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► **To cite this version:**

Juan Fernández-Manjarrés. Principles for interdisciplinary research in social-ecological research. 2022.  
hal-03870526v1

**HAL Id: hal-03870526**

**<https://hal.science/hal-03870526v1>**

Preprint submitted on 24 Nov 2022 (v1), last revised 20 Nov 2023 (v2)

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

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**Citation :** Fernandez-Manjarrés, J.F. 2022. Principles for interdisciplinary research in social-ecological research: : using analogical reasoning to build epistemological bridges. Unpublished manuscript, Working paper version: 1.0 November 2022

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 sciences  
22 before. This paper argues that for certain type of questions in which parallels can be made  
23 between ecological and social sciences, extending the set of principles of ecological theory from  
24 Scheiner and Willig (2008) can facilitate interdisciplinary research. The extended principles  
25 presented here are built on notions of spatial patterns, interactions, contingency and temporal  
26 change (evolution). The proposed non-mutually exclusive principles belong to two main types  
27 depending on the study object: *i*) humans *per se* as ecological entities and *ii*) ecological  
28 knowledge in the broadest sense. Examples in the literature are provided in which social  
29 sciences scholars borrow methods from ecological sciences posing questions akin to the  
30 extended principles proposed here. The extended principles can be used as starting points for  
31 students in ecology embracing complex problems encouraging further interdisciplinarity in  
32 more systematic ways.

33

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

35

## 36 **Introduction**

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

45           Likewise, ideas from the social sciences have allowed several important breakthroughs  
46 in ecology and evolution. For instance, the familiar formulas of gene diversity were borrowed  
47 from early 20<sup>th</sup> century studies in economics (Stirling 2007). Perhaps the most famous example  
48 of analogue thinking between the social sciences and ecology and evolution were the insights  
49 Charles Darwin got from reading Humboldt's accounts of human population differences in the  
50 Canary Islands. As population size was uncorrelated to island size but rather to resource  
51 availability, Humboldt's readings of Malthus human population growth hinted him that  
52 resource availability was the limiting factor as the larger islands are not necessarily more rich  
53 in vegetation and soils good for agriculture. The connection with intra- and inter-species  
54 competition for resources necessary to thrive and reproduce in the non-human world was then  
55 a straight forward analogy for Darwin (Egerton 1970).

56           Analogical reasoning is a well-known step in interdisciplinary research (Newell et al.  
57 2001, Szostak 2017). Ideas from one discipline often get adapted and transformed within  
58 another discipline without implying that the borrowing discipline presents a weaker theoretical  
59 foundation than the borrower. The analogical phase is not alone during an interdisciplinary  
60 process, and is part of a larger creative process that includes observing, imaging, abstracting,

61 recognizing patterns, forming patterns, modeling, transforming, and synthesizing among others  
62 (for an in-depth analysis see Spooner et al. 2004). This kind of interdisciplinary that borrows  
63 concepts has been called ‘informed disciplinarity’ where disciplinary questions require  
64 outreach to one or more disciplines (Lattuca 2001, Musacchio et al. 2005). This is different  
65 from questions that seek to link disciplines to create new disciplines by synthesis, or whose  
66 objective is to transcend from the science circles to decision makers and stakeholders  
67 (transdisciplinarity).

68         If an iterative borrowing process happens for long time, maybe a new subdiscipline or  
69 field may emerge, as molecular ecology or landscape ecology, to cite two familiar  
70 interdisciplinary fields. This process of interdisciplinary borrowing work may take decades of  
71 sorting success from dead-ends and will eventually call for an over reaching theoretical  
72 background beyond the anecdotic analogy. The farther the distance between the disciplines  
73 involved, the harder it appears to find any bridges that can initiate an interdisciplinary dialog, a  
74 situation well known between ecology and the social sciences (Barthel and Seidl 2017).

75         The biodiversity and environmental crises that we are currently experiencing have  
76 challenged and continue to challenge the disciplinary structure of faculties across the world.  
77 This is not a new issue, but something that has been on the agenda of several higher education  
78 institutions for at least 30 years now (Newell et al. 2001, Pickett et al. 1999). Graduate and post-  
79 graduate education programs need to keep up pace with complex societal demands if they are  
80 to survive in the long term. Collaboration between social scientists and applied ecological  
81 practitioners has gained momentum in conservation science (Hintzen et al. 2020), and its  
82 collaboration has been widely promoted for several years (Lowe et al. 2013, Lowe et al. 2009).  
83 In this regard, conservation biology is currently viewed within the broader field of conservation  
84 science using approaches that now include work at the scale of social-ecological systems (Mace  
85 2014) with concepts like environmental justice placed at the fore (Gould et al. 2018). Likewise,

86 calls for joint work between the natural and social sciences have been repeatedly made in  
87 sustainability studies (Clark and Harley 2020). Nevertheless, there is still a lack of consensus  
88 about how to generate the kind of interdisciplinary required, mainly because of the large number  
89 of disciplines and subdisciplines potentially involved in interdisciplinary research. For instance,  
90 sustainability research has been described as an “archipelago” of disciplines (Haberl et al. 2016)  
91 where interdisciplinarity is dictated by the questions at hand, and collaborations are  
92 idiosyncratic.

93         Lack of exposure to different epistemological frameworks (theories, concepts, methods,  
94 and data) during undergraduate and graduate studies are commonly cited by graduate students  
95 as recurrent obstacles for effective interdisciplinarity (Killion et al. 2018). Indeed, words of  
96 caution have recently been expressed, as hasty interdisciplinarity by ecologists may produce  
97 research without theoretical depth, and in some cases, it may even arrive at the wrong  
98 conclusions regarding human decision frameworks (Cooper and Larson 2020). The question  
99 thus arises as to how to better train students who can potentially call on interdisciplinarity to  
100 engage in a dialogue with colleagues in other disciplines if the question at hand so requires it  
101 without losing the perspective of their own fields.

102

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

104 As the ecological sciences are a collection of disciplines (Cooper 2007, McIntosh 1986),  
105 ecologists are as varied as they come. However, ecologists are appealed to as experts, not only  
106 because ecology is seen as the science of interactions (which follows from its more frequent  
107 definition), but also because there is an “ecological perspective” when looking at problems.  
108 Ecologists’ contribution can include, among others, theories, concepts, and methods to study  
109 the spatial and temporal distribution of organisms, contingencies (legacies and path  
110 dependencies) that have shaped the current diversity, and the process of constant change

111 omnipresent in all environments that affects organisms in one way or another. An ecological  
112 perspective would therefore involve identifying very general concepts that can be understood  
113 by different disciplines. Some fundamental general concepts or principles in ecology have  
114 already been identified by Samuel M. Scheiner, Michael R. Willig, and others as components  
115 of an ongoing construction of a general theory of ecology (Scheiner 2010, Scheiner and Willig  
116 2008, Scheiner and Willig 2011, Vellend 2010, 2020). The challenge would therefore be to ask  
117 whether these ecological principles, if extended, could guide students from their foundations in  
118 ecology toward an interdisciplinary dialogue with the social sciences, without replacing the  
119 perspectives of the latter.

120         Here, as an educator and not as a philosopher of science, I would like to address some  
121 practical challenges faced by students trained in the natural sciences. For this purpose, I will  
122 first extend by analogy the eight principles of ecological theory proposed by Scheiner and  
123 Willig (2008) in order to lay out a potential interdisciplinary transition roadmap; second, I will  
124 provide some examples from the literature addressing questions similar to the extended  
125 principles to show their usefulness; and finally, I will lay out an introductory syllabus to help  
126 students and educators in ecology initiate a dialogue with the social sciences.

127

### 128 *Using a suitable definition of ecology for interdisciplinarity*

129         Before elaborating their principles, Scheiner and Willig opted for a less common  
130 definition of the ecological sciences, which is coherent with their vision of the domain of  
131 ecology (see next section). In contrast to the more widespread definition of ecology as the  
132 science that studies the relations between organisms and their biotic and abiotic environment,  
133 these authors used a slightly different description of ecology: “The study of the spatial and  
134 temporal patterns of the distribution and abundance of organisms, including causes and  
135 consequences” (Scheiner and Willig 2008). They explain that the word “causes” encapsulates

136 the environmental limitations that determine why organisms occur where they do. In turn, the  
137 word “consequences,” among others, encapsulates the functional aspects of ecology as energy  
138 and matter flows resulting from this distribution. In their context, the relational aspects of  
139 ecology is explicit in the principles as I explain below.

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 disciplines.  
143 Here, we also retain the definition of principles given by Scheiner and Willig (2008) as “broad  
144 statements about empirical patterns and the processes that operate within a domain.” In the  
145 context of ecology, “domain” is the main subject of study defined by these authors as “the  
146 spatial and temporal patterns of the distribution and abundance of organisms, including causes  
147 and consequences,” which is very close to their definition of ecology.

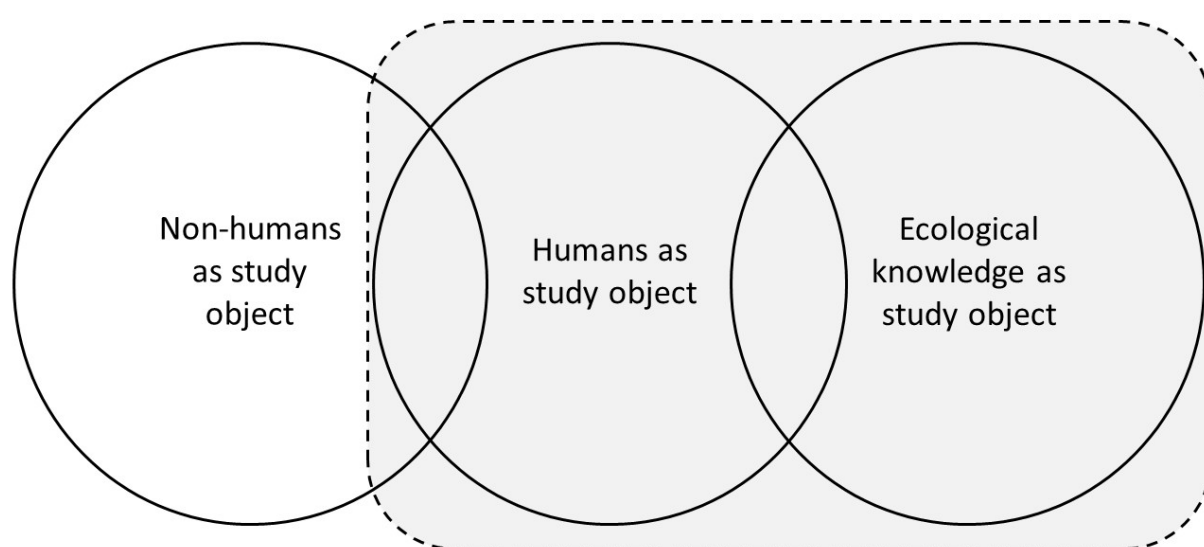
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149 The question that naturally follows is thus: what is the potential domain of  
150 interdisciplinary studies that ecologists may conduct in collaboration with social scientists? For  
151 many current scholars, this domain would be the social-ecological system (Levin et al. 2013).  
152 Here, I prefer to present a domain description that is not based on the theory of complex  
153 adaptive systems on which social-ecological system research relies; instead, I approach the  
154 issue of domains at an even more general level. So, bearing this in mind, one possible domain  
155 of interdisciplinary research between the ecological and social sciences could be the “spatial  
156 and temporal patterns of the distribution and abundance of humans within ecosystems,  
157 including causes and consequences” (my own definition). This definition of the domain will fit  
158 many disciplines like geography, history, ecological anthropology, and environmental  
159 sociology, which allows us to focus on similarities between disciplines instead of their  
160 differences. Many readers would argue, with reason, that this domain has been the *raison d'être*



161 of the branch of sociology known as human ecology for instance (Christensen 2014, Visvader  
162 2017, Young 1974), but this is a fact not well known in many natural science departments.

163 In addition to studying the causes and consequences of the distribution of humans as  
164 stated above, interdisciplinarity would further be facilitated if a second related domain were  
165 proposed, namely that of “studying the causes and consequences of the distribution of  
166 ecological knowledge” (my own definition, Figure 1). Before continuing, the expression  
167 “ecological knowledge” needs some clarification. In contrast to local ecological knowledge  
168 (and related concepts), which somewhat opposes a Western cultural and/or academic view of  
169 how to manage ecosystems to a locally evolved set of practices and rules (Davis and Ruddle  
170 2010, Lam et al. 2020), I propose using a more general definition. For knowledge, we may  
171 adopt the definition of (Renn 2014) “as the capacity of an individual or a group to solve  
172 problems and to mentally anticipate the corresponding actions.” It thus follows that ecological  
173 knowledge can be conceived as “as the capacity of an individual or a group to solve ecological  
174 problems and to mentally anticipate the corresponding actions” (my own definition). Here,  
175 ecological problems would be anything from understanding agriculture, forestry, fisheries,  
176 husbandry, watershed management, and so forth.



178 **Figure 1.** Studies about our own species are within a gradient of disciplines that span two extremes: on the one  
 179 hand, the study of organisms themselves, and on the other, the study of ecological knowledge (*sensu lato*) that  
 180 cannot be dissociated of the presences of humans themselves. In our case, the type of human knowledge of interest  
 181 to us is the ecological knowledge that humans use to survive and fulfill their essential needs. The central circle  
 182 largely represents the subject of the human ecology field.

183

184 In line with Figure 1, the subject of certain interdisciplinary studies such as human  
 185 ecology or anthropology could be seen as part of a tripartite typology: some studies address  
 186 humans within ecological systems, others focus on people's knowledge about their supporting  
 187 ecosystems and how that knowledge is maintained and shared, and finally, some explore both  
 188 aspects. The domain space depicted in Figure 1 cannot account for all possible types of  
 189 interdisciplinarity that exist or can exist between the ecological sciences and the human sciences,  
 190 but just a subset of them. Having accounted for the definition of the domains of research, I will  
 191 briefly transcribe the eight principles of ecology as proposed by Scheiner and Willig.

192

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

194 Scheiner and Willig (2008, 2011) published their principles aimed at contributing to a general  
 195 theory of ecology, while cautioning readers that their postulates may be incomplete and that  
 196 other researchers could come up with a different set of principles. We transcribe these principles  
 197 in Table 1, mostly using the 2011 version of the principles that differ slightly from the 2008  
 198 version. Bear in mind that the order in which the principles are presented do not imply a  
 199 hierarchy.

200 **Table 1.** Transcribed ecological principles (E1-E8) based on the works of Scheiner and Willig (2008, 2011)

<i>Label</i>	<i>Transcribed ecological principle</i>
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---

<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

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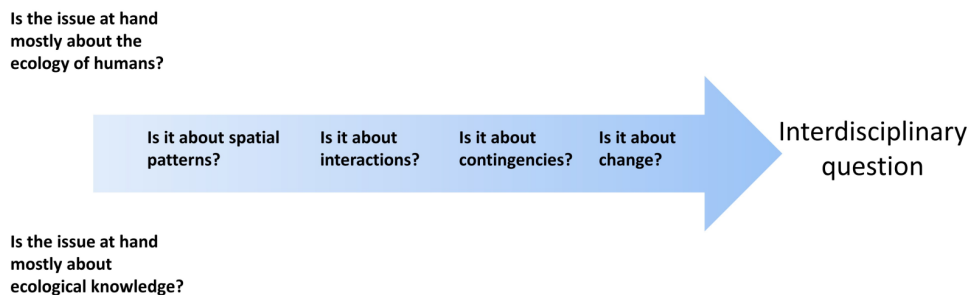
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202 In their analysis, some principles are exclusive to the ecological sciences, while some are shared  
 203 with other scientific branches (see the original publication). In these principles, “heterogeneous”  
 204 could be replaced by “non-random are framed.

205

### 206 *Extending the principles outside the ecological sciences*

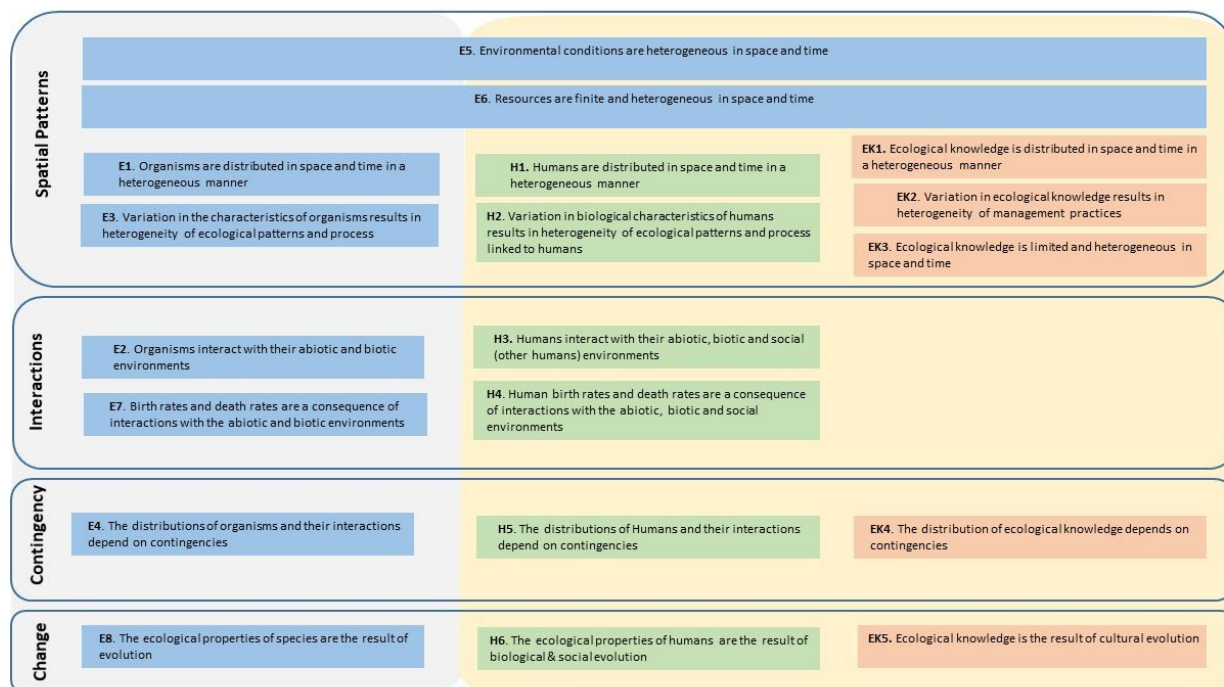
207 Through analogical reasoning, I propose here that the original eight principles of  
 208 Scheiner and Willig can first be elaborated for humans as the study object, and second, for  
 209 ecological knowledge as the study object (hopefully without upsetting our colleagues in the  
 210 social sciences too much!). The extended principles, like the original ones, are built on what we  
 211 can call an ecological perspective consisting of the following: *i*) spatial patterns, *ii*) interactions,  
 212 *iii*) *iii*) contingency, and *iv*) notions of change (evolution). These notions can help students in  
 213 ecology ask whether there is a need for an ecological perspective, and thus a place for  
 214 interdisciplinarity in the social sciences (Figure 2). The answer to these questions would be  
 215 with the aid of the extended principles.



216

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

220 Before analyzing each possible extended principle, we depict them to show their relation  
 221 to the original principles (Figure 3), shown as a continuous gradient of the domains depicted in  
 222 Figure 1. As with the original ones, the extended principles are complementary to each other,  
 223 not mutually exclusive, and without a hierarchy.



224

225 **Figure 3.** Extended principles drawing from Sheiller and Willig (2008, 2011), elaborated for humans (H1-H6) and  
 226 ecological knowledge (EK1-EK5) as the objects of study. Two of the original principles (E5 & E6) apply to all  
 227 living organisms and do not need to be elaborated. The order of the original ecological principles has been changed  
 228 in order to group the extended principles into major themes in ecology.

229

230 How close or far removed are these extended principles from existing interdisciplinary  
 231 research? Examples from the scientific literature of the different fields can shed light on their  
 232 utility. Tables 2 and 3 enumerate the extended principles while providing examples from the  
 233 literature in which this kind of thinking has been used. Two of the principles were not elaborated  
 234 for humans because they can be considered to apply to all living organisms: principle **E5**  
 235 (Environmental conditions are heterogeneous in space and time) and **E6** (Resources are finite  
 236 and heterogeneous in space and time) are thus depicted the same as in Figure 2. Some analogies  
 237 are also not possible between humans and ecological knowledge as study objects, resulting in  
 238 fewer principles for ecological knowledge than for the other categories.

239 The first three principles proposed for humans (**H1**, **H2**, and **H3**) are familiar in studies  
 240 exploring the ecological properties of the human species. In particular, principle **H3** is the most  
 241 interdisciplinary (Humans interact with their abiotic, biotic, and social (other humans)  
 242 environments), because it can only be addressed from the perspective of the ecological sciences,  
 243 the social sciences, or both. In a way, if there is one principle that would hold across many  
 244 research questions, it would be this one. Likewise, principle **H4** is highly interdisciplinary,  
 245 because human demographic parameters are a function of both the biotic environment and  
 246 human interactions, as wars and conflicts can have demographic consequences that are just as  
 247 catastrophic as diseases or pandemics, and often they are related.

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

<i>Extended principle</i>	<i>Examples in the literature</i>
<p data-bbox="248 1261 437 1290"><b>Special Patterns</b></p> <p data-bbox="509 1151 839 1245"><b>H1.</b> Humans are distributed in space and time in a heterogeneous manner</p> <p data-bbox="509 1308 847 1453"><b>H2.</b> Variations in human biological characteristics result in heterogeneous ecological patterns and processes linked to humans</p>	<p data-bbox="879 1093 1385 1274">(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)</p> <p data-bbox="879 1323 1377 1442">The emergence of lactose tolerance allowed husbandry and thus modified landscapes in Africa and Europe (Cramp et al. 2014, Ingram et al. 2012)</p>
<p data-bbox="272 1704 414 1733"><b>Interactions</b></p> <p data-bbox="509 1552 847 1646"><b>H3.</b> Humans interact with their abiotic, biotic, and social (other humans) environments</p> <p data-bbox="509 1798 847 1917"><b>H4.</b> Human birth and death rates are a consequence of interactions with the abiotic, biotic, and social environments</p>	<p data-bbox="879 1462 1385 1702">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</p> <p data-bbox="879 1738 1377 1946">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)</p>

<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

250

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

259 Principles relating to knowledge are less straightforward to deduce by analogy, because  
260 they address a study object (domain) that philosophical and social science traditions assign very  
261 strongly to the realm of human culture that has no equivalent in other species. While it is known  
262 that many vertebrates can teach their young how to find feeding spots and that primates are  
263 capable of social learning (see for example Whiten et al. 2005), scholars still do not agree  
264 whether these behaviors and information transmission are equivalent to human culture (Tennie  
265 et al. 2009). In general, knowledge is a subject of many fields, traditionally philosophy, but it  
266 is also central to anthropology (Crick 1982) and sociology (Shapin 1995). For this reason, we  
267 can expect that any principle developed by analogy may be ill fitted in many cases. Nevertheless,

268 for the sake of the argument, let us accept that under certain circumstances, “knowledge” can  
 269 also be a study object to which ecologically oriented questions (spatial patterns, interactions,  
 270 contingency, and changing notions) may be relevant, especially if they help shed light on the  
 271 distribution of the human species and their interactions with other species.

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

285  
 286 **Table 3.** Selected, non-exhaustive list of examples in the literature asking questions akin to the extended ecological  
 287 principles when ecological knowledge is considered as the study object (see text for the definition of ecological  
 288 knowledge). No interaction principles were developed for ecological knowledge to avoid over-interpretation of  
 289 analogies 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 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

290

291 *Principles in practice*

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

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

311           More generally, an interdisciplinary curriculum could be envisaged for middle to  
312 advanced levels of graduate students (Table 4). Introductory courses on the main ideas in  
313 sociology, anthropology, political science, history and physical and human geographies could  
314 be potentially discussed around the principles during the time when advanced students prepare  
315 their dissertation projects. A hybrid lecturing/ seminar approach in which each person dwells  
316 in depth on a subject allowing for critical thinking and discussion, could allow the discovery of  
317 other fields not only by students but by faculty themselves. Whether more principles, or simply  
318 other principles are needed to foster interdisciplinarity, will probably emerge through  
319 discussion, but that cannot be predicted beforehand.

320 **Table 4.** Example of a seminar curriculum for advance graduate students built around the extended principles. Contents would vary depending on the availability of  
 321 different faculty, as well as the subjects chosen to discuss.

<i>Main Subject</i>	<i>Week</i>	<i>Subject of seminar</i>	<i>Main Principles Discussed</i>	<i>Disciplines</i>	<i>Subject</i>
<b>Spatial patterns</b>	1	Heterogeneous and limited distribution of resources	E5; E6	earth sciences	<ul style="list-style-type: none"> <li>Planetary boundaries</li> </ul>
	2	Heterogeneous Human distribution	H1; H2	Human geography	<ul style="list-style-type: none"> <li>History of human colonization of the biosphere</li> </ul>
	3	Heterogeneous knowledge distribution	EK1-Ek3	Cultural anthropology	<ul style="list-style-type: none"> <li>Cosmologies of western and non-western culture</li> </ul>
<b>Interactions</b>	4	Human/non-human interactions	H5	Demography	<ul style="list-style-type: none"> <li>Understanding human population growth</li> </ul>
	5	Human/human interactions	H2; EK2	Institutional economics; political studies	<ul style="list-style-type: none"> <li>The law as a social regulator of human interactions</li> <li>managing commons pool resources</li> <li>gender inequalities</li> <li>Impacts of colonization on resource use and on biodiversity</li> </ul>
<b>Contingency</b>	6	Contingencies creating human distributions and ecological knowledge	H5/EK4	earth sciences	<ul style="list-style-type: none"> <li>Glaciations &amp; human dispersal</li> </ul>
<b>Change</b>	7	Human ecological properties through time	H6; EK5	Human ecology	<ul style="list-style-type: none"> <li>The industrial revolution and ecosystem appropriation;</li> <li>The emergence of conservation science</li> </ul>

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327 ***Concluding remarks***

328 I do not claim or imply that it is enough to simply use some analog concepts to create a new  
329 interdisciplinary stable field, whether it is the ecological sciences that borrow from social  
330 sciences or *vice versa*. Only, that they may be useful in certain cases to answer specific  
331 questions. The process of discipline evolution is far more complicated. New disciplines or sub-  
332 disciplines typically emergence from groups of researchers that actively propose research  
333 agendas that eventually become institutionalized through societies and dedicated journals, a  
334 process that may take decades. In turn, this largely social process influences the structure of  
335 higher education institutions (Wallace and Clark 2017), reinforcing discipline boundaries until  
336 a new field of research emerges and the processes is repeated.

337         Nevertheless, the main objective of these extended principles is to highlight similarities  
338 between disciplines in ecological and social sciences, as often it is the case that it is their  
339 differences that are emphasized (Moon and Blackman 2014). Many scholars will argue that  
340 similarities are superficial and that questions cannot be answered isolated from a disciplinary  
341 context, a position I agree with. The ecologist will still give her/his perspective and the social  
342 scientist theirs to the problem at hand. The use of very general principles does not call for any  
343 need of one discipline superseding another one but for an epistemic pluralism (Persson et al.  
344 2018), or a multifaceted analysis of problems having complex structures. Only a continuous  
345 iteration of the same kind of questions may push for a general theoretical framework and may  
346 produce eventually a stable interdisciplinarity as a new field.

347           The same exercise could have been done in the other direction, by starting with the  
348 social sciences and then asking the question about what they can contribute in an  
349 interdisciplinary context along with the ecological sciences. The use of terms such as population,  
350 community, and association in plant ecology is not fortuitous, as they entered into ecological  
351 thinking in the late 19<sup>th</sup> century at a time when both ecology and many social sciences were  
352 burgeoning (Egerton 2015). Today, the wealth of research in both the ecological and social  
353 sciences shows that the ideas of spatial variation, change in time, and so forth are not the  
354 exclusive prerogative of the ecological sciences. Using very general principles as the ones  
355 proposed here can help uncover insights shared among disciplines, but it is impossible to predict  
356 if new disciplines will emerge from the continuous borrowing of ideas between the ecological  
357 and social sciences.

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