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1 **A conceptual framework for the governance of multiple biodiversity-mediated ecosystem services**
2 **in agricultural social-ecological landscapes**

3

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10

11 **Abstract**

12 Context: While the concept of ecosystem services (ES) is well-established in the scientific and policy
13 arena, many challenges remain to operationalize it. Indeed, ES supply, demand and flow are related
14 to ecological and social processes at multiple spatiotemporal scales, leading to complex interactions
15 in the provision of multiple ES.

16 Objectives: To develop a conceptual framework (CF) in order to facilitate the governance of multiple
17 ES in agricultural social-ecological landscapes.

18 Method: We examine the ecological and social literatures to identify how approaches at the landscape
19 level contribute to a better understanding of ES supply, demand and flow in agricultural systems. After
20 presenting our CF, we develop a case study to illustrate how methods from different disciplines can
21 be combined in order to operationalize this CF.

22 Results: The literature suggests that the landscape level is likely to be the organization level allowing
23 to (i) integrate different components of ES co-production, i.e. ecological processes, agricultural
24 practices and social structures, (ii) understand interactions between stakeholders, including ES co-
25 producers and beneficiaries, (iii) explicit ES trade-offs, i.e. social choices between ES.

26 Conclusion: The production of multiple ES at the landscape level involves different types of
27 interdependencies among ES co-producers and beneficiaries. These need to be addressed in
28 concerted and integrated ways to achieve a sustainable and equitable governance of agricultural
29 landscapes.

30

31 **Keywords**

32 Agricultural practices; Biodiversity; Companion Modeling; Ecological functions; Mapping; Remote
33 sensing; Social interactions; Stakeholders; Spatio-temporal scales; Trade-offs.

34

35

36

37

38 Introduction

39

40 The concept of ecosystem services (ES), broadly defined as nature's benefits to people, is now
41 well-established in the scientific and policy arena (e.g. Daily et al. 2009; Burkhard et al. 2013, Bratt
42 2018; Peterson et al. 2018 but see Diaz et al. 2018). ES provision results from three processes: ES
43 supply (the potential of ecosystems to produce ES), ES demand (the level of ES provision desired or
44 required by people) and ES flow (the connection between ES supply and ES demand; Fisher et al. 2009;
45 Villamagna et al. 2013). Because it connects social and ecological dynamics, ES represent a promising
46 concept to better understand social-ecological systems and to provide recommendations for their
47 sustainable management. Numerous conceptual frameworks (CF) on ES provision have been
48 developed over the years (e.g. MEA 2005; Collins et al. 2011; Potschin et al. 2013; Larigauderie and
49 Mooney 2010; Fedele et al. 2017; Dendoncker et al. 2018). These CF have considerably improved the
50 integration of the ecological and social components of ES provision. However, few have developed an
51 integrative approach considering simultaneously multiple ES, multiple ecosystems and multiple
52 stakeholders.

53 A truly integrative approach of multiple ES governance needs to take into account several key
54 challenges. First, it needs to consider that ES provision results from the combination of ES supply,
55 demand and flow (Fischer and Eastwood, 2016). For instance, ES flow, i.e. the fact that many ES are
56 supplied by one ecosystem but provided in adjacent ecosystems remains overlooked. Second, it needs
57 to consider that multiple spatial and temporal scales and levels are involved in ES supply and demand
58 (Wu 2013; Hein et al. 2006). For instance, most CF do not take into account that ES demand may vary
59 among stakeholders who act at different organizational levels, e.g. provisioning ES are more likely to
60 be important for local stakeholders, while nature conservation may be more important for national
61 and international stakeholders. Third, it needs to consider interactions between multiple ES (Bennett
62 et al. 2009; Howe et al. 2014). In terms of ES supply, synergies/antagonisms between ES imply that
63 the supply of one or several ES increases/decreases the supply of one or several others. Antagonisms
64 among ES may generate conflicts between stakeholders with diverging ES demands (King et al. 2015).
65 Although there is a growing literature on these topics, few CF consider spatial ES trade-offs, i.e. trade-
66 offs across multiple ecosystems. Lastly, from a governance perspective, agricultural and
67 environmental policies are often designed and implemented separately, with little consideration for
68 coherence between policies (Primmer and Furman, 2012).

69

70 Landscape ecology has been proposed as a pivotal discipline to achieve a truly integrative ES
71 research (Müller et al. 2010; Wu 2013). First, landscape ecology defines “landscape” as an
72 organizational level where different ecosystems and stakeholders interact. It therefore provides a
73 suitable level to understand how ecological and social processes jointly contribute to ES provision.
74 Second, landscape ecology typically considers the role of multiple spatial and temporal scales (scale
75 being the extent or grain considered; Allen and Starr 1982). It considers that “landscape services”, i.e.
76 ES provided by multiple ecosystems in combination, are an emergent property of landscapes
77 (Termorshuizen and Opdam 2009; Wu 2013; Bastian et al. 2014). Finally, landscape ecology is
78 increasingly focusing on multifunctionality and the provision of multiple ES (e.g. Raudsepp-Hearne et
79 al. 2010). Yet, there have been few attempts to develop and implement a truly integrative ES
80 framework including simultaneously multiple ecosystems, stakeholders and ES. We posit in this paper
81 that an integrative landscape-based ES framework can support operationalizing the ES concept for a
82 more sustainable and equitable governance of the agroecological transition.

83 Agricultural landscapes dominate the world’s terrestrial area (40%) and represent highly
84 heterogeneous and dynamic landscapes. They are usually composed of a mosaic of crops, grasslands,
85 freshwater and forested systems and result from agro-sylvo-pastoral activities conducted by multiple
86 stakeholders. These activities are related to ES in two ways. On the one hand, agricultural activities
87 depend on the provision of multiple ES, as well as ecosystem disservices (EDS), i.e. ecological processes
88 that are unfavorable to human well-being (Shackleton et al. 2016). On the other hand, these activities
89 contribute to the supply of multiple ES (and EDS) that benefit (or affect) the whole society (Zhang et
90 al. 2007). Recent changes in agricultural practices associated with the industrialization of food
91 production systems have dramatically undermined the capacity of agricultural landscapes to provide
92 multiple ES that are key for both agriculture sustainability and society. As a result, there is now a
93 growing awareness of the need to design agricultural landscapes that are (i) multifunctional, i.e.
94 produce biomass (food, wood, fiber or fuel), contribute to biodiversity conservation and deliver
95 multiple other ES (e.g. carbon sequestration, aesthetic landscapes) and (ii) limit ecological processes
96 that are unfavorable to agriculture and society (e.g. pest spread). Several authors have explored the
97 role of the ES concept for agriculture (e.g. Swinton et al. 2007, Robertson et al. 2014). However, these
98 frameworks have not yet simultaneously considered multiple ES, multiple ecosystems and multiple
99 stakeholders involved in agricultural landscapes.

100 In this paper, we first examine the ecological and social scientific literatures to identify how
101 the landscape approach can contribute to a better understanding of multiple ES provision in
102 agricultural landscapes. We then develop a conceptual framework to facilitate an integrative
103 landscape-based approach for ES governance in agricultural social-ecological landscapes. In a third

104 part, we develop a case study to illustrate how methods from different disciplines can be combined in
105 order to operationalize this CF.

106

107 1. **Contributions of the landscape approach to multi-ES research**

108 In this section we first explain how the landscape approach can contribute to a better
109 understanding of multiple ES supply and flow in agricultural landscapes. We then explain how this
110 landscape approach also enables considering multiple stakeholders involved in ES co-production and
111 ES demand.

112

113 **1.1. Contributions of the landscape approach to the understanding of multiple ES supply and flow**

114 **The role of spatio-temporal heterogeneity** - The ecological literature on agricultural landscapes
115 provides significant evidence that some ES supply results from processes occurring at multiple spatial
116 and temporal levels, and that they are often provided by multiple ecosystems. This is particularly true
117 for ES relying on ecological processes based on mobile organisms such as pollination and biological
118 control (Kremen et al. 2007; Duru et al. 2015), which are central processes for the ecological
119 intensification of agriculture (Pimentel et al. 1997; Costanza et al. 1999; Losey and Vaughan 2006;
120 Federico et al. 2008; Maine and Boyles 2015). Indeed, most species contributing to pollination and
121 biological control require a combination of resources, i.e. feeding, reproduction and overwintering
122 sites. In agricultural landscapes, these resources may not necessarily be found within the same
123 ecosystem, in particular within a single type of crop. ES supply may also be influenced by mobile
124 organisms, and therefore the landscape level, e.g. the effect of large ungulates on nitrogen and
125 nutrient cycling depends on landscape composition (Thompson Hobbs 1996). Additionally, ES supply
126 depends on the temporal continuity of resources within the home range of individuals (Schellhorn et
127 al. 2015). For example, temporal variations in food resources availability due to the phenological cycle
128 of crops can influence the spillover of natural enemies and pollinators from semi-natural habitats to
129 crops (Rand et al. 2006; Blitzer et al. 2012). These spatiotemporal variations also influence EDS supply,
130 e.g. the spillover of pathogens from semi-natural habitats to crops or the negative impact of ungulates
131 on forest regrowth and crop production (Irby et al. 1996; Putman and Moore 2002; Boulanger et al.
132 2015). The role of landscape structure may be complex. For instance, the abundance of specific crop
133 types may have a negative effect on predation and/or pollination in a given year (e.g. through dilution
134 effect) but a positive effect the following year due to the positive effect of resource availability on
135 pollinator or predator population dynamics (Marrec et al. 2017).

136

137 **The role of practices at field and landscape levels** - The abundance, diversity and continuity of
138 resources used by mobile organisms depend not only on land cover, i.e. the composition and
139 configuration of land cover types (Fahrig et al. 2011), but also on land use, i.e. agricultural, forestry
140 and water management practices, at different spatial levels (Ricci et al. 2009). While there is ample
141 evidence of the effects of land cover on ES supply (see meta-analyses of Bianchi et al. 2006; Chaplin-
142 Kramer et al. 2011; Veres et al. 2013; De Palma et al. 2016; Garibaldi et al. 2011), relatively little
143 attention has been given to the effects of practices on ES supply. However both field- and landscape-
144 level practices are likely to influence ES supply, with possible non-linear and interacting effects
145 between practices and land cover (Batary et al. 2011). Landscape-level practices result in the so-called
146 hidden landscape heterogeneity, which strongly influences biodiversity and associated ES and EDS -
147 hereafter jointly referred to as E(D)S (Maalouly et al. 2013; Monteiro et al. 2013; Vasseur et al. 2013;
148 Puech et al. 2015; Carrié et al. 2017). For instance, biological control in a given field is known to be
149 influenced by agricultural practices conducted in adjacent fields (Maalouly et al. 2013; Monteiro et al.
150 2013). The temporal dynamics of practices, mainly due to crop rotation, also strongly influences E(D)S
151 supply levels (Vialatte et al. 2006; Bertrand et al. 2016; Marrec et al. 2017) as well as their temporal
152 stability (Allan et al. 2014). Finally, practices at the field-level may influence ES supply through their
153 effect on adjacent landscape elements. For instance, the combination of pesticides and fertilizers
154 applied at the field level strongly influences wild plants occurring within field margins (Schmitz et al.
155 2014). This may in turn influence resources available for beneficial organisms like pollinators
156 (Bretagnolle and Gaba 2015), and as a result, the quantity and quality of crop production (Holzschuh
157 et al. 2012).

158

159 **Synergies and antagonisms in ES supply** - The supply of multiple E(D)S may be strongly
160 interdependent across both space and time. For instance, the cascading effect of some ecological
161 processes on other processes may result in synergies. For instance, the density of ungulates influences
162 N cycling, which may in turn influence the composition of plant communities and therefore pollination
163 and biological control. Similarly, the fact that different ecological processes may be influenced by
164 common drivers may also result in synergies. For instance, an increase in ungulate density may
165 influence N cycling while increasing crop damages (Fuller and Gill 2001; Côté et al. 2004). Management
166 practices may influence the supply of multiple E(D)S simultaneously, either within the same ecosystem
167 or within two adjacent ecosystems. For instance, early sowing often increases water use efficiency by
168 crops within a given field, but increases pest colonization from adjacent ecosystems (McLeod et al.

169 1992; Vialatte et al. 2006; Raymond et al. 2014). Forest management practices may influence the
170 biological control of both forest pests (Guyot et al. 2016) and crop pests in adjacent fields (Sarhou et
171 al. 2005; Roume et al. 2011).

172

173 The ecological literature shows that spatio-temporal heterogeneity, practices, synergies and
174 antagonisms between E(D)S play a key role in ES supply and flow in agricultural landscapes. Such
175 complex ecological interactions have critical implications for stakeholders, both in terms of E(D)S co-
176 production and E(D)S demand, and for agricultural landscape governance.

177

178 **1.2 Contributions of the landscape approach to the understanding of ES co-production and ES** 179 **demand**

180

181 The European Landscape Convention has defined landscape as “an area, as perceived by people,
182 whose character is the result of action and interaction of natural and/or human factors” (European
183 Landscape Convention 2000). This definition stresses two important contributions of the landscape
184 approach to E(D)S research. First, the idea that landscapes result from both human and natural factors
185 means that people are not just E(D)S beneficiaries but also co-producers of E(D)S. Second, by stressing
186 that people have inherently subjective perceptions of landscapes, this definition highlights the
187 immaterial and subjective dimension of E(D)S derived from landscapes. The next two sub-sections are
188 dedicated to these two contributions, and for each of them, we highlight the implications for E(D)S
189 governance.

190

191 **1.2.1 ES co-production**

192

193 **Land users as ES co-producers** – Landscape research emphasizes that landscapes are shaped by
194 stakeholders such as farmers and foresters, whose activities and practices directly modify ecosystems
195 (Plieninger et al. 2015). This implies that E(D)S are not produced by ecosystems only, and that we
196 should consider these stakeholders as co-producers of E(D)S (Spangenberg et al. 2014; Bennett et al.
197 2015; Lescourret et al. 2015, Fischer and Eastwood, 2016). Farmers are obviously key stakeholders of
198 agricultural landscapes, not only as E(D)S co-producers but also as E(D)S beneficiaries. Their work
199 consists in shaping ecosystems so that they supply provisioning ES (e.g. crop production, fodder), and

200 they are among local stakeholders who are most directly depending on ES (e.g. soil fertility and
201 pollination) and E(D)S (e.g. insect pests and crop raiding by mammals; Zhang et al. 2007). A sustainable
202 and equitable governance of agricultural landscapes will inevitably rely on farmers' practices.
203 Improving this governance will therefore require understanding their constraints, interests, values,
204 representations and knowledge (Smith and Sullivan 2014). Some authors suggest that conventional
205 agriculture has tended to give higher importance to provisioning ES, which had negative consequences
206 on regulating ES, for example through forest degradation (Carpenter et al 2006; Pfund et al. 2011).
207 Yet, farmers should not be considered as a homogeneous group. A diversity of farming systems, with
208 different practices, generally coexist in a given agricultural landscape (Choisis et al. 2012; Cochet
209 2012). These different farming systems and practices shape ecosystems differently, and therefore
210 contribute to the supply of diverse sets of E(D)S (Gibon 2005). Moreover, institutions, including
211 agricultural policies influence farmers' interests, land-use decisions and agricultural practices. Finally,
212 external driving forces such as the political economic context (e.g. market prices), alarming discourses
213 on biodiversity loss, or rapid demographic changes, also influence farmers' strategies and practices
214 and therefore E(D)S supply (Verburg et al 2010).

215

216 **Implications for landscape governance : collaboration for ES supply at the landscape level** – Most
217 agricultural landscapes are used and shaped by multiple land users (Selman 2006) – although
218 exceptions can be found in places like the Argentine Pampa where very large farms are managed
219 extensively by single owners or managers (Manuel-Navarrete et al. 2009). E(D)S supply therefore
220 results from the actions and practices of multiple stakeholders, often without premeditated
221 coordination among them. There is an increasing literature stressing the need to encourage
222 collaborations among farmers and other rural land users for a more efficient ES supply at the
223 landscape level (Goldman et al. 2007; Franks 2011; Prager et al 2012; Prager 2015; Opdam et al. 2016).
224 Yet, Prager and colleagues have highlighted that, in Europe, most current agri-environmental schemes
225 involve contracts with individual land owners at the farm level; they call for the development of
226 collective contracts and incentives for agri-environmental management at the landscape level (Prager
227 et al. 2012). The seminal work of E. Ostrom on formal and informal institutions, collective action and
228 collaborative mechanisms for common-pool resource management gives critical insights to further
229 understand potential or existing collaboration processes for ES supply at the landscape level (Ostrom
230 1990, Ostrom et al. 1994). Many ES are public or common goods (Muradian and Rival 2012; Stallman
231 2011), and their governance cannot rely solely on market or state based instruments. Instead, they
232 require polycentric governance mechanisms (Ostrom 2010) combining instruments based on market,
233 state and collaboration mechanisms. However, collective action may not necessarily be relevant for

234 all ES. Because of the transaction costs of collaboration, people engage in collective action only if they
235 foresee that they can achieve higher benefits through collective efforts than through individual efforts
236 (Olson 1971). ES that are particularly dependent of the landscape structure, such as pollination, pest
237 control, or flood control, may theoretically be highly suitable for collective management (Stallman
238 2011). However, collective management of landscape features for the provision of pest control is
239 currently rarely observed on the ground. More work needs to be done to understand the barriers and
240 enabling conditions of such collaborative mechanisms. Some work suggests that high uncertainties
241 associated with ecological processes, risks involved for farmers, and the availability of less risky
242 individual options such as chemical pesticides represent barriers to such collaborative mechanisms
243 (Salliou and Barnaud 2017).

244

245 **1.2.2 ES demand**

246 **Landscape values and ES preferences** – A branch of landscape research focuses on the multiple
247 reasons why people value landscapes, from immaterial dimensions like aesthetic and place
248 attachment to more tangible benefits like outdoor recreational activities, water regulation or food
249 production (Plieninger et al. 2015). Following the seminal work of Costanza et al. (1997), monetary
250 valuations of ES have long been dominating the literature on ES valuation. Although these approaches
251 can provide a pragmatic demonstration of the value of ecosystems and biodiversity, especially for
252 decision-makers, they have been highly criticized for paving the way towards commodification of
253 nature (Gomez-Baggethun and Ruiz-Perez, 2011), and for failing to capture the diversity and
254 complexity of people’s perception of nature (Raymond et al. 2015). Numerous authors advocated the
255 need to integrate a plurality of value domains, and to combine biophysical, monetary and socio-
256 cultural valuations of ES, including discourse-based (Dendoncker et al. 2013, Martin-Lopez et al. 2014).
257 Socio-cultural valuation approaches aim at revealing “the importance people, as individuals or as a
258 group, assign to (bundles of) ES” (Scholte et al. 2015, p. 68). They aim to go beyond economic and
259 monetary ES valuations that focus on utilitarian values only, so as to integrate a more diverse set of
260 values. Many studies aim to capture how and why different people value differently various landscape
261 services, depending on their livelihoods, their interests, their representations, their personal history,
262 their cultural background as well as their access to these services (Maass et al. 2005; Bieling et al.
263 2014; Garrido et al. 2017; Da Ponte et al. 2017). Social organization levels also matters in ES
264 preferences : local stakeholders are often more interested in provisioning ES, compared to regional or
265 international stakeholders, who value more the regulating ES (Hein et al. 2006; Garrido et al. 2017).
266 However, landscape values and ES preferences are constantly evolving, depending for instance on
267 changing individual circumstances, changing contexts, or access to new information (Kumar and

268 Kumar 2008). In many cases, people are actually not aware of the whole range of benefits they get
269 from ecosystems, for instance in the case of poorly visible ES like pollination or insect pest regulation
270 (Salliou and Barnaud 2017). But access to relevant and actionable knowledge on these processes might
271 increase their awareness (Opdam et al. 2016). People's preferences can also evolve through social
272 interactions and group discussions. Raymond et al. (2015) distinguished two types of socio-cultural
273 valuation approaches: instrumental approaches involving an objective assessment of the values that
274 individuals assign to an ecosystem and deliberative approaches involving the exploration of desired
275 states of ecosystems through group discussions. Evolutions of ES perceptions and preferences can
276 then be referred to as social learning processes (Röling and Wagemakers 1998; Pahl-Wostl et al. 2007).

277

278 **Implications for landscape governance: ES trade-offs and social choices** – Managing multiple ES in
279 agricultural landscapes requires to deal with trade-offs among antagonist ES, i.e. when the supply of
280 a given ES is detrimental to the supply of another ES (Rodriguez et al. 2006). In other word, this means
281 that “we cannot have it all” (Turkelboom et al. 2018), and this results in conflicts of interests between
282 stakeholders who have different ES preferences (Martin-Lopez et al. 2012). For instance, in protected
283 areas in tropical forests, conflicts of interests between farmers and conservationists are very common,
284 due to antagonisms between provisioning ES from agriculture and regulating ES from forest.
285 Addressing these trade-offs is critical for ES governance (Daw et al, 2011; Bennet et al 2015). In many
286 cases, trade-offs arise without the stakeholders being aware of them (Rodríguez et al. 2006). For
287 instance, the industrialization of agriculture has progressively increased ES provisioning to the
288 detriment of regulating ES since the 1950s, and it is only in the 1990s that society became aware of it
289 (Rodriguez et al. 2006, Blanco et al. 2018). And yet, these trade-offs generate winners and losers (Daw
290 et al. 2011). They are therefore related to social choices that should be made explicit and collectively
291 negotiated (Barnaud and Antona 2014). Analytical tools such as multi-criteria analysis and cost-benefit
292 analysis can be useful to assess objectively these trade-offs (Koschke et al. 2012), but these
293 assessments do not necessarily capture the multiple perceptions and knowledge held by stakeholders,
294 as well as the social learning processes that can occur among them in deliberative and participatory
295 approaches focusing on trade-offs (Galafassi et al. 2017). However, because dealing with trade-offs
296 among ES involves dealing with conflicts of interests and power asymmetries, such deliberative
297 processes should not be conceptualized in terms of social learning only, but also in terms of
298 negotiation processes (Leeuwis 2004; Barnaud et al. 2018). Such negotiation processes are not only
299 about addressing diverse interests but also involve struggles over the very meanings of environmental
300 problems (Hajer 1995).

301

302 The literature suggests that the landscape level is likely to be the organization level allowing
303 to (i) integrate different components of ES co-production, i.e. ecological processes, agricultural
304 practices and social structures, (ii) understand interactions between stakeholders, including ES co-
305 producers and beneficiaries, (iii) explicit trade-offs, i.e. social choices between ES.

306

307 2. **An integrative landscape-based framework for multi-ES governance**

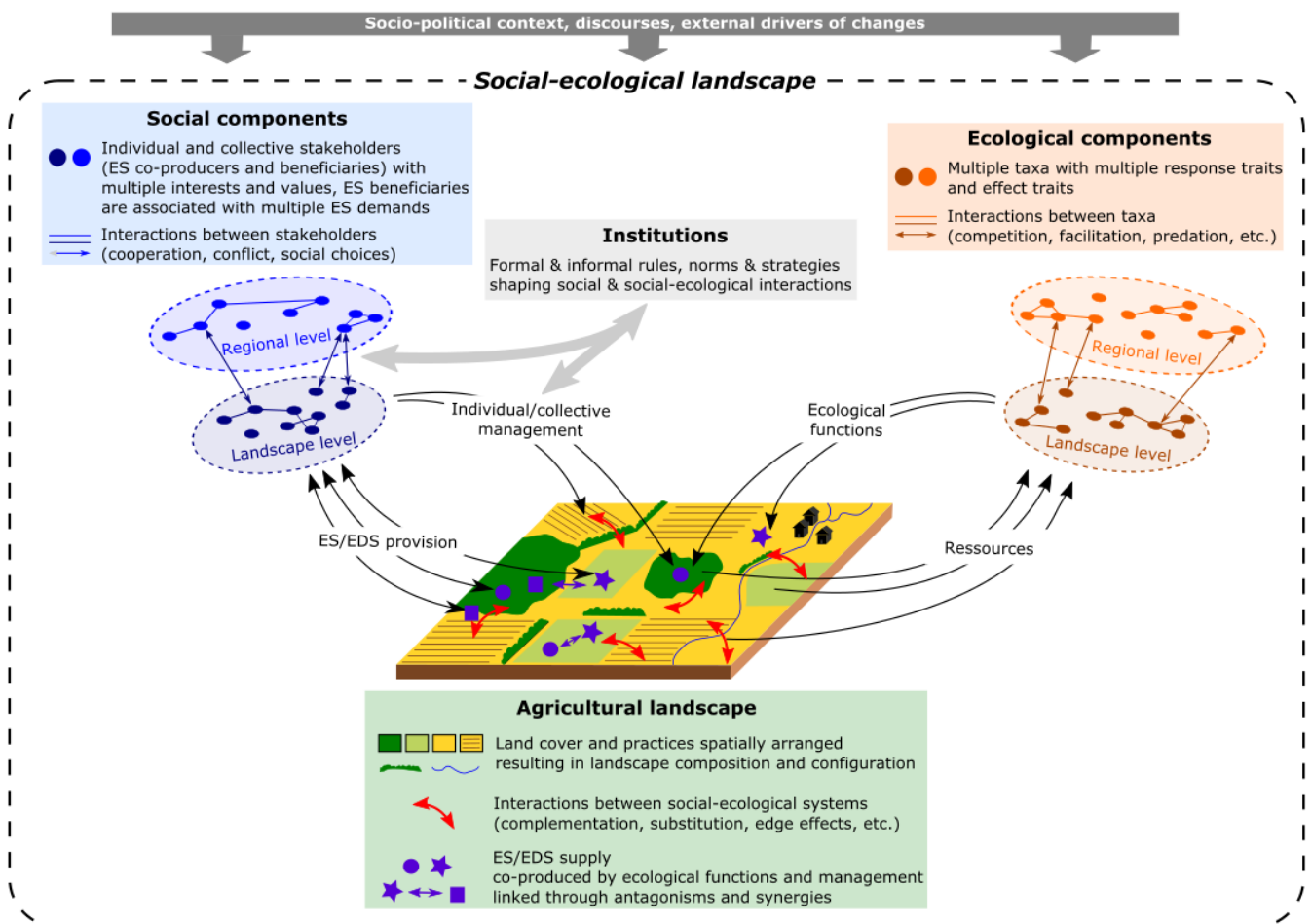
308

309 Our synthesis of the literature highlighted that a landscape approach is critical to understand
310 ES provision (supply or co-production, flow and demand) and improve multi-ES governance. There are
311 numerous conceptual frameworks (CF) on ES provision (e.g. MEA 2005; Potschin et al. 2013;
312 Larigauderie and Mooney 2010; Fedele et al. 2017; Dendoncker et al. 2018). Most of these CF have
313 focused on the integration of ecological and social components of ES provision but have yet rarely
314 explicitly considered multiple ES, multiple ecosystems or multiple stakeholders. As a result, most ES
315 research has focused primarily on the local level (i.e. field) and the provision of single ES. Recently,
316 there have been some attempts to better take into account the role of landscape composition and
317 configuration as well as the role of synergies and antagonisms between ES. For instance, Kremen et
318 al. (2007) developed a CF integrating the role of landscape structure on ES produced by mobile
319 organisms. Lescourret et al. (2015) proposed a CF integrating the ecological and social dimensions of
320 multi-ES provision in agricultural landscapes. Barnaud et al. (2018) developed a CF taking into account
321 interdependencies among multiple stakeholders and the role of collective action in ES co-production
322 and multi-ES governance. However, these frameworks fail to integrate all dimensions of ES provision,
323 namely the multi-ecosystems, multi-stakeholders and multi-ES dimensions.

324 We therefore propose a CF to facilitate an integrative landscape-based approach for multi-ES
325 governance in agricultural social-ecological systems (Fig. 1). This CF is composed of four main
326 components leading to the provision of multiple E(D)S : the ecological component, the social
327 component, institutions that influence social and social-ecological interactions and the agricultural
328 landscape resulting from land cover and practices. These components are characterised by internal
329 interactions, e.g. competition and predation between taxonomic groups, conflicts and cooperation
330 between stakeholders, complementation or edge effects between socio-ecosystems. Institutions
331 shape social interactions as well as social-ecological interactions. These components are affected by
332 the political-economic context, discourses and other external drivers of change such as migration,

333 urbanization or climate change. These components are connected through several processes 1)
 334 landscape provides resources to multiple taxonomic groups that support multi-ES supply, 2) ES
 335 beneficiaries interact with ES co-producers to influence their management of the landscape, and 3)
 336 institutions play a key role in the governance of ES by influencing social and social-ecological
 337 interactions, and 4) individual and collective management, together with ecological functions, co-
 338 produce ES/EDS at the landscape level. The next subsections develop the four processes of this CF and
 339 the role of social-ecological interactions at the landscape level on these processes.

340



341

342 **Figure 1.** Conceptual framework for an integrative landscape-based approach of ES governance in
 343 agricultural landscapes.

344

345 **2.1. Biodiversity, functions, ES supply and flow in agricultural landscapes**

346

347 **Multiple interacting ecosystems** – Our CF takes into account that the agricultural social-ecological
348 landscape is composed of multiple interacting ecosystems. Landscape structure, resulting from land
349 cover and practices, influences ES supply through its effects on biodiversity and functions. Indeed, the
350 availability in space and time of diverse resources necessary for organisms is critical for their
351 persistence in agricultural landscapes. Many ecological processes are influenced by landscape
352 structure, e.g. crop colonization by pests (Vialatte et al. 2006), competition for limited resources
353 (Vialatte et al. 2017), pollination of crops and natural vegetation (Holzschuh et al. 2012) or predation
354 of phytophagous species (Alignier et al. 2014; Raymond et al. 2014). Dynamics of biodiversity and its
355 functions imply various spatial and temporal dimensions of ES supply, resulting in potential
356 antagonisms and synergies (see examples in previous section).

357

358 **Multiple interacting taxonomic groups and functions** – Our CF takes into account that ES supply
359 depends on multiple interacting taxonomic groups and functions. Indeed, several taxonomic groups
360 contribute to a single ES. For instance, both wild bees and adult hoverflies contribute to pollination.
361 Conversely, some taxonomic groups contribute to several ES. For instance, adult hoverflies contribute
362 to pollination while the larval stage of some hoverfly species are aphid predators and therefore
363 contribute to biological control. Moreover, taxonomic groups are connected to each other through
364 trophic networks resulting in complex cascading effects. For instance, bird and bat species are
365 predators of both insect crop pests and natural enemies. Our CF therefore stresses the importance of
366 using a multi-taxa approach in order to better understand the supply and flow of multiple ES.

367

368 **Interacting landscape-level and regional-level processes** – Our CF takes into account that ES
369 supply/flow is not only influenced by landscape-level processes, e.g. landscape complementation and
370 spill-over, but also influenced by regional-level processes, e.g. climate change. Indeed, biodiversity
371 potentially occurring at the landscape level strongly depends on biogeography patterns defining the
372 regional species pool (Begg et al. 2017). This regional species pool may be influenced by large-scale
373 processes such as climate changes and species invasions. Landscape-level and regional-level processes
374 may interact and have additive or non-additive effects on biodiversity and ecosystem services, and
375 should therefore be studied simultaneously as much as possible (Sirami et al. 2017). As a result, our
376 CF stresses the importance of including both types of processes, in particular when studying temporal
377 changes in biodiversity and ecosystem services.

378

379 **2.2. From ES demand to ES co-production: social interactions among ES beneficiaries and ES co-**
380 **producers in agricultural landscapes**

381

382 **Multiple ES beneficiaries** – Various stakeholders directly or indirectly get benefits or harms from ES
383 and EDS according to their own livelihoods, interests and preferences (e.g. Monteiro et al. 2013,
384 Maalouly et al. 2013). These beneficiaries can be identified at the landscape level as well as at the
385 regional level. Our CF aims to capture which ES or bundles of ES are important for which type of
386 stakeholders, and why these ES are important to them (Barnaud et al. 2015). Our assessment goes
387 beyond utilitarian values of ES and integrates existence values, i.e. the fact that some stakeholders
388 value a component of ecosystems (e.g. a given species) for its own existence rather than because it is
389 useful to them. Moreover, following Daw et al. (2015), our CF makes a difference between ES demand
390 and ES provision, which only occurs when ES demand and ES supply/flow are met. For instance, the
391 provision of ES associated with the aesthetic value of landscape within a National Park only occurs
392 when tourists both value the aesthetic of this landscape and are able to afford the entrance fee of the
393 National Park. Finally, our CF takes into account that ES demand does not automatically translate into
394 ES co-production, even when the co-producers of a given ES are also the beneficiaries of this ES.
395 Indeed, the translation of ES demand into ES co-production is mediated by individual and collective
396 decisions that are influenced by complex social interdependencies among ES beneficiaries and ES co-
397 producers.

398

399 **Multiple interdependencies among ES beneficiaries and ES co-producers** – Our CF highlights three
400 types of social interdependencies among stakeholders involved in multi-ES governance: (i) between
401 ES beneficiaries and ES co-producers, (ii) among ES beneficiaries, and (iii) among ES co-producers
402 (Barnaud et al. 2018). All these interdependencies can be positive or negative, collaborative or
403 conflicting, and occur in more or less formalized action arenas. Interdependencies between ES
404 beneficiaries and ES co-producers include situations where ES co-producers, e.g. farmers planting
405 hedgerows, positively contribute to ES supply, e.g. biodiversity conservation, which benefits other ES
406 beneficiaries, e.g. society as a whole (Prager 2015). Interdependencies among ES beneficiaries are
407 related to antagonisms and synergies among ES. For example, chemical inputs used by a farmer to
408 increase his crop yield may negatively affect pollinators of his neighbor's apple trees, resulting in an
409 antagonistic relationship between these two ES (crop production and apple tree pollination), which
410 generates a conflict of interest between their respective beneficiaries (the crop farmer and the apple
411 producer). Our CF looks at how these antagonisms are dealt with and how social choices (trade-offs)

412 are made, in more or less explicit and concerted ways, in contexts of power relationships (Barnaud et
413 al. 2018). Interdependencies among ES co-producers are of critical importance in our landscape
414 approach. Many ES are produced at the landscape level, and their production depends on the actions
415 of multiple ES co-producers who contribute to shaping, degrading, or managing these landscapes
416 (Lescourret et al. 2015). For instance, rangelands in mountain areas are often collective rangelands,
417 used and managed by several herders who collectively settled rules and norms that frame the way
418 rangelands are managed (Balent and Gibon 2011). Collaborations among ES co-producers therefore
419 have the potential to increase ES supply levels (Prager 2015; Salliou and Barnaud 2017; Salliou et al.
420 2017). Our CF takes into account social conditions that can facilitate or impede such collaborations.
421 For instance, a case study in South-Western France showed that local farmers were not interested in
422 collective action because they did not perceive the role of landscape for pest regulation (Salliou et al.
423 2017), and had therefore no awareness of their interdependencies with neighboring farmers, a critical
424 pre-condition for collective action (Leeuwis and Ban 2004). Similarly, there is a strong demand of
425 society for climate and water quality regulation ES while these are provided by the combination of
426 multiple ecosystems managed by multiple stakeholders who are not necessarily the main beneficiaries
427 of these ES. For many farmers, agricultural practices favoring these ES (e.g. the maintenance of
428 hedgerows and grassy strips, the use of diversified crops and lower chemical inputs) appear too
429 constraining for such small individual benefits. In such cases, where ES beneficiaries and ES co-
430 producers are not mutually interdependent, collective action may not be relevant. Instead, the
431 translation of ES demand into ES co-production may require monetary subsidies, unless the
432 multifunctionality of agroecological infrastructures for crop production at landscape scale is also
433 considered.

434

435 **2.3. Institutions**

436 Interactions among social components, as well as between ecological and social components are
437 shaped by institutions, i.e. the “prescriptions that humans use to organize all forms of repetitive and
438 structured interactions” (Ostrom 2005, p. 3). Institutions include both formal and informal rules-in-
439 use, norms and strategies. In our landscape-based approach, we are particularly interested in the
440 institutions affecting collective action. As underlined earlier, the interdependencies between ES
441 beneficiaries and ES co-producers require collaboration among stakeholders for landscape-based
442 management. Institutions, such as national regulating policy instruments, informal or formal land
443 tenure arrangements, etc., provide incentives and constraints for initiating and sustaining local
444 collective action (Ostrom 2005). Institutions however do not emerge and operate in a vacuum but are

445 embedded in local social relations and symbolic resources (Cleaver 2002; Mosse 1997). A landscape-
446 based approach allows identifying policy instruments for successful collective action that go beyond
447 the current policy emphasis on incentives for farm-level management as exemplified by the Common
448 Agricultural Policy (CAP; Lefebvre et al. 2015). Institutions also influence the effectiveness of collective
449 action for natural resource management (Ostrom 1990) and shape power distribution among actors
450 (Clement 2013). Lastly, institutions provide the basis for deliberative democracy towards sustainable
451 and equitable landscape management (Robards et al. 2011).

452

453 **2.4. Landscape management and ES co-production in agricultural landscapes**

454

455 **Multiple interacting ecosystems and stakeholders** – Our CF takes into account that the agricultural
456 social-ecological landscape is composed of multiple interacting ecosystems and stakeholders.
457 Ecosystems include agricultural cover types, i.e. crops and meadows, semi-natural cover types, i.e.
458 patches such as forests or grasslands, as well as linear semi-natural elements such as hedgerows,
459 rivers, grassy margins, and human-dominated cover types, i.e. urban areas and roads. Stakeholders
460 managing these ecosystems include farmers, foresters, hunters, landscape planners, residents. We
461 consider them as ES co-producers. Stakeholders benefiting from ES in these landscape include
462 farmers, foresters, hunters, landscape planners, residents as well as tourists. A single stakeholder
463 often manages several components of the landscape. For instance, farmers usually manage several
464 patches from the same land cover type, e.g. crop fields, or several patches from different land cover
465 types, e.g. crop fields, meadows and forest. Conversely, some landscape components are managed by
466 several stakeholders, either with similar or diverging interests, e.g. rangelands in mountain areas are
467 often collective rangelands, used and managed by several herders. While some ES beneficiaries may
468 benefit mainly from one type of ecosystem, e.g. foresters benefit from forest patches, most ES
469 beneficiaries are likely to benefit from several ecosystems or a combinations of ecosystems.

470

471 **Land cover and practices** - Multiple stakeholders manage land cover through decisions such as crop
472 rotation, regrouping of fields, wood cutting or hedgerow removal. These practices influence both
473 landscape composition, i.e. the type of ecosystems occurring in the landscape, and landscape
474 configuration, i.e. the spatial organization of these ecosystems. Moreover, stakeholders influence the
475 land use within each landscape components through the nature, frequency and intensity of practices.
476 These disturbances influence the quality of all ecosystems composing the landscape. Both land cover

477 and practices influence resources that are available through space and time for the multiple taxonomic
478 groups occurring in the landscape (see examples in previous section). This availability of resources will
479 in turn influence ecological functions that contribute to the supply of multiple ES at the landscape
480 level. Our CF enables integrating both land cover and practices to understand the co-production of ES.

481

482 **Understanding ES co-producers' decision making** – Stakeholders' decisions regarding land cover and
483 practices depend on multiple factors. Our CF explicitly integrates the following dimensions of decision
484 making. First, their decisions depend on their representation of the social-ecological system (i.e. their
485 mental model), which is itself linked to their interests, values and preferences (e.g. the need of wood
486 for fuel, the need of grassland to feed the cattle; Vuillot et al. 2016, Salliou and Barnaud 2017). Their
487 decisions are also dependent on their constraints, which can be both bio-physical (e.g. slope,
488 elevation), socio-economic (e.g. labor force) and institutional (e.g. land-tenure; Gibon et al. 2006).
489 External social, political and economic drivers such as the Common Agricultural Policy also play a key
490 role in their decisions (Blanco et al. 2018). The proposed landscape-based framework provides a
491 unique lens to analyze these processes. For instance, urbanization can affect the co-production of ES
492 and EDS in even remote rural places and this can best be comprehended at the landscape level
493 (Antrop, 2000). Similarly, a discursive analysis of landscape representations across social organization
494 levels can reveal the gaps between local perceptions of landscape and ES changes and the policy
495 drivers of those changes (Quétier et al., 2010). Our CF therefore integrates both social and ecological,
496 internal and external factors that influence individual decisions and practices of ES co-producers. It
497 also takes into account that these decision-making processes are influenced by social interactions with
498 other stakeholders, i.e. other ES co-producers and ES beneficiaries, and that the dynamics of decision-
499 making processes are critical for ES governance in agricultural social-ecological systems.

500

501 **3. Case study: Applying the landscape-based framework to a French agricultural region**

502

503 Our case study focuses on the Vallées et Coteaux de Gascogne, which is part of the Long Term
504 Ecological Research Network (LTER_EU_FR_003; Deconchat et al., 2007). Located in south-western
505 France, this hilly region (250–400 m a.s.l.) covers 220km² (43°17'N, 0°54'E) and the climate is sub-
506 Atlantic with slight Mediterranean influences (mean annual temperature, 12.5°C; mean annual
507 precipitation, 750 mm).

508

509 **Land cover and practices** - The region is dominated by mixed crop-livestock farming systems
510 and therefore characterized by a mosaic of small woodlands, grasslands and crop fields (Figure 2A).
511 GIS work has shown that permanent grasslands tend to be located on steep slopes while annual crop
512 fields (winter cereals, rapeseed, corn and sunflower) are located on the most productive, drained and
513 irrigable valleys (Choisis et al. 2012, Thierry et al. 2017). Other farms of the region are more
514 specialised, either in cash crops or cattle production, with practices based mainly on chemical inputs.
515 Farms are scattered through the landscape, along a dense network of roads, with small villages. Using
516 interviews with farmers combined with GIS work, we have shown that each farm includes a mosaic of
517 land covers and that farms range from contiguous to interspersed with each other (Figure 2B).

518

519 **Stakeholders: co-producers and beneficiaries of ES** - In this rural region with low population
520 density, farmers are the main stakeholders of social-ecological landscapes. Using in-depth interviews
521 and focus groups for socio-cultural valuation of ES among farmers, we have shown that they manage
522 their farm for crop production but also consider ethical and social biodiversity values (Kelemen et al.
523 2013). On top of the importance of species and habitat diversity, farmers also acknowledge wider
524 landscape processes and value the complexity of ecological systems. By comparing agricultural
525 practices and mental models, we showed that farmers' ways of farming partly relate to farmers' ways
526 of thinking about the landscape: farmers most aware of ecological interdependencies also manage
527 diverse non-cultivated habitats like permanent grasslands, hedgerows and woodlands in the most
528 ecological way (Vuillot et al. 2016). Permanent grasslands are well integrated in the local mixed crop-
529 livestock farming systems as they provide fodder. Our analysis of historical aerial photos has shown
530 that hedgerows have declined but with contrasted trends according to their location and adjacent
531 land uses (Figure 2A and 2C). In-farm hedgerows that obstructed mechanization have declined,
532 whereas boundary hedgerows that offered wind protection and supported the maintenance of farm
533 boundaries were reinforced (Sourdril and Ladet 2008, Blanco et al. 2018). Interviews revealed that
534 farmers consider that woodlands are associated with 12 ES and 2 EDS, EDS being associated with
535 woodland edges and damages caused to fences and tractors (Blanco et al. 2018). Main reasons for
536 maintaining woodlands include firewood production for their own farm, or for sale to owners of
537 secondary residences (Eliakyme and Cabanettes 2013). Woodlands deliver other ES, including
538 construction timber, mushroom and hunting activities (Sourdril et al. 2012, Blanco et al. 2018). The
539 observed shift from family-based to market-oriented woodland management contributes to the
540 homogenization of forest management practices in this region (Blanco et al. 2018). The central social
541 network of farmers is composed by land-owners who rent their lands to farmers; agricultural advisers
542 from local cooperatives (associated to conventional food systems) and public departments, who

543 respectively guide farmers on the use of chemical inputs and of agricultural practices limiting their
544 negative environmental impacts; river technicians who analyse the water quality of rivers and
545 authorize farmers to irrigate. Other stakeholders with indirect or less frequent interactions with
546 farmers include mayors who are responsible for the development of Local Urban Planning and
547 infrastructures like roads and interact with public county level institutions; naturalists who aim to
548 preserve local biodiversity; and finally hunters who use several landscape elements for their activities
549 and aim to preserve them (unpublished data).

550

551 **Formal and informal institutions and consequences on E(D)S production** - While the strong
552 promotion of farm specialisation by the European Common Agricultural Policy has marginalised mixed
553 crop-livestock farms in Europe, our study of farm historical trajectories revealed that mixed crop-
554 livestock farming has been maintained in the Vallées et Coteaux de Gascogne region (Choisis et al.
555 2012). Anthropological surveys revealed that this trend can partially be explained by a local tradition
556 of maintaining the house-centred self-sufficient mixed crop-livestock system and hard environmental
557 conditions (Sourdril et al. 2004). However, under the influence of market globalisation and decreasing
558 workforce availability, half of the farms of the region have become more specialised, either in cash
559 crops or cattle production, and have relied on drainage, irrigation, field size enhancement and
560 increased use of chemical inputs. The comparison of surveys on practices and GIS work has shown
561 that these trends have considerably impacted the landscape structure (Figure 2A, Ryschawy et al.
562 2013). Surveys conducted with mayors, public county level agencies and river technicians have shown
563 that they identify water pollution and mudslides as major EDS, associated with high public
564 environmental, health and economic costs. They advocate for changes in local agricultural practices,
565 with the (re)introduction of agroecological infrastructures such as hedges and grassy strips, crop
566 diversification, the use of crop covers and a reduction in chemical input use. Whereas many farmers
567 have changed their practices and even created local farmers groups to support the agroecological
568 transition of their farms, these initiatives will not result in significant ecological benefits unless they
569 are coordinated at the landscape level (unpublished data).

570

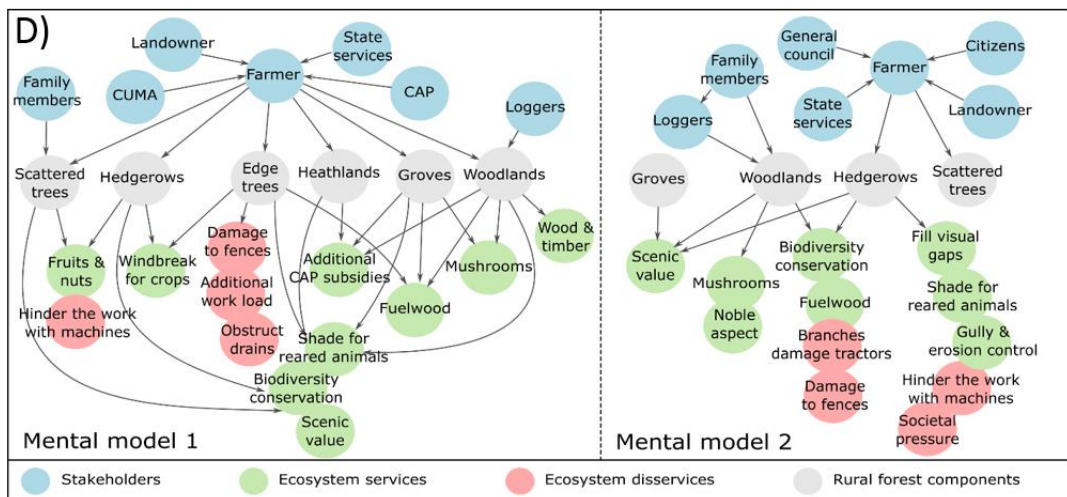
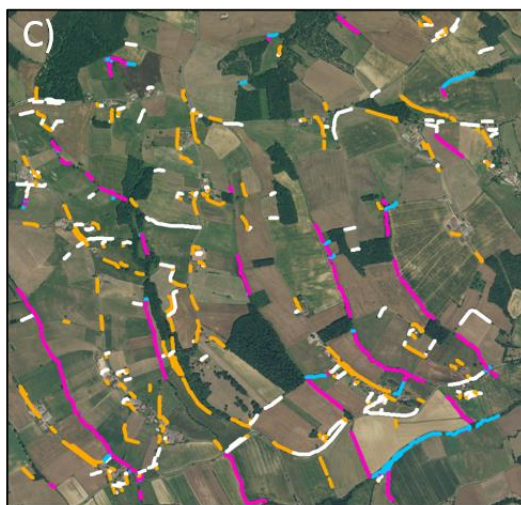
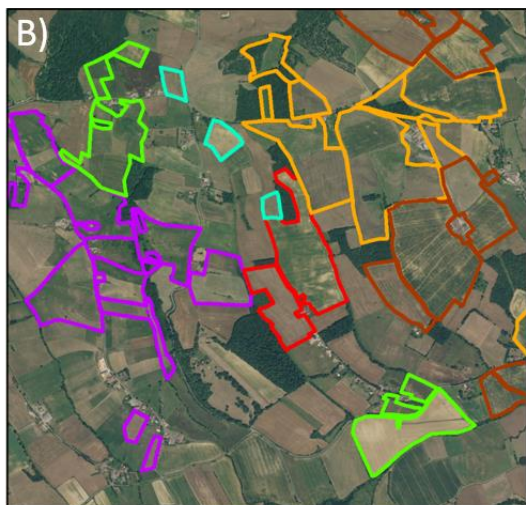
571 **Ecological actors and networks using the landscapes and the associated ES** – Several
572 ecological studies conducted in our study area have confirmed that cultivated and non-cultivated
573 ecosystems are ecologically connected. For instance, we showed that spill-over of many beneficial
574 insect species occur from semi-natural habitats, where they notably overwinter, to crop fields where
575 they provide ES such as biological control and pollination (Sarhou et al. 2005, Roume et al. 2011,
576 Alignier et al. 2014, Raymond et al. 2014). We also showed that, while management practices

577 occurring in semi-natural habitats (e.g. woodland edge maintenance) directly impact associated
578 beneficial insect communities, their effects depends on the surrounding landscape (e.g. the
579 proportion of grasslands, Andrieu et al. 2017). Moreover, we have shown that local practices within
580 fields are not sufficient to explain within-field biodiversity and associated ES, which strongly depends
581 on landscape-level practices and landscape structure (Carrié et al. 2017). Surveys conducted over
582 several years have highlighted that crop fields appear also interconnected by insect flows across years
583 by pest and beneficial insect flows (Raymond et al. 2014, Marrec et al. 2017). Using individual
584 movement tracking of ungulates, we showed that ungulate contribute to the connectivity of nutrient
585 cycles between woodlots, hedgerows and fertilized cropland in this region (Morellet et al. 2011, Abbas
586 et al. 2012). This data confirms that woodlot structure strongly influences the local presence of
587 ungulates but also revealed that woodlots complement each other at the landscape level across
588 seasons (Morellet et al. 2011). Finally, studies conducted on pest-predator networks have confirmed
589 that landscape-level processes interact with regional-level processes and jointly explain the supply of
590 biological control (Andrade et al. 2015).

591

592 **Multiple interdependencies among ES beneficiaries and ES co-producers; consequences for**
593 **operationalizing ES in decision-making** - Farmers in the Vallées et Coteaux de Gascogne region appear
594 strongly interdependent for the production of multiple ES, including food and production, pollination,
595 biological control or hunting activities. Their management decisions in terms of agricultural practices
596 or woodlot management directly influence biodiversity and ES levels within each ecosystem.
597 Moreover, spatial interactions between ecosystems as well as temporal interactions across seasons
598 and years also influence biodiversity and ES levels at the landscape level. This is particularly true for
599 insect or mammal pest outbreaks, water pollution and mudslides. Surveys conducted with farmers
600 highlighting their strong acknowledgement of ethical and social biodiversity values suggest that soft
601 policy tools could foster biodiversity-sensitive farming methods (Kelemen et al. 2013). Moreover, work
602 conducted on a study area located nearby suggests that collaborations among ES co-producers have
603 the potential to increase ES supply levels (Salliou and Barnaud 2017; Salliou et al. 2017). Actions of ES
604 co-producers also need to take into account ES demand of other stakeholders. Several studies
605 conducted on farmers mental models in this area (Vuillot et al. 2016, Blanco et al. 2018) suggest that
606 increasing stakeholders' awareness of their multiple social and ecological interdependencies would
607 represent a first step in supporting effective collective action towards agroecological transitions
608 (Figure 2D). All this interdisciplinary work conducted in the same study area has greatly contributed
609 to the development of a methodological approach to foster concerted management of multiple ES at
610 the landscape level in the context of participatory action research (Barnaud et al. 2018). A dynamic

611 E(D)S mapping in the Vallées et Coteaux de Gascogne region based on remote sensing and ecological
 612 assessments is also underway. Such mapping should contribute to inform decisions both across space
 613 and time, which is essential to develop a sustainable governance of multiple ES in agricultural
 614 landscapes.
 615



616

617 **Figure 2.** Pictures and figures illustrating our works conducted in the French case study Vallées et
618 Coteaux de Gascogne, part of the Long Term Ecological Research Network. A) Agricultural
619 intensification between 1953 (BD ORTHO® Historique, IGN) and 2016 (BD ORTHO®, IGN) affect
620 biodiversity and E(D)S through landscape structure simplification (eg. loss of semi-natural habitats
621 excepted woodlots, increase in field and farm size) and changes in farming practices (like a reduction
622 of crop diversity and an increase in the use of fertilizers and pesticides). B) Spatial configuration of
623 agricultural parcels from six farms (one color per farm, issued from RPG_ANONYME_ASP_2014)
624 showing how they are intermingled. C) Spatial configuration of two ES supported by hedgerows in
625 agricultural landscapes: water flow regulation, *ie* riparian hedgerows, and windbreak, *ie* hedgerows
626 with an aspect facing prevailing wind (in blue hedgerows with only water flow regulation potential, in
627 orange those acting only as windbreaks, in pink those with both water and wind regulation potential,
628 in white those that do not offer these ES). D) Representation of the variability of social-ecological
629 perceptions by actors (here two farmers) regarding the management of woodlot components (grey
630 circles) by stakeholders (blue circles) and associated ecosystem services (green circles) and disservices
631 (pink circles) (from Blanco et al. (2018)).

632

633

634 **Conclusion**

635

636 We developed an original CF based on a review of the literature and our own experience on the ground
637 through past or ongoing projects conducted in our research team. We believe that this CF represents
638 a valuable step to operationalize an integrative ES research for multiple ES governance in agricultural
639 social-ecological systems. Working at the landscape level facilitates inter-disciplinary approaches, as
640 already highlighted by several authors on multiple ES research in agroecosystems (Wu 2013,
641 Tancoigne et al. 2014, Mastrangelo et al. 2014). Although it is a strength, it is also a challenge because
642 different disciplines often involves different methods, scales and timeframes. Although it may appeal
643 primarily to the scientific community, we hope this CF will also facilitate dialogue between scientists
644 and a large spectrum of stakeholders, including farmers, land managers, agricultural educators,
645 environmental agencies and policy makers.

646 Altogether we are facing two main challenges regarding the assessment of sustainability of agricultural
647 landscapes: long time frames and actual experimental landscapes (Hamilton et al. 2015, Therond et
648 al. 2017). Indeed, research on ES in agricultural landscapes has so far been conducted in landscapes
649 designed over many decades with the aim to optimize conventional agriculture. Yet little is known
650 about the overall potentialities of multi-ES supply and crop production in agroecological landscapes.
651 Then as Landis (2016), we highlight the critical need to actually test design concepts at large spatial
652 and temporal scales.

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