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Relationships between human activity and biodiversity in Europe at the national scale: Spatial density of human activity as a core driver of biodiversity erosion

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ABSTRACT

Many empirical studies have analyzed the relationship between human activity and the environment. Some of these have focused on the potentially negative impacts of human activity on the environment while others have tried to identify the socio-political variables that could be at play in this relationship. Herein, we used well-adapted statistical methods to study the relationship between human activity and biodiversity in Europe at the country level. We worked with classical biodiversity indicators (two state indicators, two pressure indicators and one response indicator) on the one hand, and socio-economic variables on the other hand. We found strong relationships between economic variables and both pressure indicators (related to soil sealing) and state indicators (related to the proportion of extinct and threatened species). However, there was no relationship between economic variables and the response indicator (related to the proportion of protected area). We did find significant relationships between biodiversity and some sociological variables: in particular, interpersonal trust, which is known to favor economic prosperity, improved biodiversity levels. However, the best models all included economic variables. Our results cast a new light on an old issue: first, they reveal that the spatial density of human activity – either through economic growth or population levels – is a key variable that is positively related to land sealing levels and to both past and current biodiversity erosion; they also show that the impact of the spatial density of human activity on biodiversity state indicators tends to decelerate – but not to decrease – as the spatial density of human activity increases. Our results clearly indicate that the spatial density of human activity should be part of any political analyses related to biodiversity – including systems of biodiversity indicators. Our results also reveal the need for further studies involving these metrics. They also emphasize the tension between policy objectives related to economic growth and biodiversity preservation. Yet, they indicate that increasing social trust, which seems to favor both economic growth and biodiversity levels, might provide a solution.

1. Introduction

Ecological science has long included analyzes at the macro scale (see Arrhenius, 1921; Willis, 1922; and references in Brown, 1999; Gaston and Blackburn, 1999). Yet, this practice has only recently been formalized into a research program – called macroecology – with a strong emphasis on an empirical statistical approach to global patterns (Brown, 1999). This research program was inspired by (i) the recognition of human pressures at a scale so large they cannot simply be analyzed from smaller scale approaches (Brown, 1999; Gaston and Blackburn, 1999); (ii) the realization that empirical approaches to identifying patterns are as crucial in ecology as in other scientific disciplines (Peters, 1991; Brown, 1999; Gaston and Blackburn, 1999); and (iii) the increasing availability of databases at this macro scale (Brown, 1999). Quite surprisingly, although macroecology has extended its scope in terms of databases and scales, and has recognized the interest of the empirical approach, it remains centered on ecological objects (including geographical objects such as latitudinal gradients and topography). Indeed, neither of the two syntheses by Brown (1999) and Gaston and Blackburn (1999) includes any reference to economic or demographic indicators as explanatory variables – other than their role in motivating the emergence of macroecology.

Extending macroecology to socio-economic drivers and variables is all the more welcome since this could provide thought-provoking links

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to the social sciences. Indeed, the interplay between human pressures and ecological objects is under active investigation in the field of economics. Concern about the impact of economic activity on the environment began to rise in the 1950s, with the foundation of environmental economics as an independent field of economics; this movement accelerated in the late 1960s, after Garrett Hardin formalized the notion of the "tragedy of the commons". Early empirical studies mostly focused on environmental objects which were physical parameters ($CO2$, NOx, $SO2$…) rather than ecological phenomena. In an attempt to test the relationships between economic development and a wide array of environmental variables, Shafik (1994) pointed out that relationships can be very different according to the variables under study, and that no obvious pattern exists. Some of his results gave credit to the idea of a bell-shaped curve relating economic development and pollution, known as the Environmental Kuznets Curve, which was first introduced by Selden and Song (1994) and has since given rise to numerous attempts to identify macro-relations between environmental quality and aggregate economic parameters.

Since the 1990s, the issue of the impact of economic activity on biodiversity has been growing, in both ecology (Wright, 1990) and economics (Krautkraemer, 1995). In one of the earliest cross-national studies focusing on biodiversity, Asafu-Adjaye (2003) tested the impact of variables related to human activity on several biodiversity variables (essentially the number of mammals, birds and vascular plants). As in other studies, he found different responses depending on the biodiversity metrics used. For example, there were significant impacts of human population density (HPD) and of ratio of protected area on species richness metrics (respectively negative and positive impacts). Per capita gross domestic product (GDPc) and ratio of artificialized or agricultural land had significant negative impacts on the average annual percentage change in the number of known mammal species. He also introduced institutional factors (economic freedom, black markets), but these variables had a strongly significant relationship only for the species richness of vascular plants. As in many other studies, the impacts tended to be higher for low-income countries, although the estimators were very noisy.

Focusing on the link between HPD and biodiversity, Luck (2007) reviewed the published empirical literature through a meta-analysis. Although the published literature was skewed geographically and taxonomically, he found positive correlations between HPD and various biodiversity metrics – mainly related to species richness: the level of biodiversity was greater in densely populated zones, which was possibly due to correlations between the two metrics and other parameters such as ecosystem productivity or solar energy availability. In contrast, there were some indications of more negative relationships between HPD and species extinction, but the evidence was judged weak (Luck, 2007). Another series of results (Mikkelson et al., 2007; Holland et al., 2009) indicated that income inequality was a significant positive indicator of the proportion of globally threatened species, though only Holland et al. (2009) found that the logarithm of GDPc was a significantly negative indicator, with HPD having no significant relationship. On the whole, these results partly suggest that human activity *per se* might not be the most fundamental driver of biodiversity erosion.

The way human activity influences biodiversity might depend on much more than the level of economic activity or population size. Sociological and cultural factors may well be at play. First, national or regional cultures may be characterized by social values that are more or less favorable to the protection of biodiversity. Casual observation suggests that for a given level of human presence, there are very different attitudes across countries towards the quality of the environment. These differences in attitudes could significantly influence the quality of ecosystems at a macro level. Many studies can be found in the Convention for Biological Diversity (https://www.cbd.int/) that highlight the role of social values. Secondly, biodiversity protection may also be influenced by the general functioning of society. This is the object of the so-called "social capital" research program (Coleman, 1988; Dasgupta, 2000). In the same way the supra-national studies quoted above have tried to relate economic and environmental variables, social scientists have tried to prove that sociological indicators – in particular indicators of social values – influence economic development (Zak and Knack, 2001; Bjørnskov, 2006). The main indicators used in such studies are proxies for trust and participation in associations (see Callois and Schmitt, 2009, for a review of available indicators). Thirdly, one may wonder if there are not even more fundamental drivers of sociological characteristics. Hofstede (1980) built a 4-dimensional framework (later enlarged to six dimensions) to characterize national cultures. He claimed that these dimensions capture the anthropological features driving values and attitudes in society. The six dimensions are: power distance (i.e. acceptance of hierarchical power), individualism, uncertainty avoidance, masculinity, long-term orientation and hedonism. Using Hofstede's framework, Chambers and Hamer (2012) found that individuality and uncertainty avoidance are the main dimensions promoting economic growth. To our knowledge, few cross-country studies take into account such sociological or anthropological factors when explaining biodiversity (Asafu-Ajaye, 2003; Holland et al., 2009).

The aim of this paper is to deepen the understanding of the relationships between human activities and biodiversity variables by developing and comparing statistical models that link socio-economic indicators with biodiversity indicators at a national scale. We include not only classically targeted socio-economic variables but also more sociologically or anthropologically oriented variables. By comparing different types of socio-economic variables, we hope to identify the most relevant drivers of the human impacts on biodiversity and improve our understanding of their underlying mechanisms. With this general goal in mind, our main hypotheses were as follows:

i. Regarding response variables, a better understanding of biodiversity indicator responses to socio-economic variables can be achieved by using not only indicators of the state of biodiversity but also metrics that might be the more proximal causes of these variations or metrics that might be explained by the state of biodiversity (as e.g. in Luck, 2007; Butchart et al., 2010). Our general hypothesis is that human activity does indeed have some impact on these different variables related to biodiversity. Our approach can therefore be interpreted within the Drivers-Pressures-State-Impact-Response (DPSIR) framework developed by the European Environmental Agency (see for instance Gari et al., 2015; Dietz 2017 for a discussion of the origin and evolution of the DPSIR framework and its applications). We are not only studying the relationships between Drivers of change (here, socio-economic variables) and the State of biodiversity, but also between these Drivers and potentially more proximal causes of change than the Drivers – coined Pressures – or responses to Pressures and/or States of biodiversity, here associated with the notion of Response indicator. We selected the proportion of extinct species and the proportion of threatened species as State indicators, the proportion of protected area as the Response indicator and the proportion of sealed land and its increase as Pressure indicators.
ii. Concerning explanatory variables, we considered both economic indicators of human activity and sociological and anthropological variables. Regarding the latter, we hypothesized that sociological and anthropological variables could act as primary drivers and thus would partly explain variations in biodiversity. As for the economic indicators of human activity, we used classical metrics related to economic growth and human population but we also hypothesized that Gross Domestic Product (GDP) should be scaled not per inhabitant but per area (square kilometer) to better reveal its relationship with biodiversity indicators. Indeed, past analyses – including those related to the Kuznets curve – have almost exclusively used the classical indicator, GDP per capita (GDPc) (three exceptions are Panayotou, 1997; Kaufmann et al., 1998; Liu et al., 2005).