionalism) and agroforestry systems (LSH). We note correlations between ecological services (functionalism) and five of the six LSH terms; and between ecosystem management or nutrient cycles (functionalism) and pest management, agroforestry systems or sustainable agriculture (LSH). These correlations indicate interdependency between agriculture and natural systems.

The relationship between the compositionalism ethic and the LSH terms was overwhelmingly anti-correlated. However, the affinities between the functionalism and LSP terms was not so clear-cut, as we found correlations between functionalism and LSP terms (although

Table 3
List of keywords used to capture the compositionalism (blue) and functionalism (green) ethics in the large scientific corpus.
Source: Conservation concepts in Callicott et al. (1999).

main form	Lemmatisation forms	frequency	distinct number of documents
preservation of biological diversity	biodiversity preservation, preservation of biodiversity, biological diversity	2152	1651
ecosystem management	ecosystems management, management of ecosystems	1035	711
ecological restoration	restoration ecology, ecological restorations, restoration ecologies	1125	690
adaptive management	management of adaptation	908	600
ecosystem health	healthy ecosystem, ecosystems health	429	306
ecological services	ecological service	396	302
nutrient cycles	nutrient cycle, nutrients cycles	114	102
biotic communities	biotic community, community biotic, community biotics	104	97
biological integrity		105	74
evolutionary ecology	evolutionary ecologies, ecological evolution	51	46
ecosystem ecology	ecosystems ecology, ecosystem ecologies	35	30
biological hierarchy	biological hierarchies, hierarchy biological	3	2

Note: we excluded the functionalist term 'sustainable development' because of its broad use in the literature and its co-optation by the world of agricultural development and agribusiness after the 1999 publication. We selected only the 6 other most frequently occurring functionalism terms in the large scientific corpus so to have the same number as the compositionalism terms.

fewer than the dominant combinations noted above). We can explain these correlations by the context of use of these words. The functionalism philosophy of ecosystem management does use the LSP techniques of soil conservation, precision agriculture and conservation planning when discussing whole ecosystem management that includes agricultural land. In the same vein, the functionalism term adaptive management is a technique of conservation planning (LSP) when it is used to manage national parks and protected conservation areas – not agricultural land.

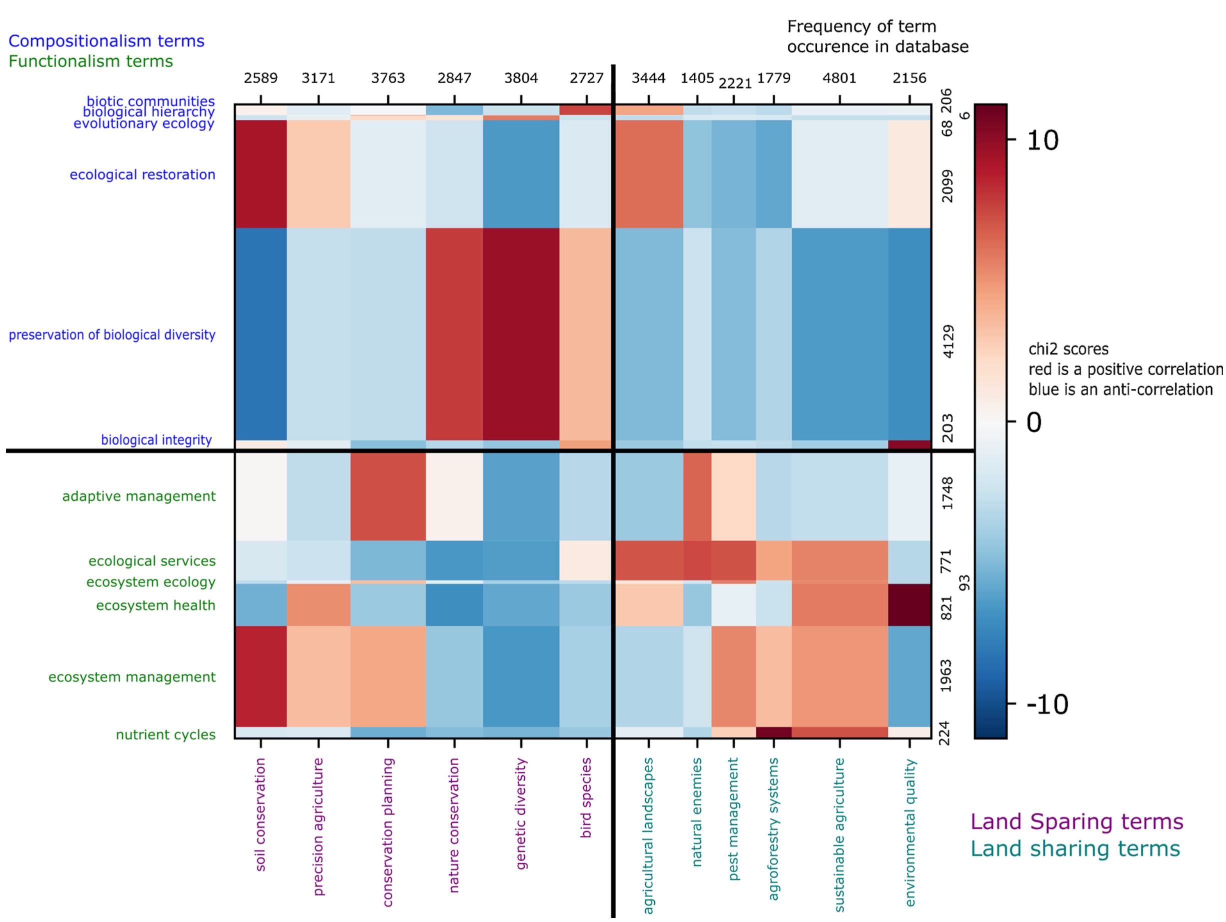

Fig. 2. Contingency Matrix between the Conservation Ethics Terms and the top 6 LSP and LSH Terms.
Note: These queries were made in the large scientific corpus. The contingency matrix shows the degree of correlation between any pair of terms from the conservation ethics list and those representing LSH or LSP. We combined the term lists to create a single matrix and we limited the number to 12 so to cover all of the ethics terms. The x-axis lists the conservation ethic terms, and the y-axis the land sparing/sharing terms. The size of the squares refers to the frequencies of the words found in the database. Red cells are the most correlated (many documents mentioning the term on the y axis also mention the term on the x axis within a 5-sentence range). Blue ones are anti-correlated (rarely does a document mentioning the term on the y axis also mention the term on the x axis within a 5-sentence range). White cells do not feature any correlation (joint mentions are neither more nor less numerous than the average co-occurrences throughout the corpus). The intensity of the colour represents the chi2 score of relevance. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

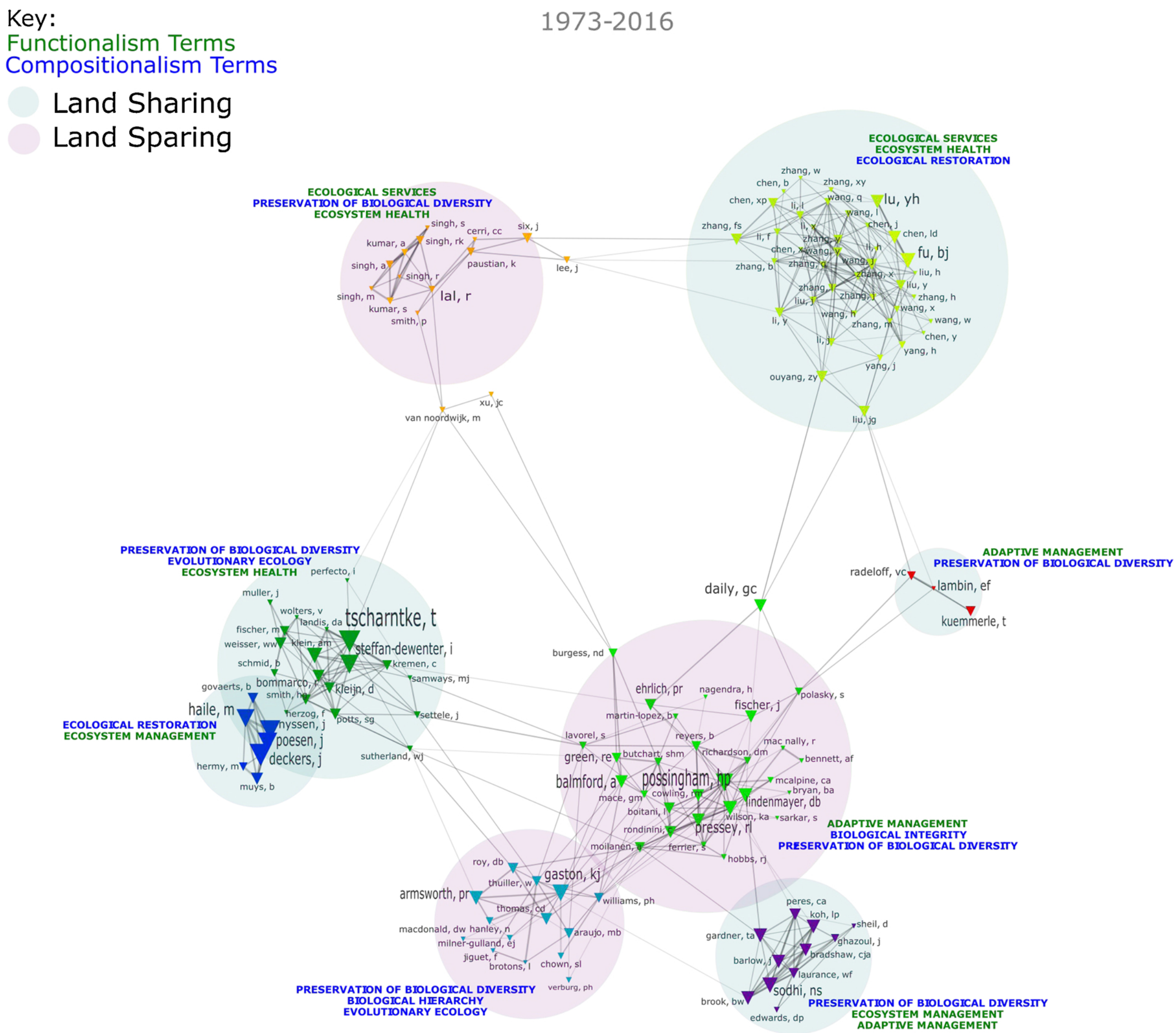

Fig. 3. Authors of the large scientific corpus clustered by Ethics terms.

Note: This figure illustrates the top 150 nodes of collaboration in the large scientific corpus. The triangles represent individual authors and their size is based on the number of co-occurrences. The more the interconnecting links between triangle nodes, the more co-publication there is between the authors. Based on the content of the articles, we identified whether clusters are LSH (turquoise) or LSP (violet). These clusters are tagged by the ethic that defines the author groupings, compositionalism (blue) or functionalism (green). The proximity of clusters signifies mention of the authors in the same or citing articles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2. Ethically bound networks

To further test these ethical underpinnings, we mapped the use of functionalism and compositionalism terms by authors in the large scientific corpus.

Fig. 3 shows a large, dense cluster of the dominant LSP authors around Possingham (Chief Scientist at the NGO Nature Conservancy and Professor at the Universities of Queensland, Adelaide and Stanford), who collaborate on the ‘preservation of biological diversity and integrity’ (compositionalism) but also ‘adaptive management’ (functionalism). A smaller cluster around Gaston (University of Exeter) focuses exclusively on compositionalism topics. Another group of LSP authors, linked through a joint publication represented by van Noordwijk (Mertz et al., 2012), focuses on a mix of compositional and functional topics through studies of the yield performance and soil health in conservation agriculture. The LSP authors dominate the work on the functionalist term ‘adaptive management’, which matches our analysis of Fig. 2.

On the LSH side, the most frequently occurring cluster is around Tscharntke (Professor of Agroecology at Göttingen University) in the middle left of the figure, and is characterised by their work on ‘ecosystem management’. The clustering is less dense among the LSH authors than the LSP authors. In general, the LSP authors are all linked, while the LSH authors are highly linked within their own clusters but not between. A large cluster of Chinese scholars (top right) working together on ‘ecological services’ is distant from the rest of the LSH clusters, which suggests that there are no co-publications. Their engagement in the literature occurs via the LSP work and via the Lambin (Stanford and Louvain) cluster that straddles the LSS controversy by contextualizing where each approach might work better (Lambin and Meyfroidt, 2011). The difference between the LSH and LSP groups that focus on ‘preservation of biological diversity’, which is the most pervasive ethic in the database, shows that these authors may discuss the same topic, but from different sides of the debate. For instance, while the LSP group seeks to achieve this preservation by creating protected areas, the studies contained in the LSH group demonstrate the importance of farmers as key conservationists through on-farm preservation of biodiversity (Bawa Kamaljit et al., 2011). Thus, while Phalan (2018, p.14) claims that “it is important to realise that land sparing is not about separating human beings from nature; it is about separating agriculture from nature”, our results suggest that the deeper ethic is at

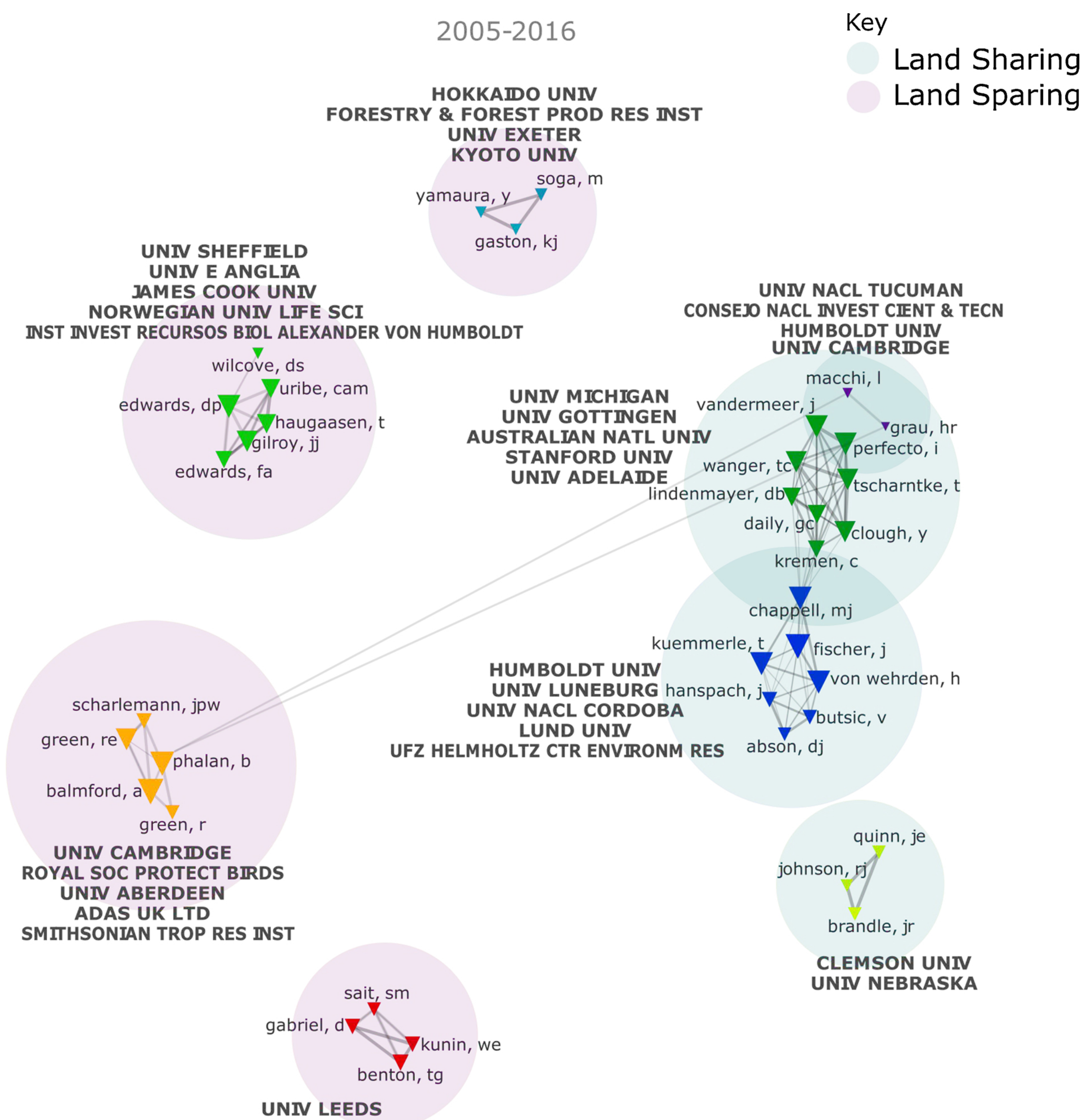

Fig. 4. Connections of Authors and Research Institutes in the Small Scientific Corpus.
Note: This figure groups together authors who co-publish together and has tagged the clusters with the 5 research institutes that are most important for each cluster. The linkages between individual authors illustrates that there is co-publication and the size of the triangles represents the importance of each author in the network based on the number of links that the author has. Clusters are identified as LSH or LSP based on our own reading of the articles.

work here; and it goes beyond simple differences in scientific traditions (Fischer et al., 2008) to separate the two sides of the controversy.

5. Legitimating controversial knowledge: the politics of connections

In this section, we examine the alliances that emerged on either side of this controversy so to reveal the networks associated with the dominant LSP ethics.

5.1. Science and industry collaboration: co-financing knowledge

In Fig. 4, we can see the LSH authors are clustered into an overlapping set of networks that group the Universities of Michigan, Tucuman, Humboldt, and Clemson. The LSP camp is separated into four contained clusters: the most well-known group includes the Universities of Cambridge and Aberdeen, the Royal Society for the Protection of Birds, ADAS UK (an agriculture and environment consultancy) and the Smithsonian Institute; the second largest is led by James Cook University, the Universities of Sheffield and Princeton, Norwegian University of Life Sciences, and the Institute Invest Recursos Biol Alexander Von Humboldt. The only linkage between the LSP and LSH clusters is through a collaboration of Phalan with Grau and Macchi; which provides insights into how agent-based modelling and landscape approaches are beginning to bridge the divide between the opposing camps.

Given the high number of co-publications, the scientists within the LSS controversy are clearly grouped in collaborating research institutes. By co-publishing mostly with colleagues in close-knit networks, each camp has built up their evidence bases through sustained collaboration on common topics. To be able to do this in practice, there must be

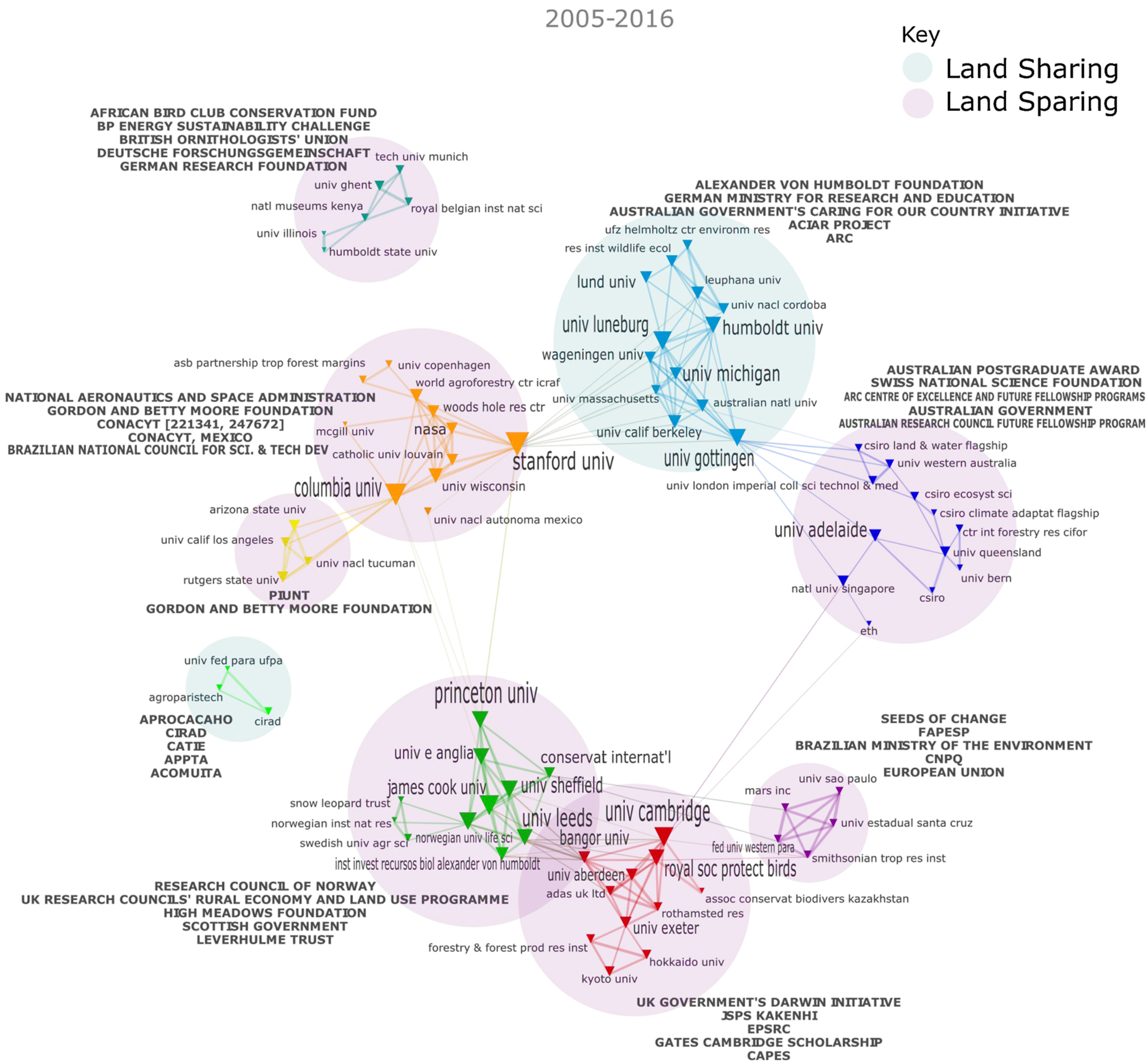

Fig. 5. Research Institutes and Funding Agencies in the small scientific corpus.
Note: This figure groups research institutes who co-publish together and has tagged the clusters with the 5 funding agencies that are most important in terms of occurrence for each cluster. The linkages between individual research institutes illustrates that there is collaboration and the size of the triangles represents the importance of each institute in the network based on the number of links that the institute has. Clusters are identified as LSH or LSP based on our own reading of the articles.

funding sources that facilitate this type of institute-focused collaboration. In comparing Figs. 4 and 5, we see that the research institutes that group authors together are also tied together through common funders. Moreover, Fig. 5 illustrates that the funders consistently finance either LSP or LSH research institutions.

The majority of funders in Fig. 5 are public research funding agencies (including ministries and international organisations), in particular from Germany, the UK, Australia and the US. A few interesting alliances between science and industry can also be seen through Foundation funding. Within the LSP group, four private donors, the Gates Cambridge Scholarship, the BP Energy Sustainability Challenge, Leverhulme Trust and Seeds of Change for Conservation International are connected to different clusters. Some have long-term investments in specific universities, but not all. For example, the Gates Cambridge Scholarship is a continuous program that funds students at Cambridge University,[11] while the BP Energy Sustainability Challenge was a one-off competition designed to fund innovative research. Seeds of Change, an organic seed company owned by Mars Inc, funded a strategic collaboration with Conservation International (CI) and university researchers on cocoa in Brazil. The project contributed scientific evidence to CI's 'Corridor strategy', which consolidates and connects established protected areas with unprotected forests to redevelop and expand essential natural habitats.[12] The published results reccomend including more 'wildlife friendly' practices in LSP strategies and to integrate these strategies into preferred buying schemes for those farmers who can be certified against sustainability standards (Schroth et al., 2011).

A key funder of the research clusters that link the LSP and LSH clusters is the Gordon and Betty Moore Foundation. Started by the co-founder of Intel Corporation, this Foundation is focused on environmental conservation and has strong links to CI. Their conservation program "balances long-term conservation with

[11] https://www.gatescambridge.org/experience/cambridge/communities, accessed 30/07/2017

[12] https://www.sciencedaily.com/releases/2007/03/070319175847.htm, accessed 05/05/2018

sustainable use."[13] The research that they have funded in the LSS controversy straddles the two communities with many results supporting LSP strategies, but with a general tendency towards developing dynamic, contextualised models that demand more integrated strategies in order for LSP to work in practice (e.g., Meyfroidt et al., 2014).

In general, it seems that there are fewer clusters of LSH researchers while their funders are typically public, like national research councils and institutes. For example, the Alexander von Humboldt Foundation, created by the famous naturalist explorer, creates opportunities for researchers to study in Germany, and is partially funded by German government agencies.[14] Many of the funders contributing to the LSH clusters provide individual research excellence grants and not the long-term grants needed for sustained collaboration among research groups. Hence the LSP clusters seem better positioned in terms of accessing funding.

5.2. The LSS terminology in industry CSR reports

According to Fig. 6, the LSP terms are also better positioned within industry discourse with regards to the uptake of their terminology in industry CSR reports. The use of the top four terms ('sustainable development', 'local communities', 'sustainable agriculture' and 'natural resources', 3 LSP and 1 LSH terms) dwarfs the other terms found in the corpus. This is an expected result, as industry is more familiar with the mono-functional agriculture promoted by LSP than with multi-functional agriculture promoted by LSH.

While the private sector use of the term 'sustainable development' is often equated with co-optation (Bruno and Karliner, 2002), 'local communities' are associated with the 'international development industry' (Hickey and Mohan, 2004).

A detailed reading of industry CSR reports suggests that the LSP terminology offers a vocabulary that industry actors can use in their required reporting for the sustainable development goals. For example, Syngenta commits to "make crops more efficient", that is, "**increase** the average **productivity** of the world's major crops by 20 percent **without using more land**, water or inputs" and states: "We are promoting and enabling action to **protect and enhance biodiversity** – primarily by managing marginal and less productive farmland **alongside fields** and waterways to create rich, connected wildlife habitats".[15] Meanwhile, in a section on "advocating for biodiversity", Monsanto claims: "we offer products and services that enable farmers to grow **more food** on **less land** using **fewer resources**, reducing the impact of farming on the natural environment."[16] In the two above quotes, the terms that we highlighted make it easy to identify the linkage between the LSP argument for separating agriculture from wildlife and intensifying production so to spare land for biodiversity conservation.

The imperative to reduce the amount of land used for agriculture is an important element of the LSP approach, which has already found practical applications. To illustrate this point, we highlight a design tool (EcodEX) that Nestle has developed to enable early-stage decisions about product design and sourcing strategies in the design process, so to reduce the environmental footprint of their products.[17] Along with four other environmental impact indicators, the tool allows non-expert product designers to measure land used for production by square meter (Adams et al., 2015). The algorithm follows the logic that the fewer the square meters used to grow any raw material, the more sustainable it is (Schenker, 2011). This logic is a direct application of the LSP argument and the result is an incentive to source from those suppliers who use less land more intensively.

5.3. Applying scientific knowledge: the power of standards

Sustainability standards first emerged in the 1980s as a way to hold supply chain captains and producers accountable for sustainable agriculture and forestry while simultaneously providing a market for certified products (Komives and Jackson, 2014). The first standards to establish sets of auditable criteria were those that focused on environmental concerns, such as the Rainforest Alliance, the Forest Stewardship Council, and organic agriculture (Loconto and Fouilleux, 2014). Embedded within environmental movements more generally, and the World Wildlife Fund specifically, these standards have offered a way to codify 'good practices' for sustainable agriculture that has gained wide ranging support from NGOs, private companies and governments (ISEAL, 2013). In 2012, certified production surpassed 10% of global production of the main tropical commodities, with coffee (40%) and cocoa (22%) leading in certified land, and with a 41% average annual growth rate (Potts et al., 2014). Sustainability standards are used by the food and beverage companies and retailers in our industry corpus to deliver results in their CSR reports, to protect their reputations and to build their consumer markets (Cashore et al., 2004).

Fig. 7 shows that LSP terms are slightly more frequently used in sustainability standards than are LSH terms. Such a difference is unsurprising, as sustainability standards are commodity specific and certification is paid per crop, thus encouraging mono- rather than multi-functional agriculture. Beyond the importance of 'local communities', which are used generally in standards as requirements for local consultation, we note that 'conservation value' dominates over other terms since 2011 that had higher usage in the past; specifically, those related to individual agronomic practices (e.g., reduced pesticide use, organic matter for mulching). Conservation value goes beyond agronomic practices as this indicator classifies some parts of a farm as land that should be saved for' natural habitats', and thus not cultivated. We tie this shift from LSH to LSP terms to a finding from Potts et al. (2014), who note that all of the seven initiatives with lower than average coverage across the environmental criteria were established after 2000, when industry-NGO collaboration became the norm in multi-stakeholder initiatives (Cheyns and Riisgaard, 2014). We note that the worst performing, in terms of containing biodiversity indicators, were created or revised after 2005. We note specifically that a requirement for the protection of High Conservation Value (HCVs) areas were added in the revisions of the FSC, RSPO and RSTS standards between 2011–2013.[18] This suggests that the LSP approach found eager users in practitioners as they adjusted the content of their standards to include indicators based on the latest scientific evidence.

This growing influence of industry actors and the reduced use of LSH terms in the standards' reports are also found in the standards' indicators themselves. We can trace a direct translation from LSP texts to the indicators. For example, Green et al. (2005a) wrote: "Approaches include the retention of patches of **natural habitat** and extensively farmed seminatural habitats within the countryside and farming in ways that **minimize the negative effects of fertilizers and pesticides** on non-target organisms"; and advocated for "increas[ing] yields on already converted land, thereby **reducing the need to convert remaining intact habitats**, and potentially **freeing up former farmland**

[13] https://www.moore.org/programs/environmental-conservation, accessed 30/07/2017

[14] https://www.humboldt-foundation.de/web/partners.html, accessed 30/07/2017

[15] In bold by the authors. Syngenta annual review 2016. https://www.syngenta.com/~/media/Files/S/Syngenta/ar-2016/syngenta-annual-review-2016.pdf

[16] In bold by the authors. Monsanto 2016 sustainability report. https://monsanto.com/app/uploads/2017/05/2016-sustainability-report-2.pdf

[17] Insight: how we're further building sustainability into our product design process, accessed 25/02/2018: https://www.corporate.nestle.ca/en/media/newsandfeatures/building-sustainability-into-product-development

[18] http://www.biodiversitya-z.org/content/high-conservation-value-areas-hcva.pdf, accessed 26/05/2018

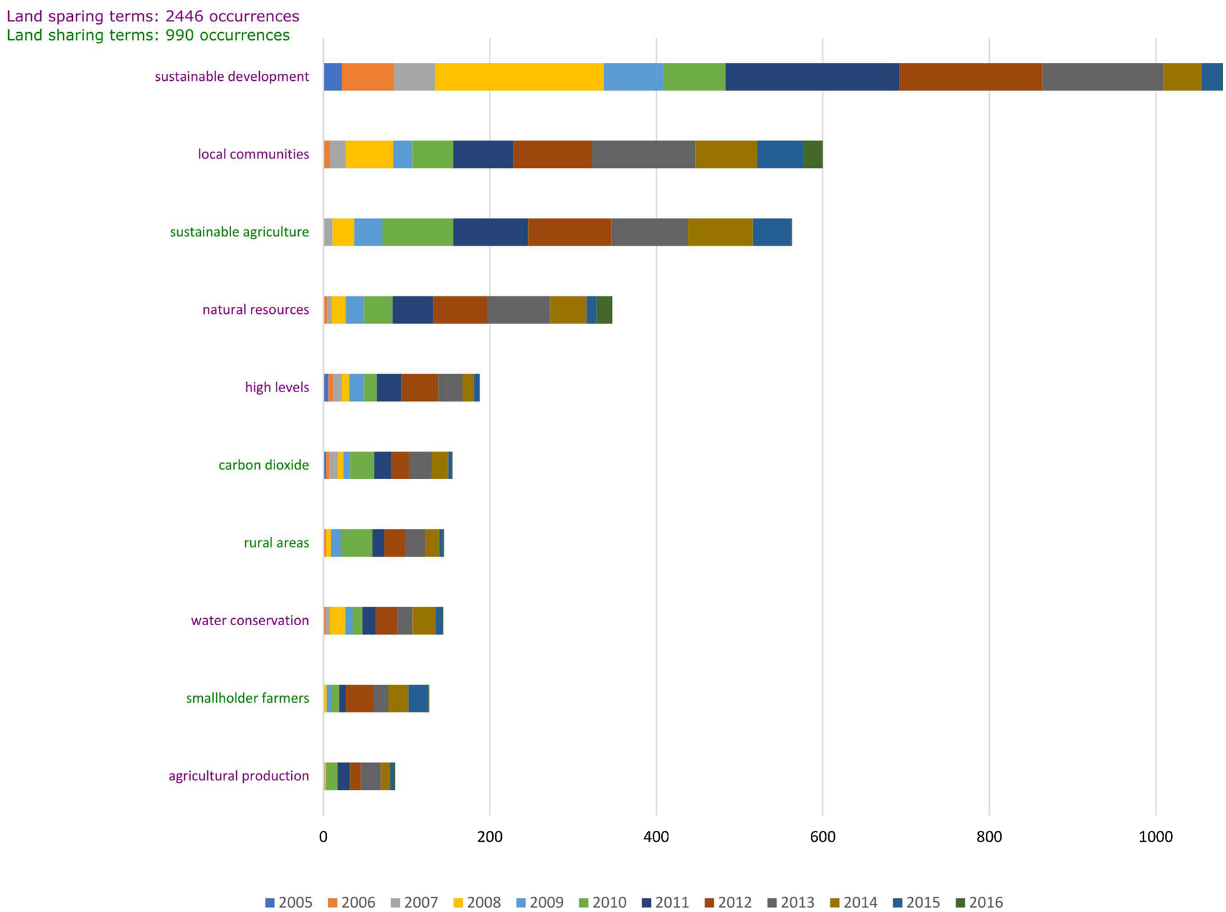

Fig. 6. Frequency of use of LSS terms in the Industry Corpus.
Note: The graph shows the frequency of the top 10 LSH and LSP terms used in the full text of the industry CSR reports included in the corpus. The x-axis represents the number of occurrences of the term in the corpus and the terms are listed on the y-axis in descending order of total occurrences.

for restoration to a more natural state" (pp. 551-2). This advice is found clearly in the standards' indicators, which consistently include requirements for 1) habitat set-asides, 2) flora densities/diversity in set-asides and 3) the prohibition of the destruction of 'high conservation value' land. The specific criteria within these indicators focus on practices to protect untouched nature, rather than to manage or restore ecosystems through adapted agricultural practices.

Potts et al. (2017) also conducted a study to compare the same standards that are in our corpus against the Biodiversity Impact Indicators for Commodity Production (BIICP) as defined in the Convention on Biological Diversity. The authors found that more than half of the standards included, on average, 50% or more of the biodiversity indicators - with IFOAM (organic) and Rainforest Alliance reporting higher than 70% average coverage. However, the indicators that separate IFOAM (a LSH standard) from Rainforest Alliance (a LSP standard) are the inclusion by IFOAM of preventing ecosystem fragmentation and encouraging ecosystem spatial management (functionalism) and Rainforest Alliances' indicators on maintaining high carbon stocks and protection of native species (compositionalism). This suggests that the way that standards write their indicators also follows the underlying ethics of the LSS controversy.

6. Conclusions

Ten years after Green and colleagues published their pivotal article, the LSS controversy remains a topic of debate both within and outside scientific circles. By spurring a controversy, which took on a life of its own, the Green et al. model rather successfully provided a way to advance public debate on agricultural intensification. By identifying conditions under which intensification could be advantageous for biodiversity, it provided environmental arguments that favoured industrial intensification. This introduction of biodiversity justifications into a debate previously dominated by food security concerns may offer scholars the chance to further clarify what environmental conditions must be met for sustainability. This stream of research may shed light on previously ignored variables that could be included in ecologists' models. Simultaneously, the existence of a model that could be deconstructed and critiqued from multiple disciplines offered economists, geographers, engineers, sociologists and political scientists the chance to question some fundamental assumptions that are made about the effects of broader food systems on biodiversity. This suggests that efforts should be made in the development of future models to be more interdisciplinary from the start.

Our examination of the LSS controversy highlights a different kind of politics that has not yet been explored in land use policy: a politics of knowledge, which can contribute to the emerging literature around knowledge and the politics of land (Pritchard et al., 2016). Our analysis demonstrates that the social networks that produce knowledge for the two sides of the debate are indeed separate and in conversation primarily via the controversy. This means that the actors and their evidence are circulating in closed clusters. We found that the LSP group had more closely linked networks and that it was better funded. We were able to trace the influence of the LSP philosophy into industry and practice, by showing conceptual relationships between LSP terminology, industry CSR approaches and sustainability standards. More research is needed to explore the extent to which these conceptual linkages are mere coincidences or the result of strategic action on the part of these actors to forward their political-economic agendas. Indeed,

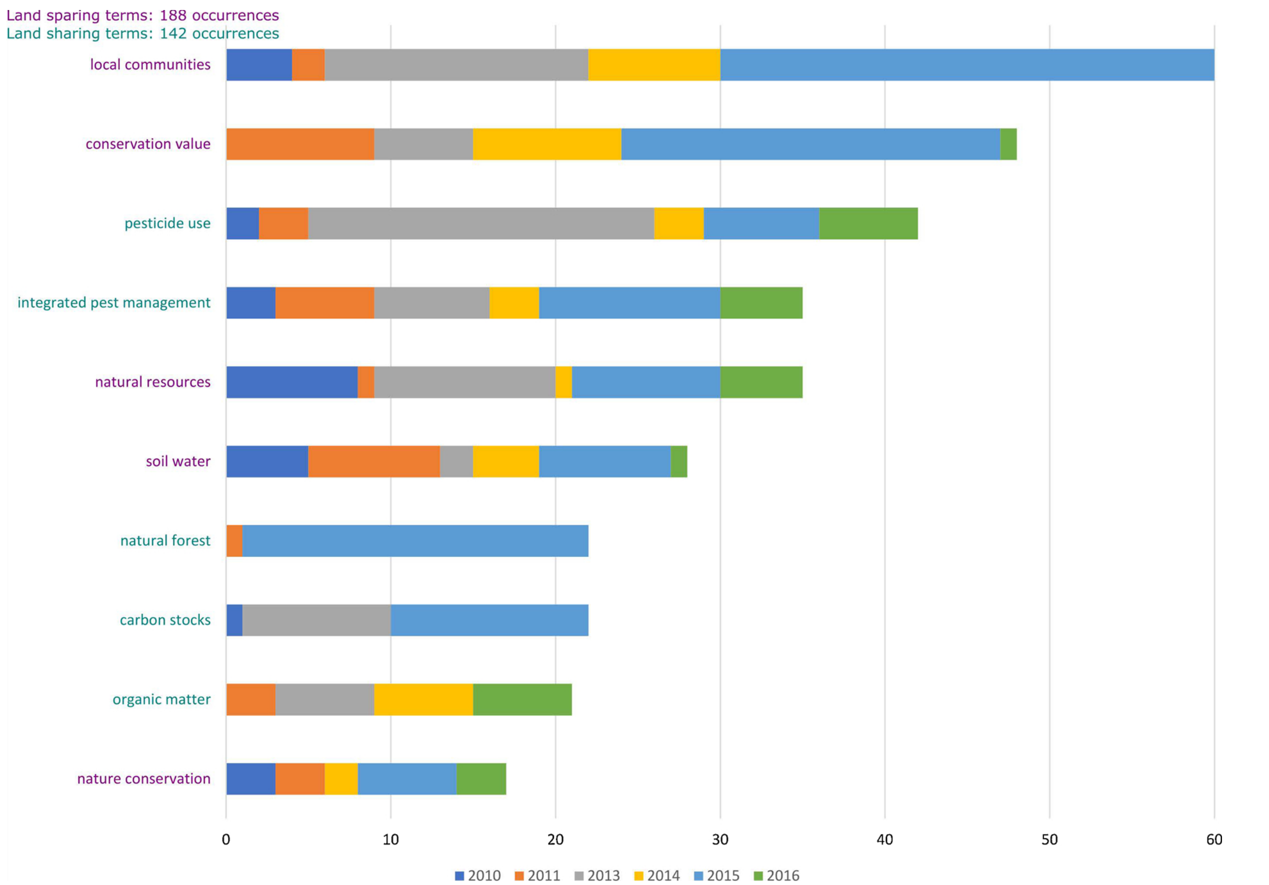

Fig. 7. Frequency of use of LSS terms in the Standards Corpus.
Note: The graph shows the frequency of the top 10 terms used in the full text of the standards organisations' annual reports that are included in the corpus. The x-axis represents the number of occurrences of the term in the corpus and the terms are listed on the y-axis in descending order of total occurrences.

while we demonstrate that the LSP results have been picked up and integrated by societal actors who promote intensive industrial agriculture (cf. Phalan, 2018), this was not the intent of the scientists who claimed that their research "does not give uncritical support to large-scale agribusiness over small-scale farming systems."[19]

Further research is needed in order to be able to examine the lasting effects of the networked actors and their terms of the debate on land use policy and practice. As we can already begin to see in the industry and standards spheres, the use of concepts follows shorter timelines than the terms of the scientific debate allow. Therefore, future research could focus on impact studies of specific policies, programs and standards, in order to identify spheres of influence and the more explicit politics of interest.

Finally, through our exploration of the LSS controversy, we were able conclude that LSP and LSH approaches are essentially promoting two very different imaginaries about how humans do and should interact with nature. This important finding demonstrates that rather than an objective tool for testing hypotheses, models and the discourses used to justify their results are truly political tools that can help to advance specific visions of the world.

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[19] https://www.cam.ac.uk/research/news/sparing-or-sharing-protecting-wild-species-may-require-growing-more-food-on-less-land, accessed 5/5/2018

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