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**Principles for interdisciplinary research in social-ecological research: using analogical reasoning to build epistemological bridges**

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17

**Abstract**

18 There is ample consensus that interdisciplinarity between ecology and the social sciences is a  
19 prerequisite for solving complex biodiversity and environmental problems. However,  
20 differences in theories, concepts, methods, and data types hamper the efforts of many young  
21 students or experienced researchers in ecology that have not been exposed to the social  
22 sciences before. This paper argues that for certain types of questions where parallels can be  
23 drawn through analogical thinking between the ecological and social sciences, extending the  
24 set of principles of ecological theory from Scheiner and Willig (2008) can facilitate  
25 interdisciplinary research. The extended principles presented here build on notions of spatial  
26 patterns, interactions, contingency and temporal change (evolution) that are also studied by  
27 the social sciences. The proposed non-mutually exclusive principles belong to two main types  
28 depending on the study object: *i*) humans *per se* as ecological agents and *ii*) ecological  
29 knowledge in the broadest sense. Examples are given from the literature of ecological  
30 scientists borrowing methods from the social sciences and vice versa, and asking questions  
31 similar to the extended principles proposed here. The extended principles can be used as a  
32 starting point for students of ecology to tackle complex problems, encouraging further  
33 interdisciplinarity in a more systematic way. A tentative curriculum for a graduate seminar  
34 discussing the different principles is provided at the end of the text.

35

36 **Keywords:** ecological principles; interdisciplinarity; graduate education; social sciences

37

## 38 **Introduction**

39           What do the ecological models of prey-predators, ideal free distribution and ecosystem  
40 function have in common? That they all have helped develop ideas by analogical reasoning in  
41 the social sciences. The principles of predator-prey models of Lotka and Volterra, originally  
42 borrowed from chemical reaction dynamics, have been used widely including the behavior of  
43 stock markets (Marasco et al. 2016). Ideal free distribution studies originally developed for  
44 understanding how animals minimize competition, have been applied to understand the  
45 patterns of nomad pastoralism and patch resource (Moritz et al. 2014). Currently, ecosystem  
46 theory is informing enterprise management studies (Hou and Shi 2021, Tsujimoto et al. 2018).

47           Likewise, ideas from the social sciences have allowed several important breakthroughs  
48 in ecology and evolution. For instance, the familiar formulas of gene diversity were borrowed  
49 from early 20<sup>th</sup> century studies in economics (Stirling 2007). Perhaps the most famous  
50 example of analogue thinking between the social sciences and ecology and evolution were the  
51 insights Charles Darwin got from reading Humboldt's accounts of human population  
52 differences in the Canary Islands. As population size was uncorrelated to island size but rather  
53 to resource availability, Humboldt's readings of Malthus human population growth hinted  
54 him that resource availability was the limiting factor as the larger islands were not necessarily  
55 the most populated. A straight forward analogy for Darwin to explain resource competition  
56 and population growth was then finally available (Egerton 1970).

57           Analogical reasoning is a well-known step in interdisciplinary research (Newell et al.  
58 2001, Szostak 2017). Ideas from one discipline often get adapted and transformed within  
59 another discipline without implying that the borrowing discipline presents a weaker  
60 theoretical foundation than the borrower. The analogical phase is not alone during an  
61 interdisciplinary process, and is part of a larger creative process that includes observing,  
62 imaging, abstracting, recognizing patterns, forming patterns, modeling, transforming, and  
63 synthesizing among others (for an in-depth analysis see Spooner et al. 2004). This kind of  
64 interdisciplinary that borrows concepts has been called 'informed disciplinarity' where  
65 disciplinary questions require outreach to one or more disciplines (Lattuca 2001, Musacchio  
66 et al. 2005). This is different from questions that seek to link disciplines to create new  
67 disciplines by synthesis, or whose objective is to transcend from the science circles to  
68 decision makers and stakeholders (transdisciplinarity).

69           If an iterative borrowing process happens for long time, maybe a new subdiscipline or  
70 field may emerge, as molecular ecology or landscape ecology, to cite two familiar  
71 interdisciplinary fields. This process of interdisciplinary borrowing work may take decades of  
72 sorting success from dead-ends and may or may not, call for an overreaching theoretical  
73 synthesis beyond the anecdotic analogy. The farther the distance between the disciplines  
74 involved, the harder it appears to find any bridges that can initiate an interdisciplinary dialog,  
75 a situation well known between ecology and the social sciences (Barthel and Seidl 2017).

76           The biodiversity and environmental crises that we are currently experiencing have  
77 challenged and continue to challenge the disciplinary structure of faculties across the world.  
78 This is not a new issue, but something that has been on the agenda of several higher education  
79 institutions for at least 30 years now (Newell et al. 2001, Pickett et al. 1999). Graduate and  
80 post-graduate education programs need to keep up pace with complex societal demands if  
81 they are to survive in the long term. Collaboration between social scientists and applied  
82 ecological practitioners has gained momentum in conservation science (Hintzen et al. 2020),  
83 and its collaboration has been widely promoted for several years (Lowe et al. 2013, Lowe et  
84 al. 2009). In this regard, conservation biology is currently viewed within the broader field of  
85 conservation science using approaches that now include work at the scale of social-ecological  
86 systems (Mace 2014) with concepts like environmental justice placed at the fore (Gould et al.  
87 2018). Likewise, calls for joint work between the natural and social sciences have been  
88 repeatedly made in sustainability studies (Clark and Harley 2020). Nevertheless, there is still a  
89 lack of consensus about how to generate the kind of interdisciplinary required, mainly  
90 because of the large number of disciplines and subdisciplines potentially involved in  
91 interdisciplinary research. For instance, sustainability research has been described as an  
92 “archipelago” of disciplines (Haberl et al. 2016) where interdisciplinarity is dictated by the  
93 questions at hand, and collaborations are idiosyncratic.

94           Lack of exposure to different epistemological frameworks (theories, concepts,  
95 methods, and data) during undergraduate and graduate studies are commonly cited by  
96 graduate students as recurrent obstacles for effective interdisciplinarity (Killion et al. 2018).  
97 Indeed, words of caution have recently been expressed, as hasty interdisciplinarity by  
98 ecologists may produce research without theoretical depth, and in some cases, it may even  
99 provide wrong insights regarding human decision processes (Cooper and Larson 2020). The  
100 question thus arises as to how to better train students who can potentially call on

101 interdisciplinarity to engage in a dialogue with colleagues in other disciplines if the question  
102 at hand so requires it without losing the perspective of their own fields.

103

#### 104 *What exactly is expected from ecologists?*

105 As the ecological sciences are a collection of disciplines (Cooper 2007, McIntosh 1986),  
106 ecologists are as varied as they come. However, ecologists are appealed to as experts, not only  
107 because ecology is seen as the science of interactions (which follows from its more frequent  
108 definition), but also because there is an “ecological perspective” when looking at problems.  
109 Ecologists’ contribution can include, among others, theories, concepts, and methods to study  
110 the spatial and temporal distribution of organisms, contingent events that have shaped past  
111 and current biodiversity, and the study of constant biotic and abiotic change omnipresent in all  
112 environments affecting one organism in one way or another. An ecological perspective would  
113 therefore involve identifying very general concepts that can be understood by different  
114 disciplines. Some fundamental general concepts or principles in ecology have already been  
115 identified by Samuel M. Scheiner, Michael R. Willig, and others, as components of an  
116 ongoing construction of a general theory of ecology (Scheiner 2010, Scheiner and Willig  
117 2008, Scheiner and Willig 2011, Vellend 2010, 2020). The challenge would therefore be to  
118 ask whether these ecological principles, if extended, could guide students from their  
119 foundations in ecology toward an interdisciplinary dialogue with the social sciences, without  
120 replacing the perspectives of the latter.

121 Here, as an educator rather than a philosopher of science, I would like to address some  
122 practical challenges faced by students trained in the natural sciences. To this end, I will first  
123 extend by analogy the eight principles of ecological theory proposed by Scheiner and Willig  
124 (2008) to outline potential interdisciplinary links between some ecological concepts and  
125 analogous ideas in the social sciences; second, I will provide some examples from the  
126 literature that address issues similar to the extended principles to demonstrate their usefulness;  
127 and finally, I will outline an introductory syllabus to help students and educators in ecology  
128 initiate a dialogue with the social sciences.

129

#### 130 *Using a suitable definition of ecology*

131 Before elaborating their principles, Scheiner and Willig opted for a less common  
132 definition of the ecological sciences. In contrast to the more widespread definition of ecology  
133 as the science that studies the relations between organisms and their biotic and abiotic

134 environment, these authors used a slightly different description: “*The study of the spatial and*  
135 *temporal patterns of the distribution and abundance of organisms, including causes and*  
136 *consequences*” (Scheiner and Willig 2008). They explain that the word “causes” encapsulates  
137 the environmental limitations that determine why organisms occur where they do. In turn, the  
138 word “consequences,” encapsulates the process of competition, exclusion and of course the  
139 functional aspects of energy and matter flows resulting from their distribution, among others.

140

#### 141 ***Principles of ecology: The starting point of an interdisciplinary dialogue***

142 The word “principles” has been used in various ways in relation to scientific  
143 disciplines. For many authors, when we refer to principles it is frequent to state the obvious,  
144 and sometimes are called “truisms”. Here, we also retain the definition of principles given by  
145 Scheiner and Willig (2008) as “broad statements about empirical patterns and the processes  
146 that operate within a [research] domain.” In the context of ecology, the research domain or  
147 main subject of study defined by these authors is “*the spatial and temporal patterns of the*  
148 *distribution and abundance of organisms, including causes and consequences*” which follows  
149 the above definition.

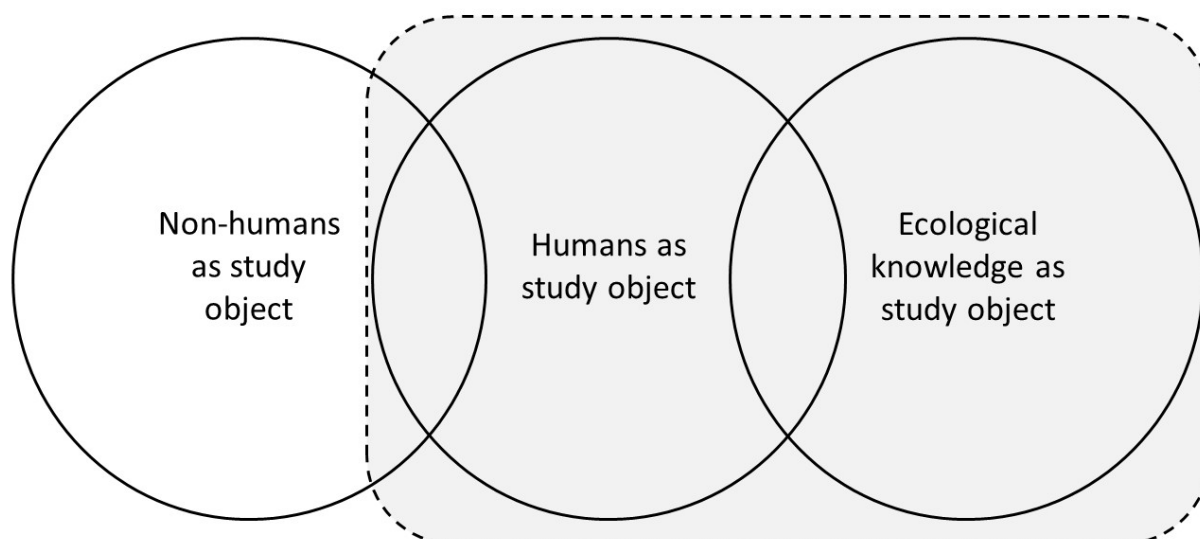
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151 The question that naturally follows is thus: what are some potential domain of  
152 interdisciplinary studies that ecologists may conduct in collaboration with social scientists?  
153 For many current scholars, this domain already exist and it would be the social-ecological  
154 system (Levin et al. 2013). Here, I prefer to present a domain description that is not based on  
155 the theory of complex adaptive systems on which social-ecological system research relies.  
156 Instead, I approach the issue of defining the domain at an even more general level as the  
157 “*spatial and temporal patterns of the distribution and abundance of humans within*  
158 *ecosystems, including causes and consequences*” (my own definition). This definition of the  
159 domain will fit many disciplines like geography, history, ecological anthropology, and  
160 environmental sociology, which allows us to focus on similarities between disciplines instead  
161 of their differences. Many readers would argue, with reason, that this domain is not new and  
162 that it has been the *raison d’être* of the branch of sociology known as human ecology  
163 (Christensen 2014, Visvader 2017, Young 1974), which is perfectly coherent with the  
164 reasoning I am trying to develop here.

165 In addition to studying the causes and consequences of the distribution of humans as  
166 stated above, interdisciplinarity would further be facilitated in some cases if a second related

167 domain were proposed, namely that of “*studying the causes and consequences of the*  
168 *distribution of ecological knowledge*” (my own definition, Figure 1).

169 Before continuing, the expression “ecological knowledge” needs some clarification. In  
170 contrast to a dichotomy between local ecological knowledge and expert knowledge (Davis  
171 and Ruddle 2010, Lam et al. 2020), I propose using a more general definition. First of all  
172 knowledge, we may adopt the definition of (Renn 2014) “*as the capacity of an individual or a*  
173 *group to solve problems and to mentally anticipate the corresponding actions.*” It thus  
174 follows that “ecological knowledge” can be conceived as “*as the capacity of an individual or*  
175 *a group to solve ecological problems and to mentally anticipate the corresponding actions*”  
176 (my own definition). Here, ecological problems would be anything from understanding  
177 agriculture, forestry, fisheries, husbandry, watershed management, and so forth.



178  
179 **Figure 1.** Studies about our own species are within a gradient of disciplines that span two extremes: on the one  
180 hand, the study of organisms themselves, and on the other, the study of ecological knowledge (*sensu lato*) that  
181 cannot be dissociated of the presence of humans themselves. In our case, the type of human knowledge of  
182 interest to us is the ecological knowledge that we use to survive and fulfill our essential needs. The central circle  
183 largely represents the subject of anthropology, human ecology and related fields. Interdisciplinarity would arise  
184 in some cases at the intersection of each object or domain.

185  
186 In line with Figure 1, the subject of certain interdisciplinary studies such as human  
187 ecology or anthropology could be seen as part of a tripartite typology: some studies address  
188 humans within ecological systems, others focus on people’s knowledge about their supporting



189 ecosystems and how that knowledge is maintained and shared, and finally, some explore both  
 190 aspects. The domain space depicted in Figure 1 cannot account for all possible types of  
 191 interdisciplinarity that exist or can exist between the ecological sciences and the human  
 192 sciences, but just a subset of them.

193

### 194 *Scheiner and Willig's eight principles of ecology*

195 Scheiner and Willig (2008, 2011) published their principles aimed at contributing to a general  
 196 theory of ecology, while cautioning readers that their postulates may be incomplete and that  
 197 other researchers could come up with a different set of principles. We transcribe these  
 198 principles in Table 1, mostly using the 2011 version of the principles that differ slightly from  
 199 the 2008 version. Bear in mind that the order in which the principles are presented do not  
 200 imply a hierarchy. Some principles are exclusive to the ecological sciences, while some are  
 201 shared with other scientific branches (see the original publication). In this context,  
 202 “heterogeneous” can be replaced by “non-random”.

203

204 **Table 1.** Transcribed ecological principles based on the works of Scheiner and Willig (2008, 2011). The labels  
 205 E1-E8 were added to facilitate the identification of each principle.

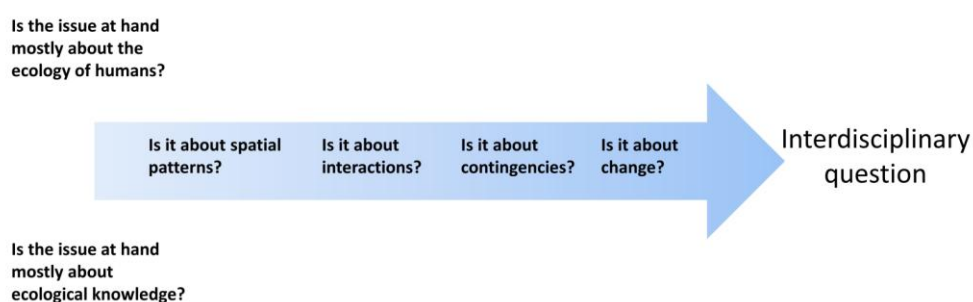
<i>Label</i>	<i>Transcribed ecological principle</i>
<b>E1</b>	Organisms are distributed in space and time in a heterogeneous manner
<b>E2</b>	Organisms interact with their abiotic and biotic environments
<b>E3</b>	Variation in the characteristics of organisms result in heterogeneous ecological patterns and process
<b>E4</b>	Distributions of organisms and their interactions depend on contingencies
<b>E5</b>	Environmental conditions are heterogeneous in space and time
<b>E6</b>	Resources are finite and heterogeneous in space and time
<b>E7</b>	Birth and death rates are the consequence of interactions with the abiotic and biotic environments (originally, this principle was defined as “all organisms are mortal.”)
<b>E8</b>	Species ecological properties result from evolution

206

207

### 208 *Extending the principles beyond the ecological sciences*

209 Through analogical reasoning, I propose here that the original eight principles of  
 210 Scheiner and Willig can first be elaborated for humans as the study object, and second, for  
 211 ecological knowledge as the study object (hopefully without upsetting our colleagues in the  
 212 social sciences too much!). The extended principles, like the original ones, are built on what  
 213 we can call an ecological perspective consisting of the following: *i*) spatial patterns, *ii*)  
 214 interactions, *iii*) contingency, and *iv*) notions of change (evolution). These notions are not  
 215 exclusive to the ecological thinking as they are used in the social sciences too. Hence, they  
 216 can be used as starting points to help students from an ecological background ask whether  
 217 there is a need for an ecological perspective when addressing a question mostly about humans,  
 218 mostly about ecological knowledge, or both (Figure 2).



219

220 **Figure 2.** Series of check questions to identify whether the ecological sciences can bring additional insights into  
 221 studies of humans or ecological knowledge. If the answer is ‘no’ to all the questions, this means that the issue at  
 222 hand is better handled by the social sciences.

223

224 Before analyzing each possible extended principle, we depict them to show their relation to  
 225 the original principles (Figure 3), shown as a continuous gradient of the three domains  
 226 depicted in Figure 1. As with the original principles, these extended principles are  
 227 complementary to each other, not mutually exclusive, and without a hierarchy. Two of the  
 228 principles were not elaborated for humans because they can be considered to apply to all  
 229 living organisms: principle **E5** (Environmental conditions are heterogeneous in space and  
 230 time) and **E6** (Resources are finite and heterogeneous in space and time) are thus depicted the  
 231 same as in Figure 2.

232           Some analogies are also not possible between humans and ecological knowledge as  
233 study objects, resulting in fewer principles for ecological knowledge than for the other  
234 categories.

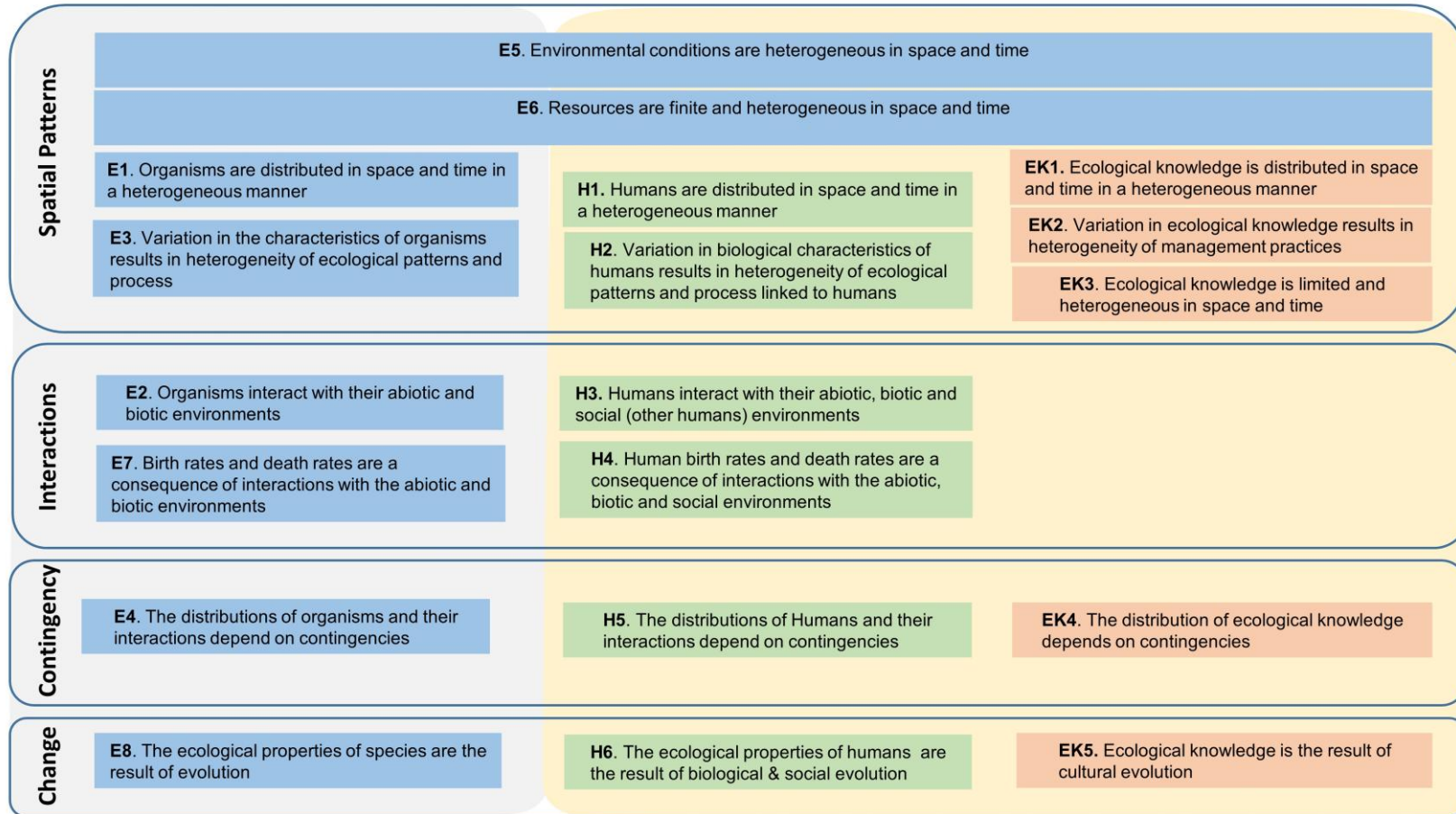
235  
236           How close or far removed are these extended principles from existing interdisciplinary  
237 research? Examples from the scientific literature of the different fields can shed light on their  
238 utility. Tables 2 and 3 enumerate the extended principles while providing examples from the  
239 literature in which this kind of thinking has been used. The first three principles proposed for  
240 humans (**H1**, **H2**, and **H3**) are familiar in studies exploring the ecological properties of the  
241 human species. In particular, principle **H3** is the most interdisciplinary (Humans interact with  
242 their abiotic, biotic, and social (other humans) environments), because it can be addressed  
243 from the perspective of the ecological sciences, the social sciences, or both. In a way, if there  
244 is one principle that would hold across many research questions, it would be this one.

245           Likewise, principle **H4** is highly interdisciplinary, because human demographic  
246 parameters are a function of both the biotic environment and human interactions, as wars and  
247 conflicts can have demographic consequences that are just as catastrophic as diseases or  
248 pandemics, and often they are related.

249           Historical processes (i.e., time related) lie at the core of principles **H5** and **H6**: the  
250 former focuses on the order of events and the path dependencies that are set in motion, while  
251 the latter directly mentions human ecological capacities as the result of biological and social  
252 evolution. In this context, “contingencies” mean not only the uniqueness of a situation, but  
253 also the random processes that create structure like genetic founding effects. For instance, the  
254 order of events during the colonization of empty niches has important consequences on the  
255 structuring of natural communities (Fukami 2015), an idea that can be transposed by analogy  
256 to situations that involve humans, with all the similarities and differences that exist.

257           Principles relating to knowledge are less straightforward to extend by analogy,  
258 because it is widely believed knowledge, but especially culture, is a human exception. While  
259 it is known that many vertebrates can teach their young how to find feeding spots and that  
260 primates are capable of social learning (see for example Whiten et al. 2005), scholars still do  
261 not agree whether these behaviors and information transmission are equivalent to human  
262 culture (Tennie et al. 2009).

263



264

265 **Figure 3.** Extended principles drawing from Sheiller and Willig (2008, 2011), elaborated for humans (H1-H6) and ecological knowledge (EK1-EK5) as the objects of study  
 266 (see Figure 1). Two of the original principles (E5 & E6) apply to all living organisms and do not need to be elaborated. The order of the original ecological principles was  
 267 changed to bring together those relating to spatial patterns, interactions, contingency and change.

268 **Table 2.** Selected, non-exhaustive list of examples in the literature asking questions akin to the extended ecological principles when humans are considered as the study object.

	<i>Extended principle</i>	<i>Examples in the literature</i>
<b>Spatial Patterns</b>	<b>H1.</b> Humans are distributed in space and time in a heterogeneous manner	(Hodder and Hassall 1971) analyzed the non-random distribution of Roman towns in England using the “central place theory,” a concept still widely used in urban studies (Hsu 2012), along with fractal (power law) analyses of urban phenomena (Mori et al. 2020)
	<b>H2.</b> Variations in human biological characteristics result in heterogeneous ecological patterns and processes linked to humans	The emergence of lactose tolerance allowed husbandry and thus modified landscapes in Africa and Europe (Cramp et al. 2014, Ingram et al. 2012)
<b>Interactions</b>	<b>H3.</b> Humans interact with their abiotic, biotic, and social (other humans) environments	A review of archaeological and paleoenvironmental datasets (300–12 thousand years ago) by (Roberts and Stewart 2018) suggests that compared to the genus <i>Homo</i> , our species developed a new ecological niche (i.e., “generalist specialist”) by occupying a diversity of environments, but also specialized in some environmental extremes
	<b>H4.</b> Human birth and death rates are a consequence of interactions with the abiotic, biotic, and social environments	Analysis of radiocarbon databases in the Amazon and Orinoco regions allowed the authors to test the hypothesis of a logistic growth of pre-Columbian populations, suggesting that carrying capacity was reached and maintained durably in the region (Arroyo-Kalin and Riris 2021)
<b>Contingency</b>	<b>H5.</b> Distributions of humans and their interactions depend on contingencies	Any study addressing indigenous displacements because of colonialist or post-colonialist practices; the current rural exodus in European countries because of economic crises (Merino and Prats 2020); any study exploring the causes of the current migration patterns
<b>Change</b>	<b>H6.</b> Human ecological properties result from biological evolution	(James et al. 2019) review evidence of how the available nutrients from the food selected in different areas of the during the expansion of <i>Homo sapiens</i> for lactose tolerance, increased amylase for digesting starchy foods, ability to digest long-chain polyunsaturated fatty acids, and ability to synthesize vitamin D from sunlight exposure

269 In general, knowledge is a subject of many fields, traditionally philosophy, but it is  
270 also central to anthropology (Crick 1982) and sociology (Shapin 1995). For this reason, we  
271 can expect that any principle related to knowledge developed by analogy may be ill fitted if  
272 not wrong in many cases. Nevertheless, for the sake of the argument, let us accept that under  
273 certain circumstances, a broad research domain of “ecological knowledge” is a useful study  
274 object to which ecologically oriented questions (spatial patterns, interactions, contingency,  
275 and evolution notions) may be relevant, especially if they help shed light on the distribution of  
276 the human species and their interactions with other humans or other species.

277 Probably one of the most useful principle is **EK2** (Variations in ecological knowledge  
278 result in heterogeneous management practices), as this may sum up the core of many studies  
279 in conservation biology, conservation sciences, and sustainability. This principle can easily be  
280 used to frame hypotheses and help comparative studies to establish cause-effect processes  
281 when various landscapes and regions are examined. Clearly, **EK2** it is a principle to be used  
282 in complement or in parallel to an anthropological and sociological analysis of the causes of  
283 these variations in ecological knowledge. Almost invariably, a historical approach will  
284 address the questions of the contingency and change of ecological knowledge (principles **EK4**  
285 and **EK5**) using geographical, anthropological, or cultural evolution approaches. Principle  
286 **EK3** is needed, because there will always be “unknown unknowns” limiting the level of  
287 agency that any people or culture may exert over an ecosystem. As for **EK1** (Ecological  
288 knowledge is distributed in space and time in a heterogeneous manner), it joins the other first  
289 principles, **E1** and **H1**, which together are the most intuitive and general principles of all.

### 290 *Principles in practice*

291 A common surprise or frustration for students trained in ecology when participating in an  
292 interdisciplinary research project is that the ecological sciences are usually used as a mere  
293 diagnostic tool. However, questions can be asked from another perspective. For instance, to  
294 assess the impact of a development project, the questions can arise in a gradient similar to  
295 what is shown in Figures 1 and 2: What is the distribution of not only the endangered species  
296 but all the species present (principle **E1**)? How does the distribution of these species correlate  
297 with the distribution of humans in the area (principle **H1**)? What kind of knowledge (or lack  
298 thereof) do these humans have with respect to the management of these species (**EK2** and  
299 **EK3**)? And which historical events can explain these patterns of knowledge (**EK4** and **EK5**)?

300

301

302 **Table 3.** Selected, non-exhaustive list of examples in the literature asking questions akin to the extended ecological principles when ecological knowledge is considered as the  
 303 study object (see text for the definition of ecological knowledge). No interaction principles were developed for ecological knowledge to avoid over-interpretation of analogies  
 304 with ecology.

	<i>Extended principle</i>	<i>Examples in the literature</i>
<b>Spatial Patterns</b>	<b>EK1.</b> Ecological knowledge is distributed in space and time in a heterogeneous manner	(Ghimire et al. 2004) analyze how knowledge about medicinal plants in the Himalayas is non-random due to “differences in level of specialization in relation to medicinal plants, to socio-cultural and institutional contexts, and to extra-local factors that govern people’s activities”
	<b>EK2.</b> Variations in ecological knowledge result in heterogeneous management practices	Virtually any comparative landscape analysis considering the cultural and physical aspects of agriculture, forestry, and so forth (van Zanten et al. 2016)
	<b>EK3.</b> Ecological knowledge is limited and heterogeneous in space and time	Any study addressing how a lack of ecological knowledge causes biodiversity loss
<b>Contingency</b>	<b>EK4.</b> Distributions of ecological knowledge depend on contingencies	(Prado and Murrieta 2018) analyze how the loss of swidden cultivation entails the loss of ecological knowledge about animal species in indigenous communities in south-eastern Brazil; lessons from colonialism imposing alien land use (Paterson 2018)
<b>Change</b>	<b>EK5.</b> Ecological knowledge results from cultural evolution	Any study addressing how knowledge is transmitted across generations, and how variations in practices are a consequence of knowledge change over time. See, for instance, the review of (Santoro et al. 2018) on the fields of cultural evolution and evolutionary ethnobiology. In this context, evolution is considered in the broadest sense as change

305           A second application of the principles would occur in the context of common pool  
306 resources. The use of common pool resources depends on the rules and norms that regulate  
307 access, which result from the complex histories and institutional development of the actors  
308 involved (Ostrom 2009b) within the context of a social-ecological system (Ostrom 2009a). At  
309 the core of this kind of analysis, there is principle **H3**: humans interact with their abiotic,  
310 biotic, and social (other humans) environments. Human interactions are addressed by  
311 sociology and institutional economics, not to mention public policy studies. If a historical  
312 perspective is needed, principle **H5** (contingency of human distributions) would be explicit in  
313 the analysis, as human populations develop around key resources, a recurrent theme in  
314 geography and history.

315

### 316 **Using the extended principles for teaching interdisciplinarity**

317           If there is any practical use of the extended principles outlined above, it would be to  
318 help teaching some possible interdisciplinary connections that exist between the ecological  
319 and the social sciences. For instance, an interdisciplinary seminar<sup>1</sup> could be envisaged for  
320 middle to advanced graduate students (Table 4), ideally inviting researchers from other fields  
321 to lead the discussions. Reviews of the main ideas in sociology, anthropology, political  
322 science, history and physical and human geographies could be potentially discussed around  
323 the principles before students prepare their dissertation projects. A hybrid lecturing/ seminar  
324 approach in which each person dwells in depth on a subject allowing for critical thinking and  
325 discussion, could allow the discovery of other fields not only by students but by faculty  
326 themselves. Whether more principles, or simply other principles are needed to foster  
327 interdisciplinarity, will probably emerge through these discussion prompting curiosity about  
328 the other fields of research in both directions.

### 329 ***Concluding remarks***

330 I do not claim or imply that it is enough to simply use some analog concepts to create a new  
331 interdisciplinary stable field, whether it is the ecological sciences that borrow from social  
332 sciences or *vice versa*. Only, that these extended principles may be useful in certain cases to  
333 answer specific questions.

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<sup>1</sup> In North American graduate programs, seminars are graduate level courses in which each student presents her/his take on a given subject which is then discussed by all the peer students



335 **Table 4.** Example of a seminar curriculum for graduate students built around the extended principles. Contents would vary depending on the availability of different  
 336 faculty, as well as the subjects chosen to discuss. Rows marked with an asterisk (\*) correspond to subjects generally taught in biology departments and faculties.

<i>Main Subject</i>	<i>Week</i>	<i>Subject of seminar</i>	<i>Main Principles Discussed</i>	<i>Disciplines</i>	<i>Potential Subjects (non-exhaustive list)</i>
<b>Spatial patterns</b>	1	Heterogeneous and limited distribution of resources	E5; E6	Earth sciences*; Demography*	Planetary boundaries; Understanding human population growth
	2	Heterogeneous Human distribution	H1; H2	Archaeology; history; human geography	History of human colonization of the biosphere; Glaciations & human dispersal;
	3	Heterogeneous knowledge distribution	EK1-Ek3	anthropology; philosophy	Cosmologies of western and non-western cultures; the notion of nature in different cultures
<b>Interactions</b>	4	Human/non-human interactions	H5	Ecology*; conservation biology*	Humans as super-predators
	5	Human/human interactions	H2	Law; Institutional economics; political studies; sociology	The law as a social regulator of human interactions; managing common pool resources; gender inequalities and environmental justice
<b>Contingency</b>	6	Contingencies creating human distributions and ecological knowledge	H5/EK4	Archaeology; history; human geography	ecological and social consequences of different colonization/wars events in history
<b>Change</b>	7	Human ecological properties through time	H6; EK5	Archaeology; history; human geography	Origins of agriculture; origins of urbanization; industrial revolution

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339 Our main goal here was to highlight *similarities* of underlying processes studied by  
340 both the ecological and social sciences, as often it is the case that it is the *differences* among  
341 them that are emphasized (Moon and Blackman 2014). Many scholars will argue that  
342 similarities are just superficial and that questions cannot be answered isolated from a  
343 disciplinary context, a position I agree with. The ecologist will still give her/his perspective  
344 and the social scientist theirs to the problem at hand based on their own set of values issued  
345 from each discipline. The use of very extended principles developed here do not call for any  
346 need of one discipline superseding another one but for an epistemic pluralism (Persson et al.  
347 2018), in which each discipline stands by its own right.

348 The same exercise could have been done in the other direction, by starting with the  
349 social sciences and then asking the question about what they can contribute in an  
350 interdisciplinary context to the ecological sciences. The use of terms such as population,  
351 community, and association in plant ecology is not fortuitous, as they entered into ecological  
352 thinking in the late 19<sup>th</sup> century at a time when both ecology and the social sciences were  
353 burgeoning (Egerton 2015). Today, the wealth of research in both the ecological and social  
354 sciences shows that the ideas of spatial variation, contingency, change in time, and so forth  
355 are not the exclusive prerogative of the ecology, far from that. However, being aware of these  
356 notions and principles may help both educators and students to better understand how  
357 scientific knowledge is developed by the different disciplines when the question at hand calls  
358 for more than one scientific field.

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