Who is Afraid of Biodiversity? Proposal for a Research Agenda for Environmental History

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ABSTRACT

There is an urgent need for studying the development of biodiversity in the (recent) past. It is one of the biggest threats to the sustainable future of mankind, which has not, however, received much attention from environmental historians. Several (historical) socio-economic drivers of biodiversity have been recognised; however, the extent, rate and precise causes of current decline remain unknown. A historical perspective on biodiversity and the network of socio-economic factors causing it, will lead to a more inclusive understanding of the complex human–nature relations resulting in biodiversity decline. The models currently used to simulate these processes, and theoretical notions about it, have not been tested against the historical record. To that end, the study is proposed of biodiversity on the basis of historical records and data – by scholars who can combine intimate knowledge of the historical sources with a deep understanding of the complex interaction between humanity and nature. Moreover, a research framework is presented that may be the starting point for the new research agenda. The framework gives a schematic overview of interconnected natural and socio-economic systems across different temporal, spatial and biological scales. Also, as this kind of research cannot focus on one country or region only, international cooperation between environmental historians and historical ecologists is proposed to address these issues in a systematic and global way.

KEYWORDS

Biodiversity, socio-economic drivers, interdisciplinary research

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INTRODUCTION

The decline of biodiversity is one of the most urgent problems facing humanity. Biodiversity plays an important role in ecosystem functions that provide supporting, provisioning, regulating and cultural services. These services are essential for human wellbeing.[1] Besides being a human problem, biodiversity loss is also an environmental problem. Biological diversity stabilises ecosystems in the face of environmental fluctuations.[2] Moreover, the conservation of nature is often also seen as an ethical goal in itself. However, biologists think we are going through the sixth mass extinction in history, but this time is different: one species, *Homo sapiens*, is largely responsible. It is the result of complex interactions between humanity and nature, and it is happening on an unprecedented scale.[3] Red List assessments show that things are getting worse, as even common and widespread species show sharp declines in occurrence and abundance, signalling wider environmental problems.[4] Pollution, alteration and loss of habitats, introduction of non-native species, climate change and overexploitation of resources are recognised as the main socio-economic causes of biodiversity decline.[5] Much remains unknown, however, about the extent, rate and causes of the current decline in global biodiversity. These knowledge gaps impede our ability to predict and mitigate its impacts. Studying past relationships between humans and nature can help conservationists develop environmentally rational and historically accurate plans of action. This will benefit ecological rehabilitation by allowing better-informed decisions for setting baselines and identifying the specific drivers and processes of biodiversity decline.[6] When the exact points of engagement are known, these drivers and processes can be redressed for the better. In a broader context, modern societies, seeking to limit the impact of human-mediated disturbances on the environment, can use historical knowledge to promote sustainable use of the natural world. The long-term perspective may clarify which benefits normal-function ecosystems may render for humans in terms of ecosystem services, but also show the boundaries of carrying capacity. In this way, it may help to avoid repeating past mistakes of depleting natural resources and destabilising ecosystems.

Environmental history as a discipline emerged in response to the growing environmental problems societies were facing in the second half of the twentieth century. It is, much like its twin brother historical ecology, concerned with the sustainability of societal development and with the interactions between

1. Millennium Ecosystem Assessment 2005; Haines-Young and Potschin 2010.
2. Tilman et al. 2006; Ives and Carpenter 2007.
3. Stuart et al. 2004; Schipper et al. 2008.
4. BirdLife International 2012.
5. Gaston and Fuller 2007.
6. Willis and Birks 2006.

humanity and nature in general.[7] However, the historical process of biodiversity loss has not had a meaningful impact on the study of history or the historical profession. Environmental historians have published extensively about man–nature interactions and their consequences for individual species and eco-systems. Recent examples are the histories of the rabbit in late Medieval Holland, of the tiger in the Malay world, or of the disappearance of the elephant from China.[8] More general environmental histories contain much information on man-nature relationships and the exploitation of ecosystems in the past, that can be integrated into the study of the development of biodiversity in recent times; for example, Roberts on the 'unnatural' history of the sea, or Richards' study of the environmental history of the early modern world.[9] Environmental historians know a lot about the fate of certain species and about the use of natural resources by man, but this is only rarely studied from the perspective of biodiversity change. The concept of biodiversity is only just beginning to appear in history textbooks and synthetic studies. In his brilliant *Something New Under the Sun. An Environmental History of the Twentieth Century*, John McNeill spends two pages, out of a total of 421, discussing the topic, repeating some of the well-known facts. In the prestigious *The Oxford Handbook of Environmental History*, of close to 800 pages, the topic is mentioned four times, but mainly as something studied by ecologists – and not by historians. The lack of real interest in this topic is striking, as historians were quick to respond to other environmental concerns: the history of pollution, for example, has received a lot of attention since the 1970s; and prominent historians like Le Roy Ladurie and Jan de Vries and many others after them did pioneering work on the history of the climate.[10]

There is, however, no doubt that this is a vast and important subject. The biologist Edgar Wilson whose *The Diversity of Life*, a seminal study of the ebbs and flows of biodiversity in the past, helped to put the topic high on the academic agenda, argued that that he could not imagine a scientific problem of greater immediate importance for humanity.[11] The historical study of biodiversity, however, has largely been left to biologists and ecologists. In the absence of historical research charting these changes, trends in the historical evolution of biodiversity have mainly been analysed by environmental scientists making use of models based on assumptions derived from contemporary research, assuming that these would also hold for the past. One of the best-known examples is the Globio3 model that simulates the decline of biodiversity since 1700 (the 'pristine' starting point before the Industrial Revolution) on the basis

7. Gonzalez de Molina and Toledo 2014.
8. Van Dam 2010 (the rabbit in Medieval England); Boomgaard 2001 (the tiger in the Malay world); Elvin 2004 (the elephant in China).
9. Roberts 2007; Richards 2003.
10. McNeill 2001; Le Roy Ladurie 1967; De Vries 1981.
11. Wilson 1992.

of changes in five 'drivers': land use, infrastructure, fragmentation, climate change and atmospheric nitrogen deposition.[12] A testing of these trends against the historical evidence has not been attempted – probably because biologists lack the knowledge of historical sources to do such research, and because historians have not been sufficiently interested in the problem of biodiversity loss. The implication of this is that the models on which policy decisions are based – such as the Globio3 model – are not properly tested against the actual development of biodiversity in the long run. The truth of the matter is that we do not really have a complete understanding of what drives biodiversity, and policies to redress the current dramatic decline may be based on incorrect assumptions about the long-term causes of the process.

In short, we argue that there is an urgent need for studying the development of biodiversity in the (recent) past on the basis of historical records and data – by scholars who can combine intimate knowledge of the historical sources with a deep understanding of the complex interaction between man and nature. This paper contains a number of suggestions for the development of such a research agenda. We will explore the promises of interdisciplinary data and research with regards to studying biodiversity in a historical perspective. First, we introduce the concept of and theoretical ideas about the evolution of biodiversity over time, then we discuss a framework that gives a schematic overview of the interconnected natural and socio-economic systems across spatial, temporal and biological scales. Such a framework may provide a starting point for developing the study into the causes of long-term decline in biodiversity. Finally, we propose a way forward for organising global historical biodiversity research.

THE CONCEPT

Biodiversity is a complex concept, encompassing the variety and variability of all life on Earth, ranging from the genetic level (the diversity within a certain species), to the species and the ecosystem levels (the diversity of ecosystems). Here, we have limited ourselves mainly to biological diversity of species, but other forms of biodiversity can in principle be studied in the same ways. Species diversity usually refers to the number of species present in a certain territory – or in the world as a whole. It is more or less known how many species of vertebrates have, for example, become extinct globally. Current estimates suggest that since the year 1500, over 332 terrestrial vertebrates, 150 of them bird species, have been reported as becoming extinct.[13] It has been suggested that current species loss is occurring at over 1,000 times the natural 'background' rate of around one to five per year. Often, it is known when and

12. Alkemade et al. 2009.

13. IUCN 2014.

why it happens, although, as arguably the most famous case, the Dodo, illustrates, such extinctions are difficult to date precisely, and there often is debate about the exact causes.[14] Similarly, it is, for example, possible to reconstruct when species appeared in the Netherlands and when they became extinct; a lot is already known about this for the recent period, but before about 1900 this has to be supplemented by historical sources to get the full picture. Case studies, such as the pioneering analysis of the history of certain birds in the Netherlands between 1500 and 1900 by De Rijk, show the potential of this kind of research.[15]

Species extinction is however only the tip of the iceberg. It is unclear how representative vertebrates (and plants) are for biodiversity as a whole; we know, for example, almost nothing about the history of the 4,000 species of beetles or 700 species of spiders that occur in the Netherlands. Moreover, the occurrence of a species is only part of the story. Species abundance (the number of species per square kilometre) is a more appropriate measure of biodiversity, which may change dramatically over time, even when no extinctions occur. Moreover, the spatial scope is also relevant. It is conceivable that at the global level species become extinct and biodiversity is declining, whereas at the same time, at the local level, biodiversity is stable or even rising, with certain species – perhaps those adapted best to human influences – becoming more widespread. To illustrate the complexity of the concept, McGill et al. distinguished fifteen different forms of biodiversity trends in the Anthropocene, and briefly discussed the empirical evidence for these trends, concluding, however, that 'even patterns that seem well established, like the global decline in biodiversity, have never been directly measured and rely on models to estimate the changes. Many trends are almost completely unstudied.'[16]

The complexity of the concept, and the difficulties that arise when it is measured even for today, imply that historical studies can only make use of proxies that are indirect measures of biodiversity in its entirety. Historical sources – in particular when they stretch far back in time – often relate to vertebrates, especially mammals and birds, which therefore figure most prominently in historical studies. Historical studies on plants often resort to early taxonomical works, but also to herbals, agricultural statistics and historical maps. One way to overcome this problem is to select 'indicator species' that provide information on the overall status of the ecosystem and of other species in that ecosystem. Such species include umbrella species, whose requirements for persistence encapsulate those of an array of associated species; keystone species, on which the health of the ecosystem depends; and foundation species, that define much of the structure of a community by creating locally stable conditions for other species. Indicator species may also reflect the quality of

14. Fuller 2003.
15. De Rijk 2015.
16. McGill et al. 2015.

and changes in environmental conditions and various aspects of community composition.[17] By making a careful selection of 'indicator species', representing the various biological characteristics of ecosystems in a region of country, one can get a deeper understanding of the evolution of biodiversity. Moreover, the impact of anthropogenic disturbances can be studied by selecting 'indicator species' that are sensitive to environmental change. Indicator species are in contemporary indices of the evolution of biodiversity (such as WWF Living Planet Index), which are based on what is known about trends in a limited range of species, most of them birds and mammals.[18] Applying such an approach in historical biodiversity research may be more complex, as availability of historical sources could be a limiting factor in selecting the appropriate indicator species. Several studies, however, have successfully used indicator species in historical research (see 'Measuring historical biodiversity').

THEORETICAL IDEAS

The concepts and approaches (as described above) generally only focus on parts of the network of drivers, pathways and effects related to historical changes in biodiversity. There are, however, also theories that entail the integral research network, albeit at different levels of complexity. For example, a lively scientific debate has developed around the question of whether economic development can benefit the environment or if it typically leads to an escalation of environmental problems.[19] The Ecological Modernization Theory (EMT) in sociology and the Environmental Kuznets Curve (EKC) in economics, hypothesise that economic development and modernisation do not necessarily increase environmental problems and even suggest that the most (economically) developed countries will eventually propagate environmental reform.[20] The EKC hypothesis assumes that the relationship between indicators of economic development, often quantified with per capita income, and environmental quality has an inverted U-shape.[21] Meanwhile, the EMT hypothesis suggests it is not economic development in itself that leads to environmental reform, but that modernisation causes institutional changes such as the development of nature conservation organisations and the rationalisation of bureaucracies.[22] Critical opponents of these theories, however, argue that the modernisation process and economic growth in particular, almost always lead to increasing environmental degradation. They hypothesise that a tipping point is never reached

17. Lindenmayer et al. 2000; Siddig et al. 2016.
18. Loh et al. 2005; McRae et al. 2016.
19. Buttel 2000; Clausen and York 2008.
20. Buttel 2000; Dina 2004.
21. Loh et al. 2005.
22. Ehrhardt-Martinez et al. 2002.

and that environmental impact continues due to profit maximisation and the relentless drive for growth.[23] The empirical studies addressing this debate have mixed findings, depending on the environmental issues studied and the type of data and methodological approach used in the analysis.[24] Evidence for the EKC is typically found only for a few local environmental impacts, such as air and water pollution, but not for sources of global environmental problems, such as greenhouse gas emissions and resource consumption.[25] The opposing hypothesis that increased economic growth only leads to increased levels of environmental degradation, on the other hand, has received considerable empirical support.[26] These national-level studies, however, have focused on the emissions of greenhouse gases and air pollution, instead of biodiversity decline as environmental impact.

In this paper, we examine and highlight the important role for (historical) empirical records. However, global biodiversity analyses are often performed by modelling social-ecological systems, which may provide important and complementary information on past biodiversity changes. Such approaches are often based on hypothetical (linear, univariate) relationships between biodiversity loss and certain socio-economic drivers, for instance, increased energy use, land-use change, forestry and climate change.[27] For example, the GLOBIO3 model builds on the IMAGE-NCI model and uses (empirical) cause–effect relationships to link environmental drivers with biodiversity impact.[28] The model describes biodiversity as the remaining mean species abundance (MSA), relative to their abundance in a pristine or primary situation, which is assumed not to be fundamentally disturbed by human activities. Individual species responses are not modelled in GLOBIO3 as MSA relates to response of a set of species.[29] Another model is the HYDE model, which provides spatially explicit land-use maps covering the period 10,000 BC to AD 2000 by combining historical population, cropland and pasture statistics with satellite information and specific allocation algorithms.[30] Hypotheses on the size and magnitude of historical land-use changes can be tested using the model.[31] Different global-scale policy options have been evaluated using these models – for instance, studying the effect on biodiversity of an increase in protected areas.[32] A common feature of these models is that they are based on assumptions derived from

23. Foster 1992; O'Connor 1998.
24. Siddig et al. 2016; Clausen and York 2008.
25. Loh et al. 2005; Cavlovic et al. 2000; York et al. 2003.
26. Ehrhardt-Martinez et al. 2002; Cole and Neumayer 2004.
27. Brink 2000.
28. Alkemade et al. 2009.
29. Tucker and McConville 2009.
30. Klein Goldewijk et al. 2011.
31. Klein Goldewijk and Drecht 2006.
32. Alkemade et al. 2009.

contemporary research, assuming that these will hold for the past.[33] They are, however, not sufficiently tested against the actual historical development of biodiversity. Model parameterisation and validation using empirical historical biodiversity data may give more reliable model results.

COMPLEX NETWORKS

Two pre-industrial events have been recognised as the beginning of human activity adversely affecting the biosphere, leading to (global) biodiversity decline.[34] The first was the extinction of the Pleistocene megafauna after *Homo sapiens* migrated from Africa to other continents.[35] The second was the emergence of agriculture with the Neolithic revolution, resulting in habitat destruction and fragmentation and other human-mediated disturbances.[36] The industrial revolution, the third major event, caused a significant increase in the human impact on the global environment.[37] In the last 200 years, the global population has grown from approximately one billion to six billion, leading to a major increase in energy use (forty-fold) and economic production (fifty-fold).[38] Moreover, the percentage of land area impacted on by intensive human activity increased from about ten to thirty per cent.[39]

Analysing the impact of these historical socio-economic developments on biodiversity is difficult. However, much of the knowledge about the drivers, root causes and impact pathways of current biodiversity loss is applicable for past conditions. The broad categories of socio-economic causes – i.e. pollution, alteration and loss of habitats, introduction of non-native species, climate change and overexploitation of resources – also hold for the historical perspective. Much remains unknown, however, about the relative importance of each driver along the temporal-spatial gradient. For instance, it is widely acknowledged that the Rhine-Meuse ecosystem has suffered severely from pollution, intensified fishery and large-scale river regulation over the last two centuries. Historical sources, however, indicate that significant anthropogenic pressures on the catchment area, like fisheries, small-scale river training and facilitation of invasive species, have been present, at least, since the Middle Ages.[40] Therefore, the assumption that historical declines in fish stocks result solely from the Industrial Revolution and associated demographic changes (c. 1800)

33. Brink 2000.
34. Steffen et al. 2011.
35. Alroy 2001; Roberts et al. 2001.
36. Dupouey et al. 2002; McLaughlin and Mineau 1995.
37. Alkemade et al. 2009.
38. McNeill 2000.
39. Lambin and Geist 2006.
40. Hoffmann 1996; Lenders et al. 2016

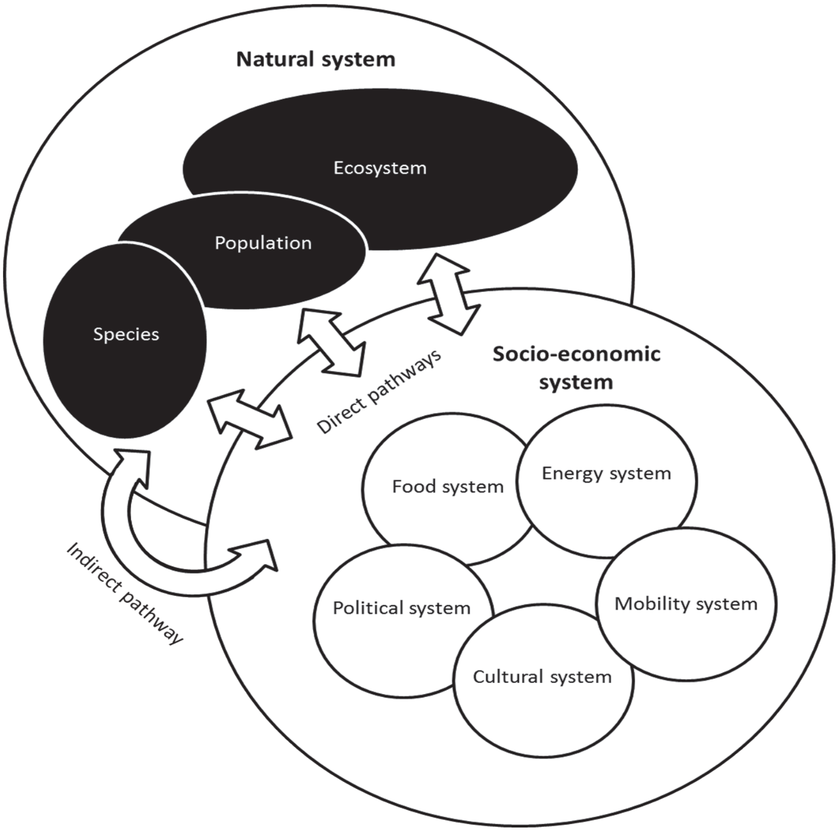

Figure 1. Interconnected natural and socio-economic systems via direct and indirect pathways.

may not provide a complete picture. Furthermore, the occurrence of species is determined by a complex web of interrelated drivers that have an impact through different direct and indirect pathways, which may also change over time (Figure 1). Direct pathways include biodiversity loss due to destruction of habitats and overexploitation of species. Indirect pathways include impacting biogeochemical cycles, such as the water cycle; and even natural drivers, such as autonomous climate fluctuations, also have a significant impact on the natural system. Moreover, biodiversity decline does not simply mean losing a species or two – it can have far-reaching consequences for the stability of natural systems. Biodiverse systems are more likely to include species that can compensate for the function of species that are lost due to natural or human-induced environmental fluctuations.[41] Moreover, losing one species from an ecological community can have cascading effects, for instance due to alteration in the food-web structure and energy flows, that lead to the extinction of other species.[42]This is especially the case when keystone or foundation species are among those lost. Adding to the complexity is that the interaction between the socio-economic and natural system is multidirectional. Changes to the natural system also impact on the socio-economic system, potentially leading to positive or negative feedback loops. For example, loss of biodiversity can lead to resource scarcity, which in turn leads to the exploitation of other, alternative, natural resources. Analysing the different socio-economic and natural drivers of biodiversity in conjunction with each other, and weighing their relative impact, will lead to a more inclusive understanding of the complex human-nature relations causing biodiversity decline.

Socio-economic and natural drivers affect biodiversity on different temporal, spatial and biological scales (Figure 2). Interaction between the socio-economic and natural system should therefore be studied in a long-term perspective to be able to identify events, processes and patterns occurring on different temporal scales.[43] Short-term events such as economic cyclical movements and political changes do not necessarily have a great impact on biodiversity, while long-term processes such as technological transitions or natural changes may have a more fundamental impact. Also, the patterns and processes should be analysed across different spatial levels. Furthermore, the impact of socio-economic and natural drivers may vary between, and within, taxonomic groups.[44] Historical biodiversity research should therefore include comparative analyses across species and examine linkages between spatial levels.

Summarising, to better understand current global biodiversity decline long-term human-nature interactions should be analysed across temporal, spatial and biological scales.[45] This type of research calls for an interdisciplinary approach in which the natural sciences and humanities are brought together by sharing and combing concepts, theories, methods and data. In recent years, several innovative studies have shown that such an interdisciplinary approach can provide promising results. For instance, it has highlighted that human perceptions of ecological conditions often lack historical perspective (shifting baselines) and may not account for long-term changes spanning decades, centuries, or millennia (i.e. climatic variability).[46] Until now, however, the long-term development of biodiversity has mostly been studied in an ecological context on

41. Ives and Carpenter 2007.
42. Pearse and Altermatt 2013.
43. Bradshaw et al. 2006.
44. Dullinger et al. 2013.
45. Hjorth and Bagheria 2006; Robinson 2004; Willis and Birks 2006.
46. Papworth et al. 2009; Jackson et al. 2011.

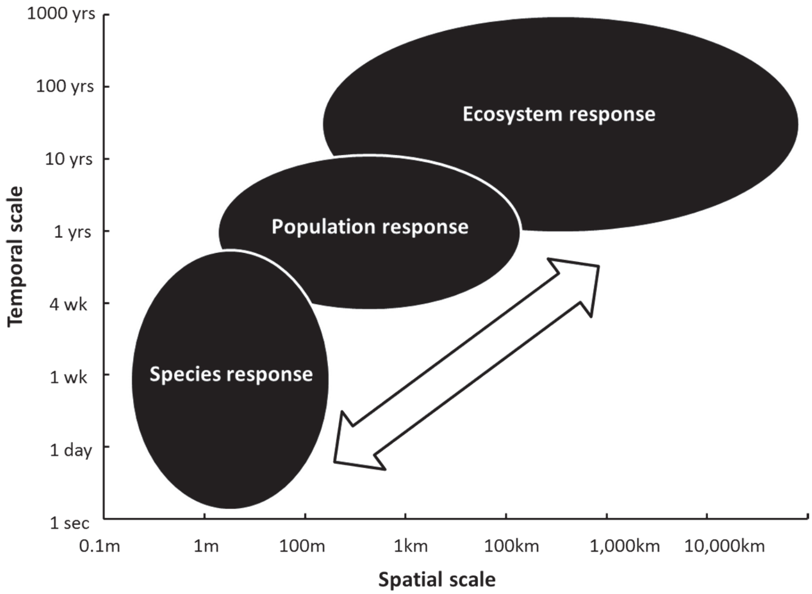

Figure 2. Spatial and temporal scales within which individuals, populations and ecosystems respond to socio-economic and natural stressors (Adapted from Suter, 1993).

local to regional scales.[47] Studies with a broader scope, for instance, relating socio-economic developments to long-term trends in biodiversity, are limited. The recent book by Rotherham on biodiversity and conservation in England gets closest to this, but as the author is an ecologist, historical sources are underexploited; moreover, the book lacks a systematic measure of biodiversity.[48] Rotherham's perspective is that of the history of the eco-cultural landscapes that evolved in Britain due to intense man–nature interactions. This fits into a tradition of research by ecologists and historical geographers to analyse the historical evolution of landscapes and related ecosystems, which forms an important source of information for the new paradigm proposed here (Spek is an excellent example).[49] A few studies have assessed the impact of climate and land use change on long-term trends in biodiversity on a global scale. These studies, however, used representative proxies or model approaches, instead of empirical data.[50]

47. McClenachan et al. 2015; Rick and Lockwood 2012.
48. Rotherham 2014.
49. Spek 2004.
50. Perring et al. 2015; Vellend et al. 2013.

RECONSTRUCTING LONG TERM TRENDS IN BIODIVERSITY

Major global biodiversity datasets, such as the PREDICTS database, IUCN Red Data list or the WWF Living Planet Index, generally only contain data dating back to 1950. Much of our knowledge of long-term patterns of species distributions, and the processes that determine them, has therefore come from restricted subsets of species, regional data sets or indirect indicators of species loss.[51] To overcome this limitation, it has been propagated that an interdisciplinary approach is needed.[52] By combining data from interdisciplinary sources, longer and more complete records of the development of biodiversity and the socio-economic and natural determinants of species occurrence can be compiled.[53] Such an approach may help transcend the 'pre-1850 problem', i.e. the lack of data from before the 1800s.[54] Ecologists can provide data on a microscale (<150 years), while historians can contribute data on a mesoscale (<2000 years).[55] Furthermore, archaeologists and paleobiologists can provide data at the macroscale (<10,000 years). Comparing data from these partially overlapping scales can help characterise the influence of anthropogenic and non-anthropogenic processes on species occurrence and biodiversity in general.[56]

Data sources

Researchers have used diverse (non-traditional) sources, including archaeological remains and palynological data, but also archival records and oral histories, to reconstruct long term trends in biodiversity (see Table 1 for a short overview). Several reviews have described the use of different data sources for reconstructing (historical) biodiversity: Pyke and Ehrlich for biological collections; Hudson et al. for observational data; Steele for zooarcheological records; Kidwell, Willis and Birks, and Willis et al. for paleoecology; McClenachan et al. for archival records; and Vellend et al. and McClenachan et al. for historical data.[57] Many of the data are available online via (disciplinary) global databases. Many digitalised collections and surveys have been compiled in GBIF (http://gbif.org). Other database include PREDICTS, Living Planet Index for surveys, The Paleobiology Database (http://paleodb.org) and Neotoma Paleoecology

51. Collen and Nicholson 2014; Willis and Birks 2006; Klein Goldewijk 2011.
52. Szabó and Hédl 2011; Rick and Lockwood 2012.
53. Robinson 2004; Papworth et al. 2009.
54. McClenachan et al. 2015; Loh et al. 2005.
55. Callicott 2002.
56. Rick and Lockwood 2012.
57. Pyke and Ehrlich 2010; Hudson et al. 2014; Steele 2015; Kidwell 2015; Willis and Birks 2006; Willis et al. 2010; McClenachan et al. 2015; Vellend et al. 2013.

Database for archaeological and paleoecological records.[58] Historical sources have been underrepresented, as compared to archaeological and biological data, in studies on historical development in biodiversity.[59] This might be because there are no global databases for historical records on plant and animal species, only national databases, archives and repositories. Or, alternatively, historical sources are underrepresented because environmental historians have not asked these questions in the past. Only historians can open the archives for this kind of research, as they know the sources, can contextualise them and see how they can shed light on biodiversity in the past. A good but rare example of this is the HMAP Data Collection containing marine catchment data from historical archives.[60] Historical sources and data are often challenging to gather in major databases as they may be in a variety of dialects (or languages), contain disparate information as they were created for different purposes, or be unavailable in a digital format (or without metadata). Recently, however, an increasing number of studies show the potential of using these non-traditional sources.[61]

Measuring historical biodiversity

An historical perspective on biodiversity includes reconstructing different aspects of biodiversity through time and space, e.g. (i) population size, (ii) distributions and abundances of species, (iii) species composition in particular areas, (iv) habitat and behaviour, (v) variations in species traits. Ideally, consistent and standardised quantitative data is used for such long-term analysis of biodiversity. Unfortunately, in the real world such data is often not available. Alternatively, long-term population change can also be analysed by determining the relevant timeframe upfront, and then collating the dataset matching the change over this time period.[62] In most cases, the best available data will be qualitative or semi-quantitative, and often originate from multiple disparate sources.[63] The nature, extent and accuracy of information available in such data sources needs to be considered before using it in historical analyses (see also the data type specific reviews mentioned above). In general, historical data are often incomplete or contradictory. Historical descriptions of species may reflect the particular political, religious and economic settings in which they were made, thus complicating interpretation of the data and resulting,

58. Hudson et al. 2014 (PREDICTS database); McRae et al. 2016 (Living Planet Index); Goring et al. 2015 (The Paleobiology Database and Neotoma Paleoecology Database).
59. McClenachan et al. 2015.
60. http://www.hull.ac.uk/hmap/
61. Szabó and Hédl 2011; McClenachan et al. 2012; Vellend et al. 2013.
62. Rick and Lockwood 2012.
63. Branch et al 2004.

Table 1. Available data suitable for reconstructing long term trends in biodiversity arranged according to fields of research. The type of source and information, respective time period and available databases are given.

Fields of research	Type of source	Type of information									Time period	Main global databases
		Species occurrence			Socio-economic drivers			**Natural drivers**				
		Quantitative	Proxy	Qualitative	Quantitative	Proxy	Qualitative	Quantitative	Proxy	Qualitative		
Main sciences												
Ecology	Ecological knowledge			X			X			X	N/A	N/A
	Species observations	X		X				X		X	1850 – present	PREDICTS, LPI, GBIF
	Herbarium records	X	X	X		X			X		1700 – present	GBIF
	Museum collections	X	X	X		X			X	X	1650 – present	GBIF
	Natural history works, flora, bestiaria	X		X		X	X		X	X	1500 – present	*National databases
History	Oral histories	X	X	X	X	X	X	X	X	X	1900 – present	*National databases, papers and repositories
	Newspaper articles	X	X	X	X	X	X	X	X	X	1800 – 1950	
	Catchment, yield data and statistics	X	X	X		X			X		1700 – present	HMAP, national databases
	Paintings, prints and photographs		X	X		X	X		X	X	1500 – 1950	*National databases
	Exploitation and trade documents	X	X	X		X			X		1400 – 1950	*National databases, papers and repositories
	Narrative descriptions, maps and charts	X	X	X		X			X		1200 – 1950	
Archeology	Domestication /exploitation practices			X	X	X	X		X	X	11k BC – 1900	N/A
	Plant macro remains and pollen	X	X	X		X	X		X	X	11k BC – 1900	The Paleobiology Database
	Animal bones, teeth, and shells	X	X	X		X	X		X	X	11k BC – 1900	

Adjacent sciences												
Pale-ontology	Dendro-climatological information		X			X		X	X	X	1000 – present	Neotoma Paleoecology DB
	Paleo-climatological data from ice cores		X			X		X	X	X	800k BC-1900	
Physical geography	Geo-morphological maps		X	X		X	X		X	X	10k BC –present	*National databases
	Phenological records of natural processes				X			X	X	X	1k BC – present	PPODB
Economics	Theory of economic processes						X				N/A	N/A
	Historical macro-economic statistics				X	X	X				1500–present	CLIO-INFRA
	Historical demographic statistics				X	X	X				1500–present	
Anthro-pology	Theory on the human condition and its relation to the natural world			X		X	X				N/A	N/A

for instance, in uncertainty about species identification.[64] Also, most historical sources were originally not intended to be used in scientific research. They often have inherent biases and limitations, suggesting that they are more useful in some contexts than in others.[65] Natural history collections, for instance, have been most useful in the context of assessing properties of individual species and population averages derived from them.[66] Attempts to reconstruct species distributions from these collection have been less successful, because of the manner in which they have been established.[67] Moreover, historical records often contain heterogeneous structured and unstructured information on the use of species, ecosystems and land. Historical data on species is, therefore, often only available for proxies of biodiversity such fish stocks, or rather the yield of these stocks in the form of the produce of fisheries. Much historical research on species trends is based on such data – the 'harvest' of furs, fish, whales, ivory etc. – which is intermediated by the 'effort' put into hunting

64. Herrmann 2013; De Rijk 2015.

65. Newman et al. 2004; Newton et al. 1992.

66. Graham et al. 2004.

67. Pyke and Ehrlich 2010.

and fishing.[68] The History of Marine Population Project (HMAP) pioneered the use of such data by developing methodological standards for its analysis. Lenders et al. successfully used such historical proxies in combination with other historical sources and archaeozoological records in their study of the pre-nineteenth century collapse of Atlantic salmon stocks in North-Western Europe.[69] By analysing historical fishery, market and tax statistics, independently confirmed by interdisciplinary data, they demonstrated that populations declined by up to ninety per cent between the Early Middle Ages (c. 450–900 AD) and Early Modern Times (c. 1600 AD). Moreover, the historical perspective contributed to a better understanding of the primary drivers that led to declines in salmon populations. They showed that the dramatic declines coincided with improvements in watermill technology and their geographical expansion across Europe. In another study, Lenders used the same type of historical sources and methodology to show that salmon decline might have caused a cascade in the River Rhine ecosystem as fisheries shifted to, especially, Allis shad and Twaite shad, followed by (near-)extinction of these species.[70] This example shows that, although such data may be inherently biased through human influences, the study of trends in biodiversity and man-nature interactions do not differ fundamentally from other branches of historical research. Historians also have to deal with problems concerning the limitations of historical sources, but they have been trained to put historical sources into context and interpret them, doing justice to the research question and the historical context in which they came into existence.

Recently, several methods and analytical approaches have been proposed to synthesise data from heterogeneous sources and incorporate semi-quantitative information on past conditions. Although experience with these types of statistical methods in combining interdisciplinary data for historical biodiversity research is relatively limited, several studies have shown its potential.[71] For instance, Ferretti et al. used regression techniques to extract population trends of sharks from multiple historical sources.[72] The diverse set of records included commercial and recreational fishery landings, scientific surveys and sighting records, dating back to the early nineteenth century in the northwestern Mediterranean Sea. The results showed that Hammerhead, blue, mackerel and thresher sharks declined up to 95 per cent relative to their former abundance. Another statistical approach that has been proposed is hierarchical Bayesian analysis, which allows the inclusion of informative biological knowledge to help extract population trends from various historical sources.[73] Branch et al.

68. Poulsen 2006.
69. Lenders et al. 2016.
70. Lenders 2016.
71. Graham et al. 2004; Pyke and Ehrlich 2010.
72. Ferretti et al. 2008.
73. Kadmon et al. 2004.

used blue whale biology and population trends of other blue whale populations to extract population trends from three historical sighting series of Antarctic blue whales.[74] They found that the Antarctic blue whale population was increasing, avoiding extinction, although the population size was still only at one per cent of pre-exploitation level. Also, ecological niche and species distribution modelling have been proposed in case only presence-only species data is available, which is often the case in historical sources.[75] These modelling approaches, especially when combined with paleo-geographical/climatic information, have potential to be an additional tool for reconstructing biodiversity.[76] These studies illustrate that integrating disparate datasets proves to be challenging, but not impossible.[77] Hence, non-traditional data should not be discarded because they differ in format, quality and resolution from structured datasets. There is, however, another challenge to overcome, as most historical datasets pertain only to population trends of a single species on a local scale. These trends can be aggregated to develop more complex biodiversity indices, though, either in terms of number of species included or the spatial resolution covered. A potential viable approach is the Living Planet Index (LPI) methodology. The LPI is a measure of the state of global biological diversity based on aggregated population trends. It uses a generalised additive modelling framework to determine the underlying trend in each population time-series.[78] Average rates of change are then calculated and aggregated to the species level. The method of aggregation includes a weighting system to counteract the uneven spatial and taxonomic distribution of the data. In general, a better understanding of long-term changes in biodiversity can only be achieved by combining many different types of novel data, methods and approaches.

Other than the methodological challenges regarding data quality and integration, there is the issue of limited data availability for specific regions, timeframes or species groups. To deal with this, various approaches are possible. Studying a selection of indicator species' representing various regional ecosystems, could offer an important tool for further biodiversity analysis. Billeter et al. showed, for a contemporary setting, that selecting indicator species that correspond to a select list of European agricultural landscapes and land-use parameters can help to infer large-scale patterns of species diversity resulting from biogeographical variation.[79] Indicator species analysis has also been applied in a historical setting, e.g. for river systems, forests and

74. Branch et al. 2004.
75. McClenachan et al. 2015.
76. Phillips et al. 2006; Elith et al. 2006.
77. Newton 2010.
78. Collen et al. 2009; Loh et al. 2005.
79. Billeter et al. 2008.

agricultural landscapes.[80] Supplementary information can come from studying historical evidence still to be found in contemporary habitats, for instance, genetic species analysis of rapid population decline (RPD), studying remnant species or comparing contemporary with reference habitats. [81] To overcome the lack of continuous times series of species data benchmarks can be constructed and compared. These are historical periods for which detailed information about the occurrence of species is available; for the Netherlands, for example, this can be done for the years since about 1900, when, for example, the first regional censuses of breeding birds were held.[82] This allows for the in-depth study of ecosystems in this particular period, putting together, as in a jigsaw puzzle, all the sources that can be found in order to reconstruct the overall picture of biodiversity in a given time-span.

ANALYTICAL FRAMEWORK: UNDERSTANDING HISTORICAL TRENDS IN GLOBAL BIODIVERSITY

As shown above, an interdisciplinary approach is important for reconstructing trends in biodiversity. In a broader context, however, the interdisciplinary approach may be even more important as it is essential for understanding complex relationships between humans and nature over the long term. To that end, an inclusive perspective on environmental change is needed, which draws on a broad spectrum of evidence from the biological and physical sciences, ecology and the social sciences and humanities.[83] Moreover, an interdisciplinary grammar needs to be developed and shared concepts and understandings identified.[84] This means that the customary disciplinary methods and protocols are to be respected, but the structure of the research field as a whole is synergetic.[85] This can be achieved by using a holistic research framework that considers the socio-economic and natural systems as part of the same interrelated system. Historians have an important role to play in this regard, not only because they are trained to interpret historical sources (see above), but because the socio-economic and natural systems are organised and interacting in a non-hierarchal and non-linear manner. Historians are well equipped for analysing such heterarchical systems.[86]

80. Noble et al. 2007 (river systems); Hermy et al. 1999 (forests); De Rijk 2015 (agricultural landscapes).
81. Li et al. 2016 (RPD) ; Billeter et al. 2008 (remnant species); Smits et al. 2004 (habitats).
82. Van Zanden 2018.
83. Hornborg and Crumley 2007.
84. Newell et al. 2005.
85. Liu et al. 2007.
86. Crumley 2005.

Several integrative frameworks and initiatives to study social-ecological systems over time have been proposed. For instance, the Integrated History and Future of People on Earth (IHOPE) initiative is a global network of researchers and research projects using integrative frameworks to study the sustainable development of future societies.[87] IHOPE promotes integrating perspectives, theories, methods and networks from the social and Earth system sciences, the humanities and communities of practice. Other such initiatives and frameworks focus on global ecological assessments, ecosystem services, hierarchical theory and social-ecological dynamics.[88] From an environmental history perspective, the integrative analysis of the human and natural worlds proposes spatial and temporal frameworks of unusual amplitude. Although not formalised frameworks in themselves, major environmental history scholarly works include Alfred Crosby's work on the transfer of plants, animals, and illnesses caused by the 'discovery' of America, and the impressive range of case studies compiled by Donald Hughes to analyse dynamics of the co-evolution of societies and their ecosystems.[89] These frameworks and initiatives encourage global, transnational or comparative studies, writing 'big' histories, and exploring interdisciplinary and international links. None of these frameworks, however, has a focus solely on biodiversity. Environmental historians know a lot about the fate of certain species and about the use of natural resources by man, but this is only rarely studied from the perspective of biodiversity change. The tentative methodological framework proposed here is 'new' in the sense that biodiversity (change) is analysed in the (very) longue durée and on a global scale. The central idea is that humanities and biological disciplines need to be coupled to be able reconstruct biodiversity and understand its drivers.

The initiative that most closely matches the approach and aims of the proposed analytical framework is the HMAP project. They aimed to reconstruct long-term changes in stock abundance, analyse the ecological impact of large-scale harvesting by man, and study the role of marine resources in the historical development of human society. Interdisciplinary research teams analysed data from a variety of unique sources to piece together changes in specific populations over time.[90] The environmental history of the Dutch herring by Poulsen is an example of a HMAP case study.[91] Herring populations were reconstructed over the past 400 years by using ships' logs and the changes were interpreted in a political, social and economic context. Major theories and methods resulting from the HMAP project have been collated in a systematic way in the book

87. Costanza et al. 2012; Hibbard et al. 2010.

88. Global ecological assessments: Millennium Ecosystem Assessment 2005; Ecosystem services: Anderies et al. 2004; Ostrom 2009; Hierachical theory: Bourgeron et al. 2009; Social-ecological dynamics: Carpenter 2002; Lade et al. 2013; Lansing et al. 2014.

89. Crosby 1972; Hughes 2001

90. Máñez et al. 2014

91. Poulsen 2006.

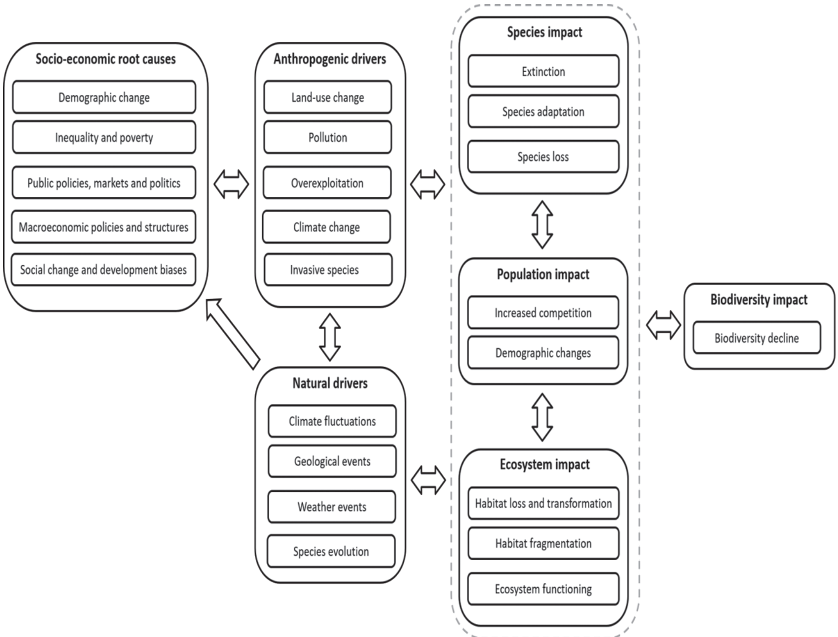

Figure 3. Research framework for analysing long-term trends in biodiversity in relation to socio-economic and natural drivers.

Perspectives on Oceans Past, which allows building on results of the marine environmental history discipline.[92]

Figure 3 shows the proposed research framework for analysing long-term trends in biodiversity in relation to socio-economic and natural drivers. To understand historical biodiversity decline, the direct causes of biodiversity decline cannot be analysed without considering (indirect) anthropogenic and natural drivers and socio-economic root causes, and vice versa. Several main anthropogenic drivers of biodiversity decline have been recognised: land-use change, by agricultural expansion (food and biofuel production), infrastructure development and deforestation; pollution, including pollution of the terrestrial, air and freshwater and marine compartments; overexploitation, by fisheries, mining and commercial wood extraction; climate change; invasive species, by

92. Schwerdtner Máñez and Poulsen 2016.

agriculture and trading.[93] Besides anthropogenic drivers there are also natural phenomena, such as climate fluctuation, weather and geological events and species evolution, that can have a direct effect on biodiversity. Beyond the study of direct drivers of biodiversity loss, lies the analysis of socio-economic root causes of biodiversity decline. The rationale is that biodiversity loss is indeed caused by direct drivers, but that these drivers in turn are influenced by human activity. Studying the economic and social causes provides information complementary to biological explanations of the biodiversity problem. Socio-economic root causes of biodiversity decline have been recognised along five main axes, each reflecting different (theoretical) approaches for analysing biodiversity loss:[94]

(a) *Demographic Change:* Globally, human populations are growing, leading to increases in energy consumption and the exploitation of natural resources.[95] However, the location of population growth is perhaps equally as important for biodiversity loss as the absolute numbers to analyse, for instance, habitat conversion.[96]

(b) *Inequality and Poverty:* Inequality determines patterns of resource use at all geographic levels. Poverty has been linked with poor management of resources, while wealth has been linked with high consumption and short-term management of resources, both leading to environmental degradation.[97]

(c) *Public Policies, Markets and Politics:* Policies and market dynamics often provide incentives which degrade biodiversity.[98] This can be seen as a failure of the political system to incorporate the monetary value of biodiversity into decision-making and to integrate biodiversity concerns as a standard element into policy.[99]

(d) *Macroeconomic Policies and Structures:* Biodiversity loss is linked to the structure and behaviour of international and national markets and government policies. Trade and exchange rates liberalisation have led to globalisation, resulting in uniform and large-scale production, mechanisation and concentration of production. These processes have altered the

93. Land-use change: Cowlishaw 1999; Foley et al. 2005; Lunt and Spooner 2005. Pollution: Barker and Tingey 1992; Vörösmarty et al. 2010. Overexploitation: Flynn et al. 2009; Worm et al. 2006. Climate change: Chapin et al. 2000. Invasive species: Gurevitch and Padilla 2004.

94. Stedman-Edwards 1998; Wood et al. 2000.

95. Liu et al. 2003.

96. Cincotta et al. 2000

97. Cole and Neumayer 2004; Fisher and Christopher 2007.

98. Brink 2012; Pascual and Perrings 2007.

99. Christie et al. 2006; De Groot et al. 2010.

patterns and intensity environment degradation on a global scale.[100]

(e) *Social Change and Development Biases:* The current development paradigm fails to incorporate sustainability, i.e. biodiversity conservation, as a central goal.[101] Development remains synonymous with an increase in consumption and the transformation of natural resources, leading to biodiversity loss.[102]

Such a research framework provides opportunities for studying the dynamic relationships between the socio-economic and natural drivers of long term trends in biodiversity.[103] It can be used to analyse the variability of ecosystems, populations and species across space and time in relation to the social system at various levels of abstraction. There is an important role for humanities researchers in such analyses as they have intricate knowledge about socio-economic systems and contexts in the past. The key elements in social-ecological systems linked to historical developments in biodiversity are detailed below:

- *Baselines and Trends:* Long term biodiversity data can be used to assess the difference between present conditions and less disturbed historical conditions, and to subsequently derive baselines used in nature conservation.[104] Typically, a pre-industrial reference point in time is taken as baseline. However, the assumption that all natural areas in pre-industrial periods had pristine ecological conditions has recently been debated. In some cases, it is diffcult to identify a specific stage in time that can be used for reference, as impacts of low intensity, long duration nature utilisation might be more important than previously assumed.[105] Connected to this are natural trends in biodiversity, but also individual elements and drivers in the system. Identifying these trends and patterns can help to understand how current drivers and ecosystem states relate to baseline (low or pre-impact) levels. Familiar patterns can also suggest path-dependency.[106] More profound knowledge on the history of biodiversity and anthropogenic influence thereon can provide important input to the 'shifting baseline' debate.[107]

- *Testing hypothesis and post hoc analysis:* Long-term biodiversity data can be used to test (conflicting) hypotheses. For example, surface water acidification was a major international problem in the 1980s. Due to a lack of long-term observational data, however, there were a number of alternative

100. Asafu-Adjaye 2003.
101. Gladwin et al. 1995.
102. Mebratu 1998.
103. Arrow et al. 1995; Dearing et al. 2006; Dearing et al. 2015.
104. Scholes and Biggs 2005.
105. Bradshaw et al. 2006.
106. Dearing et al. 2006.
107. Pauly 1995.

theories as to its causes, e.g. the effects of forestry and long-term natural biogeochemical cycling. Definitive evidence was provided by using historical biodiversity and instrumental data in a hypothesis-testing approach.[108] Furthermore, post hoc analysis may prove valuable to ascertain previously unknown drivers or patterns of species loss, as this type of analysis consists of studying the data for patterns that were not specified a priori.[109] Unanticipated patterns or events related to biodiversity loss can be identified, for instance, patterns related to major climate events.[110]

- *Long-term processes and spatio-temporal variability:* Extending the timeframe of analysis can provide a very powerful means for understanding long-term processes and spatio-temporal variability.[111] This allows the study of typical modes of response of drivers and biodiversity (e.g. cyclical, high frequency variability), feedback mechanisms in the system, dynamic relationships (responses explained by linear bivariate or multivariate analyses of drivers), thresholds and regime shifts (alternate or transitional states).[112] For instance, anthropogenic climate change needs to be analysed over long time periods and on local, regional and global scales, as it may provide information on the resilience and resistance of species and ecosystems to natural variability of the climate.[113] Moreover, losing one species from an ecological community can have cascading effects that lead to the extinction of other species.[114] Empirical evidence for this hypothesis is available for simple ecological communities with short-lived, large turnover species.[115] However, extinction cascades need to be analysed in more complex communities and across regional scales, as these processes might take place over decades or centuries.[116]

- *Model parameterisation and validation:* Global environmental assessment models are used for policy purposes to assess the impact of human drivers on biodiversity, e.g. the GLOBIO3 and HYDE models. These models, however, often have considerable model uncertainty, as they use assumptions based on cause-effect relations.[117] Long term, empirical biodiversity data is needed for model validation and parameterisation[118]. Furthermore,

108. Liu et al. 2003; Battarbee et al. 1985.
109. Liu et al. 2003.
110. Bernstein et al. 2008.
111. Callicott 2002; Morgan et al. 1994.
112. Liu et al. 2003; Dearing et al. 2015.
113. Parmesan and Yohe 2003; Walther et al. 2002.
114. Cardinale et al. 2012.
115. Pearse and Altermatt 2013.
116. Krauss et al. 2010; Thomas et al. 2004.
117. De Heer et al. 2005; Alkemade et al. 2009.
118. Leemans et al. 2007.

scholars have estimated that species extinctions are currently occurring at a rate of up to 100 species a day and yet less than 1,200 extinctions have been recorded in the last 500 years.[119] A clear discrepancy exists between empirical extinction data and (modelled) extinction rates. The reasons for this discrepancy include successful conservation efforts for protected species, resilience in species survival and species not being equally prone to extinction.[120] However, more empirical data on species extinctions are needed to validate these hypotheses and results.[121]

- *Views for the present:* A historical perspective on the social-ecological system can help to determine operating spaces for policy. It can help inform guidelines for maintaining specific biodiversity goals within sustainable limits regarding social conditions.[122] It can also be used as an early warning signal, as increasing variance, skewedness or autocorrelation might represent growing instability.[123] Also, sustainable management might be informed by the past by identifying (eco-)systems that are historically durable, insensitive or resilient to volatility of socio-economic and natural drivers, or analogues to serve as templates for modern governance, policy and management.[124]

A GLOBAL RESEARCH NETWORK

The compilation of archaeological, historical and ecological data, within an integrated and well-defined research design by interdisciplinary teams, is a crucial step toward providing more comprehensive understanding of the socioeconomic causes of biodiversity decline. The complexity of interlinked systems at various geographical, socio-economic, and temporal scales will require an extensive use of interdisciplinary methods. However, the field of research concerned with studying long-term human–nature relations on a global scale has no leading specialised institutes.[125] An important reason for this is that the data are too scattered across the globe and, moreover, are too different with respect to the nature, extent and accuracy of the available information. Hence, it is impossible for a single scholarly institute to assemble global interdisciplinary datasets alone. Assembling global trends in biodiversity is only feasible by bringing together leading scholars in the respective fields of research and regions in collaboratories. These virtual communities of researchers provide

119. Stork 2010.
120. Dearing et al. 2006.
121. Feeley and Silman 2008.
122. Dearing et al. 2014.
123. Scheffer et al. 2012.
124. Costanza et al. 2007.
125. Szabo 2015.

cross-pollination across regions and disciplinary domains. Researchers and scholarly communities will not only become involved in interesting interdisciplinary working groups operating at the frontier of knowledge, but they will also acquire access to data with which to compare their own (disciplinary) data. By providing a forum for sustained interaction between historians, archaeologists, paleoecologists and biologists, a greater depth of collaborative research is promoted to put together interdisciplinary data sets, review contributions and documentation and to reach agreements on unified methodologies.

An important step is to create a global network of datasets that hold state-of-the-art data, and that are shared in the joint effort to create a comprehensive body of knowledge on global historical biodiversity. Such a research network can be built on the model of connected data hubs. Data hubs offer data collections on specific issues. An example of such a network of datasets is the ATHENA project in the Netherlands (www.athena-research.org). The ATHENA project brings historical sources, archaeological information and observational data on flora and fauna together and combines them in an online data portal. The data portal provides much needed additional and contextual information to the individual sciences involved. By doing so the project alerts disciplinary scientists to new data sources that they are unfamiliar with, thereby integrating scientific disciplines. A global such initiative could use data hubs found in various fields, for example The Paleobiology Database or the Neotoma Paleoecology Database. Special attention needs to be given to historical sources on species occurrence. Museum collections, botanical gardens and other historical sources can play a vital role, since these records contain a vast wealth of information on which species was found at a particular location in time.[126] Such data are currently, however, not available in any data hubs. Also, interpreting historical data is challenging as a thorough understanding is needed of how historical information was handed down and shaped by cultural contexts. As a consequence, a regionalised approach for reconstructing and analysing biodiversity based on historical sources seems most promising.[127] A strong collaboratory is therefore necessary to (further) bring together relevant (knowledge based on) historical data on a global scale.

The research collaboratories can build on the experiences and results of past initiatives, such as the History of Marine Animal Populations (HMAP), Long Term Ecological Research (LTER) and programs of PAGES such as, LandUse6K and International Geosphere Biosphere Programme (IGBP-PAGES).[128] HMAP implemented its global mission through a regionalised approach. Case studies were used that were generally regional in scope and focused on a few species or habitat and biodiversity changes. The case studies

126. Sax and Gaines 2008.

127. Dearing et al. 2015.

128. Máñez et al. 2014 (HMAP); Redman et al. 2004 (LTER); Oeschger 1993 (PAGES); Gaillard et al. 2015 (Landuse6K); Parmesan and Yohe 2003 (IGBP-PAGES).

were selected based on data availability and relevance. The IGBP-PAGES program has shown that regional approaches also hold when integrating social-ecological histories for identifying patterns of broader environmental change in the past.[129] The LandUse6k project showed major opportunities in combining empirical and model approaches to be able to address the research topics on multiple geographic and temporal scales.[130] They focused on developing more accurate and complete historical land use and land cover maps, instead of directly looking at species responses, to support research into a wide variety of fields.

CONCLUSION

In this paper we suggest that biodiversity decline – one of the most fundamental threats to the sustainability of societies – should be studied more systematically by environmental historians, as they have the expertise to unlock the historical sources documenting the historical evolution of species and can analyse the drivers behind it. The models used to simulate these processes in the past – such as the Globio3 model – and theoretical notions about an Environmental Kuznets curve have not been tested against the historical record. We really do not know what happened to biodiversity in the historical period, and what was driving it, although there are of course various hypotheses to direct research. We have also suggested a number of hypotheses and relevant sub-questions that can help to develop this new research agenda. Finally, we think this kind of research cannot focus on one country or region in the world only, but that international cooperation between environmental historians and historical ecologists is required to address these issues in a systematic and global way.

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129. Dearing et al. 2015.
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