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ORIGINAL PAPER

On diversity of human-nature relationships in environmental sciences and its implications for the management of ecological crisis

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Abstract Decision makers addressing the ecological crisis face the challenge of considering complex ecosystems in their socioeconomic decisions. Complementary to ecological sciences, other scientific frameworks, grouped under the umbrella term environmental sciences, offer decision makers the opportunity to pursue sustainable paths. Because the environmental sciences are drawn from different branches of science, environmental ethics must go beyond the legacy of ecology and the life sciences to describe the contribution of scientific knowledge to addressing the ecological crisis. In this regard, I analyze and compare three environmental sciences based on their seminal articles: Conservation Biology, Sustainability Science, and Sustainability Economics. My analysis shows that conservation biology and sustainability economics share strong similarities despite their different disciplinary backgrounds (life *versus* social sciences). Both seek to contrast a biocentric and an anthropocentric perspective. The goal of sustainability is therefore understood as a balance that must be found between these two perspectives. If the issue of balancing human and non-human interests is still relevant to sustainable science, it is more likely to take place in an ecocentric perspective based on alternative ontological and normative prescriptions. Based on this analysis, I distinguish between 'proscriptive value-based' scientific work that cannot be used for policy advice but is flexible to different value systems, and 'prescriptive value-based' scientific work that can be used for policy advice but is fixed within a given value system. Conflicting recommendations

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from environmental scientists therefore result from the coexistence of multiple 'prescriptive value-based' scientific approaches based on different conceptions of the relationship between humans and nature.

Keywords Conservation biology · Sustainability economics · Sustainable science · Biodiversity · Sustainability

1 Introduction

Climate change, the decline of biodiversity, the melting of glaciers, the de- pletion of the ozone layer: all these issues are at the center of public debates.today. Faced with the first ecological crisis caused by humans, societies are trying to conceive and implement sustainable development (Díaz et al., 2019, IPBES, 2016, Corlett, 2015, Loh & al 2014). Based on the idea of responsibility to future generations, sustainable development is usually defined by the semi- nal Brundtland report *Our common future* as 'the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1988). Due to the interdependent relationships between societies and their surrounding natural environment, maintaining this capacity over time requires the simultaneous management of both socioeconomic drivers and ecosystem dynamics (Carpenter et al. 2009, Ostrom, 2009, Dasgupta, 2007). Decision makers pursuing such a goal therefore face the challenge of accounting for complex ecosystems and their inherent uncertainty in their social analyzes and economic decisions (Cheaib et al., 2012; Perrings, 2011).

Valuable information about ecosystem dynamics, functioning, structures, and resilience is provided by the ecological sciences (Figueiredo & Pereira, 2011, Butchart et al. 2010, Pereira et al., 2010, Ives & Carpenter, 2007, Walker et al., 2004, Loreau et al., 2001). In this regard, this scientific ecological knowledge directly helps decision makers to make informed decisions and implement a sustainable development path for human societies (Slobodkin, 2003, Ferré & Hartel 1994). It is not surprising, therefore, that there is an extensive literature in environmental ethics on the contribution of the ecological sciences to addressing the ecological crisis and the challenge of sustainability (see, for example, the seminal articles by Evans (1956), Golley (1987), Callicott (1986)). However, there are other scientific approaches that provide guidance to decision makers for sustainable action. These include conservation biology, political ecology, sustainability economics, sustainability science, earth science, etc. While these disciplines are grouped under the umbrella term of environmental science (Miller & Spoolman 2016), they have different backgrounds, as shown in O'Riordan (2014) or in Chiras (2010). It is of particular interest that many of them do not originate in the life sciences. For example, political ecology has its origins in political science and sociology, sustainability economics in economics, sustainability science in systems science, or earth science in physics and geology. Only conservation biology has its roots in biology and ecology.

I suggest that this diversity of lineages could lead to significant differences in ideas about the relationship between humans and their surrounding natural environment in a sustainable future, which in turn could lead to recommendations from different environmental scientists steering decision makers in opposite directions. As a result, I will argue that characterizing the contribution of scientific knowledge to addressing the ecological crisis requires an environmental ethics that goes beyond the legacy of ecology and the life sciences to examine the diversity of backgrounds.

I analyze and compare three environmental sciences: Conservation Biology, Sustainability Science, and Sustainability Economics. Conservation biology stems from the biological sciences and explicitly assigns intrinsic value to biodiversity (Soulé 1985). Sustainability economics stems from neoclassical economics and extends the normative goal of equity to nonhuman beings (Baumgartner & Quaas, 2010). Finally, sustainability science studies complex systems and explicitly considers inter- and transdisciplinary knowledge (Jerneck et al., 2011). This corpus covers two dimensions of heterogeneity in environmental science backgrounds: proximity to the life sciences and disciplinary roots. The corpus includes one area that is strongly related to the life sciences (*i.e.* conservation biology), a second that is only weakly related to them (*i.e.* sustainability science, which has its roots in the natural sciences without a specific connection to the life sciences), and a third that is more distant from them (*i.e.* sustainability economics, which emerged from the social sciences). Second, the corpus includes two discipline-based fields (conservation biology and sustainability economics) and one problem-based field (sustainability science), as defined in Nowotny et al. (2003).

To define the three fields, I have chosen to look at their seminal articles and related debates. This choice is justified in two ways. First, by considering the ways in which the domains define themselves, rather than establishing predetermined and common analytical criteria, the general heterogeneity of the three fields is captured. Indeed, the nature of the definition and the criteria chosen by scholars to define their own field are vectors of information *per se* with potential implications for implicit ontological and normative propositions, and thus for recommendations to decision makers. Second, looking at debates alongside seminal articles offers the opportunity to simultaneously explore what the concrete reality is alongside what has been officially announced and expected. Finally, I have chosen to focus on the early years of the emergence of the fields without considering recent articles and debates. This choice makes it possible to identify seminal convergences and divergences between the fields that could be deepened or smoothed out in the more recent past. Tracking the analysis in recent years provides a natural perspective for this study.

The article is structured as follows. First, I discuss the three fields in terms of their foundations and the challenges they pose. Then I discuss the human-nature relations that underlie the three different fields, combining the temporal perspective of Mace's framework (designed by Georgina Mace in her Perspective Insights, published in Science (Mace, 2014)) with ontological and normative specifications. Finally, I will demonstrate the implications of environmental science's different understandings of human-nature relations for addressing the ecological crisis. More specifically, I distinguish two scientific approaches and argue that conflicting recommendations by environmental scientists may arise from the coexistence of multiple 'prescriptive value-laden' scientific approaches based on different conceptions of the human-nature relationship. I conclude the article with perspectives regarding the connection between normativity explanation and the role of interdisciplinarity.

2 Conservation biology

2.1 The life science of biodiversity

Conservation biology was developed in the 1980s, particularly following the second conference on conservation biology held in Ann Arbor, Michigan, (Gibbons 1992). This led to the formation of the Society for Conservation Biology (SCB) and its journal *Conservation Biology* (Soulé 1987a;1987 b). Michael E. Soulé, a founding member of SCB and chair of the journal's editorial board, defined the organization's goal as 'to provide the guidelines and tools to protect biological diversity' (Soulé 1985, Meine et al., 2006), then 'biodiversity protection', as the term 'biological diversity' was gradually replaced by the concept of 'biodiversity'. To achieve this goal, conservation biology relies on a fundamental and structuring normative premise set forth in the seminal article entitled '*What is Conservation Biology?*' by Michael E. Soulé in the journal BioScience: 'Biodiversity has intrinsic value[1]' (Soulé 1985). According to the author, consideration of the intrinsic value of biodiversity is the only way to avoid an anthropocentric view of environmental issues and ultimately to maintain functional and stable ecosystems. Various postulates are derived from this premise (Noss, 1999). They generally fall into two categories: functional or mechanistic postulates on the one hand, and ethical or normative postulates on the other.

Functional postulates derive directly from theoretical and empirical results in the life sciences, ecology, or population genetics. They refer to the preservation of the form and function of natural biological systems. Following the structure proposed by Soulé (1985), I group them as follows:

(1) The species forming a natural community are the result of a process of coevolution,

This postulate is part of an evolutionary perspective and emphasises the influence of the environment on the present and future state of an ecosystem. It suggests that current biological diversity, both structural and functional, has been selected by environmental conditions.

[1] No precision is provided by the author, but I will comment this concept in the following section.

(2) Most ecological processes have thresholds beyond which they become irregular or chaotic,

In other words, ecological processes occur in physical processes that are intermediate in scale in time and space, and begin to collapse at the boundaries of these processes. Indeed, certain processes disappear in systems that are too small. In contrast, ecological processes on very large temporal or spatial scales (e.g., geologic time or continental scale) are generally dominated by geochemical or geologic processes.

(3) From a certain population threshold, random and nonadaptive forces tend to predominate over adaptive and deterministic forces.

There is a relationship between stochastic factors in population extinction and the minimum conditions for population viability. This means that the probability of persistence of a local population is a positive function of its size. Consequently, natural selection is less effective in small populations due to genetic drift and loss of genetic diversity.

In addition to these mechanistic postulates, three normative postulates explain what nature should be, taking into account the above functional specifications. They are usually presented as follows:

1. Nature should be diverse,
2. Nature should be able to evolve,
3. Nature should be complex.

The first normative postulate is a compositionalist approach: it consists of measuring biodiversity at different levels of ecosystem organization—from genes to species to the ecosystem as a whole. Biodiversity, seen as the result of evolution, has value and should therefore be conserved. As a result, extinction should be avoided. This first postulate clarifies the value of biodiversity-as-property (Maris, 2016). In the second normative postulate, biodiversity is considered as a determinant of the future. Because the postulate focuses on the evolution of living things, this perspective is functionalist. This dynamic understanding emphasizes the idea of biodiversity-as-process (Maris, 2016) can be defined as a system of mechanisms operating simultaneously at different levels: genetic mutation, reproduction, predation, competition, mutualism, etc. Although the list of these mechanisms and their relative weights are still controversial, a consensus has emerged on the importance of maintaining evolution and the diversification process. The combination of the first two normative postulates opens up the idea of a complex environment. The third perspective is broader than the first two assertions and implicitly emphasizes the diversity of habitats and the complexity of ecological processes, conditions that are absolutely necessary for the mechanisms that make diversity possible.

2.2 Conceptual issues

By focusing on the concept of biodiversity, conservation biology faces conceptual challenges regarding its definition.

The Convention on Biological Diversity, established in Rio de Janeiro, Brazil, in June 1992, offered a first element of characterization by defining three hie- rarchical levels (genetic, taxonomic, and ecosystem) from which the concept's prefix 'bio' is derived. In addition to this initial specification, the ecological literature sought to clarify the term 'diversity' (Tilman, 2001). More specifically, three main characteristics are usually distinguished: composition, structure, and function. Compositional diversity refers to the identity of the elements within the group in question, and specifically to the variability of that identity. Structural diversity refers to the variety of relationships among the elements within the group of interest. Finally, functional diversity refers to the variety of functions supported by the elements of the group of interest (Tilman et al., 1997).

By defining both 'bio' and 'diversity', this dual characterization (hierarchical levels and primary attributes) could open the way to simple and consensual concepts of biodiversity. However, difficulties arise when trying to combine these two characterizations (Delord, 2014). Indeed, according to Norton, there are two types of definitions: the first describes objects that have differences without specifying the nature of those differences, while the second specifies the nature of the differences without defining the contours of the objects. According to Norton, the combination of these two types of definitions is structurally impossible, since they do not talk about the same thing. From this point of view, it seems difficult to combine the first definition, which is based on hierarchical levels and related to inventory-definitions, with the second one, which is based on primary attributes and related to difference-definitions.

Moreover, the project of combining the two characterizations encounters practical difficulties (Maclaurin & Sterelny, 2008). On the one hand, the hierar- chical levels remain ambiguously defined, as different objects of study could fit on the same hierarchical level. For example, chromosomes, genes, and nucleotides belong at the genetic level. The taxonomic level includes species, of course, but also genera, families, and orders. Finally, the ecosystem level includes ecosystems as well as landscapes or biomes. Some of the scales commonly used by scientists seem to fall between two hierarchical levels, creating additional ambiguity. For example, populations may be considered from a genetic and taxonomic perspective, or communities that fall between the taxonomic and ecosystem levels. These intermediate levels raise questions about the relevance of ternary partitioning and what place to give them. In essence, these intermediate levels are the reason that the three hierarchical levels are not independent of each other. In this context, how can diversity be properly characterized with partially collinear criteria? Even if the idea of a hierarchical structure is rather intuitive, it does not seem to be easily definable and manageable in the concrete perspective.

On the other hand, the 'diversity' side of biodiversity also opens up practical debates (Casetta et al., 2019). While a scientific consensus on diversity of composition and structure is emerging, the use of function as a primary attribute raises questions. Some authors object to placing ecological processes at the center of diversity, even though they are essential for maintaining living diversity. Based on empirical studies, they argue that ecological processes are a consequence of diversity at different levels of the hierarchy (Schlapfer & Schmid, 1999; Tilman, 1999). In this way, ecological processes might be a consequence of compositional and structural diversity rather than a fundamental unit of analysis.

These few elements illustrate the difficulty of defining the concept of biodiversity, which is, after all, the core of conservation biology. The ambiguity among conservation biologists about the term 'biodiversity' freezes the debate about the intrinsic value that biodiversity should have (Vucetich et al., 2015, Justus et al., 2009). Indeed, without a clear delineation of the biological entity of interest, it seems tricky to examine the epistemological rationales that underlie their new moral consideration (Sagoff, 2009). The goal of conservation biologists is to somehow extend the moral community to non-human elements. However, the use of the term 'intrinsic value' remains ambiguous (Batavia & Nelson, 2017; Maguire & Justus, 2008). Since the authors do not specify, it is not clear whether they mean objective intrinsic value (both non-anthropocentric and non-anthropogenic) or non-intrinsic value (non-anthropocentric but anthropogenic, *i.e.* value generated by a human mind but independent of human interests). One element of the answer is found in the goal of 'protecting biodiversity' asserted by conservation biologists. With such an explicit practical goal, one should speak of anthropogenic rather than non-anthropogenic value, the latter being ultimately beyond human control.

3 Sustainability economics

3.1 The economics of 'extended' justice

In the late 1980s, the field of ecological economics emerged with the founding of the International Society for Ecological Economics (ISEE) in 1987 and the journal *Ecological Economics* launched in 1989. This approach aims to explicitly rethink the interaction between economic and ecological systems. This pluralistic movement formed the starting point for sustainability economics in the late 2000s (Baumgartner & Quaas, 2010; Pezzey & Toman, 2002; Soderbaum, 2007). Sustainability economics has its roots in the field of economics and adopts its ethical framework. More specifically, it draws on the standard normative goal of economics, the satisfaction of human needs and wants. Classically, it takes into account people's subjective preferences by explicitly considering their desires in addition to so-called basic needs. Thus, the originality of sustainability economics consists in the combination of this economic framework with the concept of sustainability (Klaassen & Opschoor, 1991).

As described in the seminal article '*What is Sustainability Economics ?*' by Stefan Baumgartner and Martin F. Quaas in the journal Ecological Economics, sustainability economics presents an interpretation of sustainability based on the idea of 'justice' (Baumgartner & Quaas, 2010). Contrary to the neoclassical economic proposition, justice is examined in an 'expanded' perspective by considering three dimensions (Becker, 2006):

- Justice between people of different generations (intergenerational justice),
- Justice between people of the same generation (intragenerational justice),
- Justice between humans and nature (physiocentric ethics).

The first two forms of justice might imply nature conservation, but only because of its instrumental contribution. It is precisely because nature brings value to humans today or tomorrow that it should be protected. Consequently, natural elements that prove useless or harmful to humans are not protected (see Jean and Mouysset (2022)'s review for methodological details and examples of articles). Sustainability economics proposes to go beyond the standard instrumental framework: by adding a third component that relates to justice [2] with nature, it implicitly attributes nature a non-instrumental value. As a result, all natural elements should merit ethical consideration.

However, the normative concept of justice is meaningful only in a problematic context, *i.e.* a context in which resources, both natural and technological, are scarce. Therefore, sustainability economics assumes that actions should be taken based on the following normative principles (Baumgartner & Quaas, 2010):

(1) *The allocation of resources should meet people's needs and desires.*

This first principle belongs to an anthropocentric approach and is fully consistent with economics. Interestingly, it contains an intertemporal dimension, since 'needs' refer to the present, while subjective desires have an implicit reference to the future.

(2) *The distribution of resources should be equitable.*

This second principle aims to link the canonical issues of economic efficiency with issues of equity. This perspective fits into the definition of sustainable development in the Brundtland report (Brundtland, 1988).

(3) *Justice should be applied to all aspects of the set of realities in question.*

This principle leads to a multi dimensional conception of justice that implicitly combines intrinsic value and instrumental value.

[2] The concept is not specified in the seminal article and can be interpreted in different directions by sustainability economists

3.2 Epistemological issues

By intending to extend justice to non-human beings, sustainability economics differs from other social sciences and offers a unique worldview in the field of economics (Illge & Schwarze, 2008). Interestingly, the father of utilitarianism, Jeremy Bentham, did not exclude non-human living beings from his moral community, as animals were explicitly included in that community (Bentham, 1789). But by looking at nature in a broader perspective, sustainability economics goes beyond sentient animals and a pathocentric utilitarianism.

By including nonhuman entities in a moral community based on utilitarianism, sustainability economics implicitly admits the existence of a biophysical reality per se. As a result, it faces the crucial ontological challenge of defining the biophysical and social realities it seeks to account for. Such an ambition requires going beyond a strict constructivism that views all realities as social constructs and that does not allow for attributing intrinsic value to a biophysical reality. However, because sustainability economics is rooted in the social sciences, it cannot adopt a strictly reductionist perspective in which social realities are reduced to their biophysical properties. The challenge, then, is to find an intermediate solution.

Critical realism offers one possible answer (Spash, 1997). The ontology of critical realism proposes an ordered hierarchy of sciences (physical, chemical, biological, social, and economic sciences). This ontological framework assumes that there are intrinsic differences among these sciences, which are thus not reducible to one another. For example, biological entities are physical but not reducible to the laws of thermodynamics. Biology belongs to the physical sciences but is not reducible to them. Likewise, the social sciences belong to biology, and economics belongs to the social sciences. This non-reductionist, nested structure seems particularly important in understanding the two realities put forward by sustainability economics.

This framework of critical realism leads to ontological considerations defined as follows (Spash, 1997):

1. There is an objective reality independent of humans, guided by biophysical laws.
2. Human constructs a social reality on this biophysical reality by prescribing the existence of values that are inseparable from the facts.
3. There are in fact two realities, one social and one natural, which are different but interconnected. More precisely, they are nested (biophysical, social, economic) and form a whole, but remain irreducible.

Once the ontological entities are defined, normative questions arise from the justice postulate (Baumgartner & Quaas, 2010; Ropke, 2005). First, the concept of justice needs to be specified. Dobsonian classification (Dobson, 1998), for example, calls for sophisticated clarifications about the donors and recipients of justice, the basic structure, the objects, and the rationale of justice. In addition, information should be provided about the institutions that are capable of providing such an objective of justice.

4 Sutainability science

4.1 The problem-driven science of complex systems

In the 1990s, the International Council for Science (ICSU) initiated the development of science and technology in the service of sustainable development. However, it was not until after the Friday Workshop on Sustainability Science that the goals of sustainability science were defined in the seminal article entitled "*Sustainability science*" published by R.W. Kates and colleagues in Science (Kates et al., 2001). A set of questions and a research agenda were then developed in the 2000s (Clark & Dickson, 2003; Jerneck et al., 2011; Komiyama & Takeuchi, 2006; Martens, 2006; Swart et al., 2004).

Sustainability science is a newer scientific approach that emerged in response to the failure of earlier approaches to provide effective solutions to the environmental crisis. For proponents of sustainability science, the disciplinary nature of previous responses is responsible for this failure (McMichael et al., 2003). In this approach, the environmental crisis is seen primarily as a crisis of a system: a global system that includes the planet with its geosphere, atmosphere, hydrosphere, and biosphere, but also social systems with political, economic, and industrial structures created by humans. Although these two systems have specific characteristics and their own dynamics, they are not considered independent but completely interdependent (Reid et al., 2010). The Earth, for example, sustains life by providing natural resources and energy. Major fluctuations in Earth systems such as climate or tectonic plates can dramatically affect human survival and activities. The rapid expansion of human activities has in turn led to the human species becoming a crucial factor for changes in the global system: climate change and the destruction of the ozone layer are good examples.

According to sustainability scientists, the interactions between these biophysical and social subsystems are crucial to understanding the future dynamics of the global system (Jerneck et al., 2011). While an approach that focuses primarily on one subsystem, as is the case with the so-called traditional disciplines, clearly contributes to a better understanding of a particular subsystem and thus of the global system, it remains structurally inadequate. In response, the underlying thesis of sustainability science is the study, understanding, and management of a metasystem that includes the environment and society and their interactions within the concept of the social-ecological system (SES) (Clark, 2007).

In choosing this object of study, sustainability science places the concept of complexity at the center of the field (Martens, 2006). Rather than attempting to simplify the complex object of study, the goal is to deconstruct it in order to understand it in all its complexity (Axelrod & Cohen, 2001). More specifically, sustainability science aims to identify and analyze the relationships of complex systems at different levels of organization and different spatial and temporal scales (Berkes & Folke, 1998; Janssen, 2002; Norberg & Cumming, 2008). The complexity of these systems reveals nonlinear dynamics, threshold effects, and breaking points. These tipping points, sometimes irreversible, are essential for understanding the long-term dynamics of the system and for assessing its sustainability. In sustainability science, the goal of sustainability is interpreted by examining situations in which an SES is or is not sustainable and why.

This concept ties into debates about the resilience of ecological systems and the vulnerability of sociological systems. Sustainability scholarship has attempted to synthesize these various discussion points (Clark et al., 2005), which has led to various analytical frameworks. For example, Rockström et al. (2009) has proposed a set of nine planetary boundaries that address climate change, chemical pollution, ocean acidification, ozone layer depletion, biogeochemical cycles, freshwater use, land use change, biodiversity loss, and greenhouse gas emissions. If none of these limits are exceeded, the system is in what the authors call a 'safe operating range,' *i.e.* a sustainable state. However, if one or more of these limits are exceeded, the system may exhibit abrupt and nonlinear effects and tip into irreversible states that no longer allow its dynamics to be maintained, leading to its collapse. This is based on the idea of a 'safe minimum standard' (Ciriacy-Wantrup, 1952), which emphasizes the existence of tipping points to risk zones. This concept was later developed further in the framework known as 'Oxfam-Doughnut' (Raworth, 2012), which identifies zones where a socio-ecological system is sustainable. By focusing on boundaries that should not be crossed and zones in which a complex system should evolve, sustainability science seeks to maintain a sustainable state and avoid collapse. By viewing sustainability through the lens of vulnerability (Turner et al., 2003), the former is no longer seen directly as a goal to be achieved, but rather as *a minima* vision of sustainability (namely, sustainability as some states that must be maintained above their thresholds).

4.2 Methodological issues

To figure out why certain SES are sustainable and others are not, the analytical framework of sustainability science is built around two types of questions (Clark et al., 2005). First, there are the analytical questions. This is about describing a complex system and knowing how it works. For example, what are the key dynamics and feedback loops? What are the critical thresholds beyond which the system tips into a different behavior? Second, there are normative questions. Here, the goal is to tie the description of the system back into a functional analysis of sustainability: In the context of nature-human co-evolution, what areas are achievable for SES but not sustainable? What criteria can be used to distinguish sustainable and unsustainable futures?

Answering these questions raises difficult methodological issues because it involves applying knowledge of how each part of the SES functions, *i.e.* the subsystems that constitute nature and ecosystems on the one hand and society and the economy on the other. Each of these systems has already been studied in depth by different disciplines. However, because they are in different scientific traditions, the resulting analytical frameworks, theories, and models may differ significantly (Gibbons, 1999). The methodological challenge of sustainability science is to link a subject defined as complex with highly specialized disciplines. Developing an integrated understanding of systems therefore requires two methodological principles advocated by sustainability science.

First, methodological pluralism is required. Given the diversity of available methods and models, including those of traditional disciplines, knowledge must be organized within a more comprehensive analytical framework (Brandt et al., 2013). However, given the amount of knowledge available, it is difficult to integrate everything. Each process of simplification is influenced by one or the other of these disciplines, resulting not an unique summarized analytical framework but in a multitude of proposals (Jahn et al., 2012). Sustainability science therefore promotes methodological pluralism as a necessary condition for a more comprehensive understanding of the system (Gasparatos et al., 2009; Kauffman, 2009). This methodological pluralism is seen primarily as a necessary feature of sustainability science as a whole, but it is not necessarily essential for every research project.

Second, and beyond methodological pluralism, transdisciplinary approaches are needed. Sustainability science goes beyond a simple compilation or juxtaposition of knowledge from different disciplines. It seeks to go beyond the limited perspectives of disciplinary knowledge to investigate the emergent properties of the global system (Spangenberg, 2011). In this sense, it is defined by its proponents as a transdiscipline (Lang et al., 2012), the only method capable of generating future scenarios of change of a system in its entirety (Kajikawa, 2008; Komiyama & Takeuchi, 2006).

However, combining existing knowledge with the emergence of a new front of transdisciplinary research is not sufficient to capture the full methodological challenge facing sustainability science. Grasping complexity is a process that is particularly knowledge intensive. Therefore, it is difficult to imagine that the current state of knowledge is sufficient to define an analytical framework 'once and for all'. Sustainability science not only creates a dialog between disciplines, but also opens the debate about the role of science in society. It proposes a reflexive approach to progressively improve our knowledge and thus the ability to describe sustainable states and, conversely, the risks to sustainability (Martens, 2006; Swart et al., 2004). In this respect, sustainable development becomes a process of adaptive management and social learning in which knowledge plays a central role (Cash et al., 2003; Steffen, 2004). The goal is to foster and leverage collaboration among researchers from different disciplines as well as non academic stakeholders from industry, government, and civil society (Miller et al., 2014). This collaboration between researchers and non-academic stakeholders not only brings in other types of knowledge, but also lends credibility to the process and ensures that society has an interest in shedding light on the topic under study, *i.e.* sustainable management of SES.

5 Discussion

5.1 Temporal perspective thanks to the Mace's framework

To analyze and compare the areas described above, I first consider the overall framework provided by Georgina Mace in her Perspective Insights published in Science in 2014 (Mace, 2014). The author distinguishes 4 periods. First, until the 1960s, scientists were primarily concerned with 'nature *itself*'. Second, in the 1970s and 1980s, in response to major environmental disasters such as the Amoco Cadiz or pollution problems such as acid rain, human societies were perceived almost as a threat, a potential source of ecosystem destruction. The perspective was how to protect 'nature *despite* humans' with human seen as an invasive species of wild nature. Then, in the 1990s, a reverse trend began as people became aware that ecosystems provide services to society. This observation gave rise to the well-known concept of ecosystem (Daily, 1997). As a result, ecosystem erosion leads to a decline in ecosystem services and human welfare (Costanza et al., 1997). In Mace's framework, this is the era of 'nature *in service* to society'. More recently, in the 2000s, a more balanced position emerged, according to the author, with a relationship she calls 'nature *and* society' (Mace, 2014). The last three relationships between humans and nature are related to today's ecological crisis.

This historical analysis is instructive in understanding the dynamics of the emergence of the three domains presented in the previous sections. Indeed, it is quite easy to observe that conservation biology and its goal of protecting biodiversity fits the 'nature-despite-human' relationship. Sustainability economics, based on a social science background, fits the anthropocentric 'nature-for-human' relationship. Sustainability science, based on the notion of a social-ecological system, fits the 'nature-and-human' relationship. Mace's time frame seems to match the periods of emergence of the three proposals of interest (70s- 80s, 90s, and 00s, respectively).

However, Mace's frame may suggest that there was a successive replacement over time between the different concepts of the human-nature relationship (*i.e.* the concept of 'nature for itself' was replaced by the concept of 'nature despite man', then by the concept of 'nature for man', then by the concept of 'nature and man'). It should be noted, however, that when a new scientific framework emerged in the scientific literature, it did not gradually replace the existing perspectives: the three domains and the three concepts of the human-nature relationship coexist in the environmental sciences today. One can therefore legitimately examine their coexistence in the debate on the environmental crisis. Are they incompatible or complementary in order to guide decision makers towards sustainable development? Answering this question requires a closer examination of the epistemological specifications of the three human-nature relationships. This epistemological analysis could help identify specific points of convergence or divergence among the various human-nature relationships in the environmental sciences.

5.2 Ontological and normative specifications

To deepen the epistemological analysis of the various human-nature relations at play in the environmental sciences, I analyze the three domains in terms of two epistemological specifications. The first characterizes the ontology underlying the human-nature relationship, while the second considers the normative dimension.

The three fields of interest simultaneously examine human society and its surrounding nature. The first question I raise here concerns this aspect of simultaneity. Indeed, any joint consideration can either take a monistic form or adopt a dualistic perspective. Are humans and ecosystems defined as two separate entities, related but ontologically distinct? Or are they defined as distinct parts of a unique whole system and thus share a common ontology?

Sustainability science is very clear about its object of study, which it defines as a complex social-ecological system encompassing the environment, society, and their interactions. Such a view of the whole system implies a monistic perspective and suggests a common ontology between humans and ecosystems. Conservation biology is also clear about its object of study: biodiversity. While it considers its relationship to society, it focuses on the biodiversity *per se*. This focus leads to the construction, consolidation, and defense of a new moral category that relates to biodiversity and stands alongside the moral unity of humans (Kareiva & Marvier, 2012). In this respect, conservation biology seems to maintain the dualistic ontology it inherited from modern philosophy (Descola, 2005). Sustainability economics is less clear on this point, as it is based on a normative goal rather than an object of study. As discussed in section 3, this goal includes two secondary goals: Efficiency and Equity. Each of these aims to characterize the allocation of scarce resources, including natural and human resources. It must be both efficient and equitable between human and nonhuman elements of the system. Such requirements can apply with either a dualistic or a monistic ontology. However, considering critical realism's contribution to structuring the field and its explicit grounding in the social sciences, we should assume that the ontology underlying these normative goals tends to be dualistic in the seminal articles we have examined in this analysis.

My second criterion of analysis concerns the normative postulates and their prescriptive intentions. The three fields are unambiguous with respect to their normative goals. Sustainability economics explicitly takes a normative position as it defines prescriptive rules for the allocation of rare resources with a particular focus on equity. Conservation biology, while explicitly adding a value system to the study of ecological systems, is based on normative principles that describe what *should* be. In this context, it clearly falls under a prescriptive concept of normativity. Sustainability science is also quite explicit, but from a different perspective than the previous two fields. By proposing a *a minima* vision of sustainability through tipping points that should not be crossed and states that the system should avoid, it focuses on what reality *should not* be rather than what it should be. Although the approach remains normative, it is not prescriptive and offers a proscriptive vision of normativity.

This analysis suggests strong similarities between conservation biology and sustainability economics. Indeed, the two fields preserve dualistic ontology and exhibit prescriptive normative goals. In this way, they both attempt to contrast a biocentric perspective with an anthropocentric one. The goal of sustainability is therefore understood as a balance to be found between these two perspectives, between the two fundamentally different elements, humans and ecosystems. Their different backgrounds (biological sciences *versus* social sciences) are the driving forces for understanding the tension between humans and the natural environment, as embodied in Mace's expressions of nature-*despite*-humans versus nature-*for*-humans. As a result, the balance between biocentric and anthropocentric views will differ in the two fields.

On its side, sustainability science seems to offer a real epistemological gap in relation to the other two environmental sciences. The differences concern both the ontological and normative sides. First, this field pursues a monistic ontology; second, its normative criterion is prospective. If the issue of balancing the interests of humans and non-humans is still relevant, it takes place more in an ecocentric perspective. In this particular case, it turns out that the human-*and*-nature relationship represents an epistemological transition from the earlier conceptions of the human-nature relationship.

5.3 Implications for the management of the ecological crisis

Combining my specifications with Mace's historical perspective, I show that the responses to the sustainability challenge were initially prescriptive-normative approaches (*i.e.* conservation biology and sustainability economics). Although the two approaches take different viewpoints, they share the same goal of linking scientific knowledge to the normative goal that society seeks. Given the ultimate goal of helping decision makers, there is a certain logic to this strategy: Starting from a starting point defined as a problem, namely the ecological crisis, building a comprehensive framework that encompasses both scientific facts and societal values seems to be the most efficient strategy to formalize concrete solutions for management and to guide decision makers toward sustainable choices. However, when two comprehensive frameworks with different understandings of the relationship between humans and nature (humans-despite-nature versus humans-for-nature) coexist, there is a risk that the resulting recommendations will conflict with each other and leave no room for negotiation. Apart from cohabitation between the two administrations at different sites, it is impossible to combine the two opposing viewpoints.

It is in this closed scientific landscape that the newer approach of sustainability science has emerged. From a practical perspective, sustainability science has led to a broader consensus. By eliminating the main point of contention, namely prescription, the field has the distinct advantage of keeping open the compatibility between different environmental views. Nevertheless, because of its focus on describing a system and its undesirable states, this approach is not able to provide decision makers with a direction *towards* which they should move, but rather *from* which they should move. Without prescriptive guidelines, the field remains unable to provide specific recommendations for decision makers. To guide action, the sustainability science proposal must be combined with an additional normative exercise that explicitly re-introduce the issue of values and normative goals to be achieved. For example, it is possible to introduce here a welfare criterion that allows choosing between two actions that are consistent with the normative statement.

As a result, I characterize two different scientific approaches in environmental science: on the one hand, a 'proscriptive value-laden' scientific approach that cannot be used for policy advice but is flexible for different value systems, and on the other hand, a 'prescriptive value-laden' scientific approach that can be used for policy advice but is inflexible and fixed within a plan of predetermined values. Conflicting recommendations from environmental scientists therefore result from the coexistence of multiple ‘prescriptive value-laden’ scientific approaches based on different concepts of the human-nature relationship.

This analysis is of particular interest for public decisions involving many interest groups and lobbyists with different views. The Common Agricultural Policy (CAP) in Europe is a typical example. For 30 years, this European public policy has faced the challenge of stopping its negative impact on the environment (Donald et al., 2001; Kleijn et al., 2001). Since the 1990s, successive changes have been made to integrate sustainable perspectives into European policies historically focused on production and modernization (Gray, 2000). Nevertheless, numerous articles are regularly published in the scientific literature, especially by conservation biologists, emphasizing the overly restrictive effects of these policies on biodiversity erosion, such as Peer et al. (2014). At the same time, Mouysset (2014) has shown that the measures are quite well designed in terms of their objective, which is not a purely ecological one but a sustainable one (*i.e.* combining ecological and social objectives). This dispute shows the typical antagonism between environmental scientists who oppose conservation biologists’ criticism of CAP and the economists who guided their design. Our analysis underscores that they can neither agree nor coexist in a consensual resolution because they both mobilize two different ‘proscriptive value-laden’ scientific exercises. Considering the importance of such public policies for the future of European countries, as well as the amount of budgetary resources involved,[3] the clarification of such structural antagonisms between the scientific experts guiding the policy decisions seems crucial to find efficient solutions to the sustainable challenge and environmental issues.

6 Perspectives

In our corpus of environmental science, the ‘prescriptive value-laden’ statement fits the disciplinary anchoring: the two disciplinary environmental sciences of interest (conservation biology and sustainability economics) retain this prescriptive ambition, while the problem-oriented (sustainable science) rejects it in favor of a proscriptive goal. In this way, the problem-oriented statement and its inherent perspective of interdisciplinarity could be interpreted as driving the weakening of the normative ambition, perhaps precisely to realize interdisciplinarity. It would be interesting to explore this conjecture with other environmental sciences, including political ecology or earth sciences.

Finally, it would be interesting to follow the analysis of the fields by considering recent definitions and debates in addition to the basic propositions. Indeed, there has been divergence within each field in recent years. Accounting for such intra-field heterogeneity could complicate the analysis, as different schools of thought in a field

[3] CAP is the European policy with the highest budget allocated by the European Union

might follow different trends. Extending the analysis to recent years is therefore a natural perspective of this study.

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