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# Place-based social-ecological research is crucial for designing collective management of ecosystem services

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ABSTRACT

Agricultural intensification tends to maximize provisioning services at the expense of regulating, cultural and supporting ecosystem services (ES). Enhancing agroecosystem sustainability requires both individual and collective solutions, but these are particularly difficult to design and implement since knowledge is lacking and ES may be considered either as private, common or public goods. This study focuses on the role that research can play in such complex design processes. It draws on the reflexive analysis of a place-based and long-term research programme conducted in a Long-Term Social-Ecological Research (LTSER) infrastructure, the Zone Atelier Plaine & Val de Sèvre (western France). In this programme, researchers explored several pathways of collaboration with local stakeholders to both produce knowledge and design solutions for sustainable ES management. Four major steps in the research programme are highlighted: (i) a centralized landscape management strategy to reconcile agricultural production and biodiversity; (ii) a participatory design approach to design sustainable agroecosystems; (iii) the implementation of social-ecological experiments on farms to reduce the use of chemical inputs; and (iv) a multifaceted intervention research project to involve a diversity of stakeholders in designing sustainable agrifood systems. For each of these steps, we describe the targeted issues, the ES at stake, the scientific concepts, theories and protocols used, and the design processes and types of interactions developed with stakeholders. We draw lessons from each step, underlining the achievements and difficulties. The paper concludes with insights on the role that researchers can play to foster the collective design of a social-ecological system delivering multiple ES.

## 1. Introduction

The notion of ecosystem services (ES), broadly defined as "the benefits that humans can derive from ecosystems" (Millenium Ecosystem Assessment, 2005), emphasizes interdependencies between humans and ecosystems, and underpins the concept of social-ecological system (Bretagnolle et al., 2019; Folke et al., 2005; Ostrom, 2009). Although the ES approach has gained momentum at both the scientific and the institutional level over the past two decades, ES governance has been mainly thought of in terms of policy and market instruments, such as certification and labels, payments for ecosystem services, ecological compensation mechanisms, subsidies, taxes or agri-environmental schemes. This has been criticized in various respects, for resulting potentially in scale mismatches between ES management and ecological processes (Cumming et al., 2006), for being normative and overlooking social-ecological complexity (Norgaard, 2010), for the fact that focusing on a limited number of ES may have counterproductive effects (Kronenberg and Hubacek, 2016), and for being based on expert views rather than local stakeholders (Daily and Matson, 2008, Spangenberg et al., 2015), thus neglecting the various types of knowledge that could help address social-ecological system complexity.

Collective action for ES management could be a promising alternative pathway to overcome the pitfalls resulting from policy and market approaches (Stallman, 2011, Muradian, 2013), because cooperation can help resolve trade-offs between ES resulting in win-wins, or allow for arrangements between ES producers and beneficiaries (Barnaud et al., 2018). Yet, scholars point that setting up collective action in ES management is challenging because of high transaction costs (Ostrom et al.,

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1994), power asymmetries and conflicts of interest (Pahl-Wostl et al., 2007), or uncertainty and lack of knowledge (Barnaud et al., 2018). To address these challenges, various pathways are proposed in the literature, such as steps for the design and implementation of policies that will encourage collaboration and coordinated actions (Prager et al., 2012), increasing people's awareness of their mutual interdependencies, thereby fostering collective action (Barnaud et al., 2018), or tools to build a shared understanding of the issues at stake (Lopes and Videira, 2015).

Yet most of the literature on ES management considers ecosystems as givens or as stocks to preserve, and supposes that the knowledge to do so already exists. Although some scholars recognize that ES are "social constructs", i.e. subjective perceptions socially situated and constructed (Spangenberg et al., 2015, Barnaud et al., 2018), decision-makers and ES managers are generally assumed to have the knowledge for targeting the ES that will ensure ecosystem sustainability, and/or for developing the management practices to implement. This is however highly questionable because the ecological processes and functions that underpin ES are partly unknown, the potential advantages and values attributed to these services are not easy to assess, the potential ES are not necessarily all known, and the stakeholders in charge of managing them are numerous, diverse, and often poorly coordinated (Ainscough et al., 2018, Barnaud et al., 2018). Similar criticism may be levelled at approaches in governance of the commons (Berthet et al., 2016): in Ostrom's (1990) framework of common-pool resources, resources are assumed to be givens, communities are generally delineated, and best practices for resource management are considered as identifiable through trial and error. Both ES-based and commons-based approaches tend to neglect the design work underlying ecosystem and ES management.

In this paper, we argue that ES are not only commons to manage, but also commons to design. Such a design approach makes it possible to overcome some pitfalls. First, considering the list of ES to manage as open provides leeway for the exploration of other, potential or even new ES. Second, involving a diversity of stakeholders in the collective exploration of the ES at stake and of management strategies may facilitate the take up of ES policy approaches. Lastly, as knowledge is not a priori considered as acquired and shared, the importance of supporting collective learning and collective design processes is highlighted. We explore the theoretical aspects of this design approach and navigate between theory and practice, using a longitudinal study of a social-ecological system where biodiversity, agriculture and Human-Nature relationships are the core of the research project. Our interest in building a design-oriented collective action for ES management raises the question of collaboration between researchers, policy makers and local stakeholders. We use the longitudinal empirical case to analyse not only how research may support the collective design and management of ES, but also the challenges this raises and the trajectory that researchers have followed, from conventional approaches based on deductive hypothesis testing and knowledge transfer, to transdisciplinary approaches and knowledge co-production (i.e. post-normal science (Funtowicz and Ravetz, 1993)). As all co-authors have been heavily involved in this research programme (though to varying degrees), this paper is mainly reflexive.

## 2. Theoretical background

This paper highlights the collective design effort necessary to target and reach desirable social-ecological systems and the ES they produce. Such design encompasses the identification of previously unknown ecological processes or functions, the exploration of potentially new values of services (e.g. exploration of new uses), or of new practices and new organizations enabling the generation of previously unknown services. Berthet et al. (2016; 2019) proposed a conceptual framework for the collective design of an agroecosystem, drawing upon Georgescu-Roegen's "fund-flow" model (1996) and recent design theories (Hatchuel and Weil, 2009). The first step consists in qualifying the object of design. Georgescu-Roegen criticized the classical "stock-flow" economic model for failing to adequately account for production processes, and introduced the notion of "funds" as the factors of production for flows, stressing the importance of care for funds. Funds may be applied to agroecosystems as a notion that encompasses both ecological and social processes involved in the provision of ES. Berthet et al. (2016) defined "ecological funds" as the production factors of ecological flows (such as water, nutrients, species), i.e. the configuration of biophysical entities enabling ecosystems to self-regulate and to provide a range of ecological flows (expected or not). Qualifying an ecological fund requires the identification of ecological processes to manage, as well as the underlying ecosystem properties to enable these processes.

The second step of the conceptual framework is to use the ecological fund to initiate a collective design process. Georgescu-Roegen posits that, unlike flows, which are created, transformed or destroyed during a production process, funds remain constant. His model however does not account for innovation processes that may modify the funds. Here, drawing on design theories, we do not consider ecological funds as givens but rather as open-ended. Although ecological funds have some known properties that need to be maintained, the ways in which these properties can be ensured are multiple. Moreover, ecological funds may also have unknown properties and values to explore. An ecological fund should not be considered as a common *good*, whose properties are known, but as a common *unknown* — a partly unknown object that can be the subject of collective design (Le Masson and Weil, 2014). Identifying a common unknown requires a diversity of stakeholders to be involved in the creative resolution of conflicts and "lock-ins". It may help to avoid stakeholders with diverging interests negotiating over a zero-sum outcome, by instead collaboratively exploring what a collectively desirable future might look like, and thus by improving or even transforming the outcome. Yet such a process involves two difficulties. First, qualifying an ecological fund supposes a thorough understanding of agroecosystem functioning. Second, stakeholders' potentially conflicting interests may complicate the definition of a "collectively desirable" agroecosystem. While the proposed design process places ecology at the forefront of agroecosystem design, it organizes interactions with other disciplines (such as agronomy and hydrology), as well as with non-scientific knowledge systems (see Berthet et al., 2019) for three illustrative examples). Delimiting the scope of what can be managed in an agroecosystem makes it possible to identify who should be involved in the design process. In this perspective, instead of being considered as givens, ES are considered as open-ended, to allow for a collective design process. highlighting such ES design perspective points to the critical issue of knowledge: what knowledge do stakeholders need to characterize desirable ES and ensure their sustainable delivery? How can stakeholders share knowledge so that the collective design of ES and ES management are possible?

## 3. The case study

We focus on an original research infrastructure, the Long-Term Social-Ecological Research (LTSER) programme at the "Zone Atelier Plaine & Val de Sèvre" (ZA PVS), a study site located in western France ((Bretagnolle et al., 2018); see Fig. 1 and Box 1). The social-ecological system concerned is an agroecosystem producing a diversity of resources (cereals, water, habitats, biodiversity and so on), for which different stakeholders have diverse interests. We first present the ways in which the research programmes have progressively been developed in


**Fig. 1.** The LTSER Plaine & Val de Sèvre. a) Location of the LTSER Zone Atelier Plaine & Val de Sèvre and delimitation of the Natura 2000 site; b) Landscape views (S. Gaba photo credits); c) A male Little Bustard, one of the flagship species in the area (V. Bretagnolle photo credits).

the ZA PVS over the last 25 years to produce knowledge on the agroecosystem functioning and dynamics, as a first mandatory stage. Without being exhaustive, we highlight the multiple expansions of this generative research programme (Hatchuel et al., 2011) that is simultaneously related to scientific disciplines, protocols, the objects and ES taken into account, interactions with local stakeholders, and governance. We then analyse how, in relation to knowledge development and the intention to turn knowledge into action, the researchers contributed to design solutions for ES management, as our second step. We show how such design processes evolved, with regard to not only the objects of design but also the stakeholders involved and the nature of interactions between them. Lastly, we draw some conclusions on the role that research may play in contributing to setting up adaptive governance for sustainable ES management.

Box 1: **The Long-Term Social-Ecological Research (LTSER) site "Zone Atelier Plaine & Val de Sèvre" (ZA PVS)** is located south of Niort, a city in the Nouvelle-Aquitaine Region, in western France (see Fig. 1). This large-scale and long-term research infrastructure is managed by the CEBC (Centre d'Etudes Biologiques de Chizé), an ecology research lab. The ZA PVS is a large (ca. 435 km$^2$) rural territory encompassing about 400 farms: 15 farms practice conservation agriculture, 45 are organically farmed, and 340 practice conventional agriculture; among these 340 farms, about 150–180 have subscribed to Agro-Environmental Schemes (AES). There are 24 municipalities inside the ZA PVS for a total human population of 29,000 inhabitants (human population density of c.60/km$^2$). Less than 10% of the area is urbanized, and fragments of deciduous forest cover less than 3% of the area. The ZA PVS is an intensive arable plain with mainly winter cereals (mainly wheat), but also maize, sunflower, oilseed rape, and peas. Grasslands, including both permanent grasslands and temporary hay (such as alfalfa), cover about 13.5%. This area is representative of agricultural intensification and specialization that took place in many parts of France after 1950. It has progressively experienced a shift from mixed farming systems (i.e. livestock combined with crop production) towards intensive cereal crop farming on the one hand and industrial goat farming on the other. This shift led to an increase in the use of chemical inputs and a simplification of landscapes, characterized by the decrease of hedge density and a ten-fold increase in the average size of cultivated fields since the 1960s. At the same time, the area of cereals has increased by 20% in the last 25 years, while the area of semi-perennial forage crops has decreased by approximately 75% in the last 75 years (Bretagnolle et al., 2011a). These changes have led to major environmental degradation (Geiger et al., 2010), threatening many commons (water, biodiversity, soil fertility….) for private interests. To reverse trends in the many threatened and flagship bird species, half of the study area has been designated as a NATURA 2000 site since 2003 (the entire ZA PVS is also within a protected water catchment). These environmental challenges, combined with the agricultural trajectory, make the location of the LTSER very relevant to understand SES dynamics due to agricultural modernization. The research team in charge of the ZA PVS is composed mainly of ecologists and agroecologists who have built partnerships with social and agricultural scientists, based on the needs of each individual project. The ZA PVS became an observatory of the agroecosystem: land cover has been monitored yearly at the field scale since 1994 (~19,000 fields in 1996, ~13,000 in 2015). Since 1994, biodiversity surveys have been carried out every year, including the monitoring of birds, small mammals, arthropods, plants and soil organisms (Bretagnolle et al., 2018). Since 2005, socio-economic data have also been collected.

## 4. First step: From flagship species conservation to landscape multifunctionality: A centralized implementation strategy

### *4.1. Expanding the research agenda from bird conservation, to identification of key ecological trophic variables*

Between 1994 and 1997, the research project was targeting flagship bird species, such as the Little Bustard *(Tetrax tetrax)* or various raptor species. The former was found to be in alarming decline in the area: 90% of its population had disappeared in 20 years (Bretagnolle et al., 2011b). The aim was then to understand the population dynamics of these various endangered farmland birds, and the research project consisted mainly in a conservation biology project, with conservation actions aiming at protecting nests in farmers' fields. However, it soon became obvious that these top predator birds were directly affected by the variation of abundance of species at lower trophic levels, i.e. their prey (Furness et al., 1993). Thus, the research project shifted gradually to studying the entire trophic network, and aimed to better understand these birds' ecology, which, at that time, was almost unknown (Bretagnolle et al., 2011b). Studies were conducted to evaluate the carrying capacity of the local agroecosystem, i.e. its ability to support the Little Bustard population by providing nesting sites and food resources. This led to the monitoring of species diversity and abundance in the trophic network, land cover and later agricultural practices. The ZA-PVS became an observatory of the agroecosystem, where ecological as well as socioeconomic data have been continuously collected since then (see Box 1). It was eventually shown that the decline was mainly due to reproduction failure, because of food shortages during early chick-rearing, when chicks rely solely on insects (Inchausti and Bretagnolle, 2005). Insect populations had indeed radically declined because of the intensive use of herbicides and insecticides in the area, as well as intensive ploughing that destroyed eggs (Badenhausser et al., 2009).

Integrating the prey dynamic into the research agenda required a shift from an implicitly simplified representation of the agroecosystem to a more complex one that accounts for the spatio-temporal heterogeneity of the landscape mosaic (Fig. 2), including semi-natural areas (high-quality habitats) and annual cropped areas (low-quality habitats). In landscapes dominated by intensive cereal cropping, multi-annual forage crops such as meadows and mown grasslands can be considered as high-quality habitats (Bretagnolle et al., 2019), since these "perennial habitats" remain in place for at least 3–4 years. Their management thus contrasts with that of annual crops, which are tilled, sowed, cut and harvested, involving mechanical work, pesticides and fertilizer applications. As a result, perennial crops, similarly to field margins and other non-crop habitats, can act as refuge for wildlife within the agricultural mosaic. To account for this spatial heterogeneity, metapopulation theory (Hanski, 1999) was used as a framework (Berthet et al., 2012). In order to offset the decline of insect populations, a solution identified was to recreate a high-quality landscape matrix, where insect migration rates could balance local extinctions. Such a representation of the agro-ecosystem made it possible to extend the research focus on a single type of ecosystem service, species conservation (a cultural service) to a second type of ecosystem service, food production (a provisioning service). Both services are generally considered as antagonistic hence, there was a need to explore the trade-off among them in a creative way (see Table 1). Based on various empirical observations and grasshopper literature (the main prey of the Little bustard), a target of 15% of grassland areas in the landscape was set, with grassland field size preferably medium (3–6 ha) and randomly dispersed with a minimum distance of less than 1 km between neighbouring plots (Berthet et al., 2012). The "distance between grasslands" was identified as a key variable for the design of a landscape mosaic maintaining grasshopper populations and more generally agro-ecosystem biodiversity (Bretagnolle et al., 2019). The research programme suggests that "a landscape mosaic comprising ca15% grassland areas" may be considered as an ecological fund as presented previously: indeed, designing such a landscape mosaic may ensure ecological regeneration in this social-ecological system.

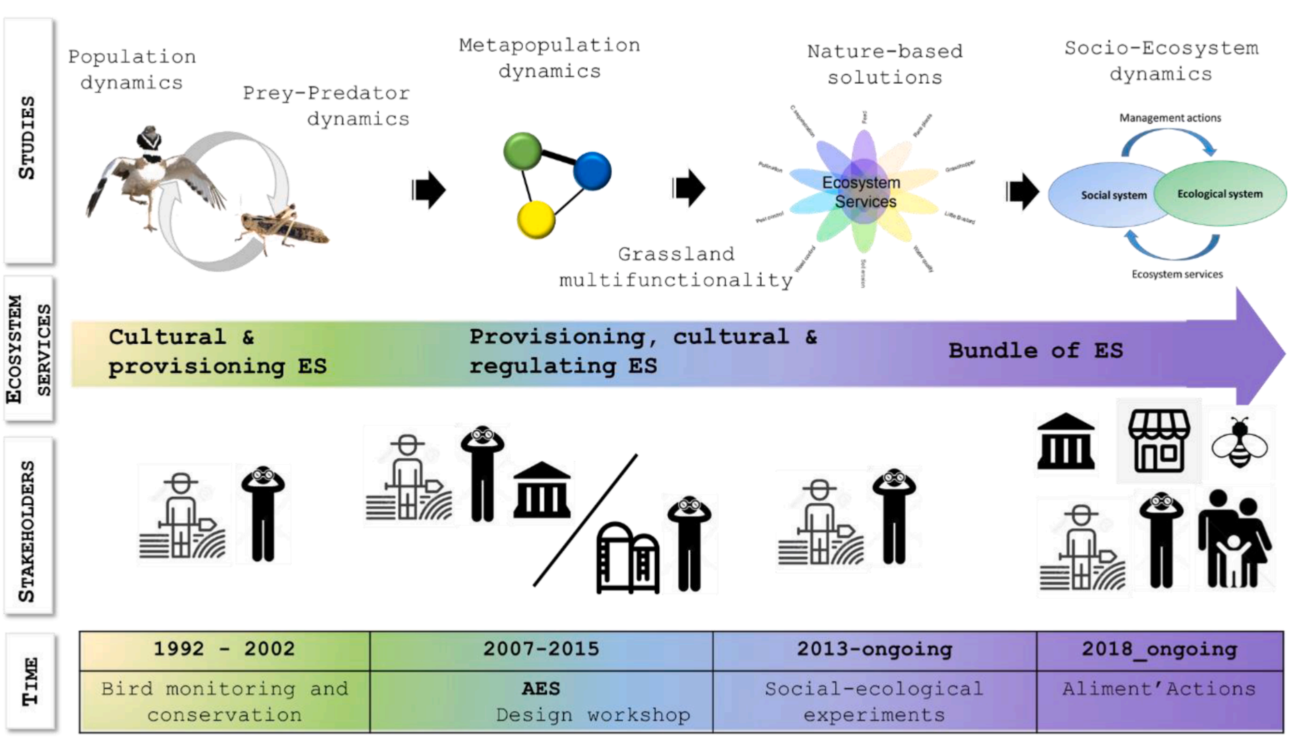


**Fig. 2.** Evolution of the research agenda related to grasslands in the ZA PVS.

### 4.2. *Exploring a first implementation pathway, through centralized agroecosystem design and individual incentives*

Managing the distribution of grasslands across the landscape mosaic requires coordination at a higher level than farms, i.e. from a logic of crop rotation within a farm to a coordinated logic across farms (Fig. 2). The first pathway that was explored was a centralized design and management strategy. During the course of research and conservation projects, experimental contracts with farmers had been developed to reconcile agricultural production and biodiversity preservation. These experiments required strong interactions between researchers and farmers, which were mainly bilateral (Fig. 2). One such pathway was delayed grassland mowing, and another was the conversion of arable crops into grasslands (Bretagnolle et al., 2011a).

These experiments informed the design of local agri-environmental schemes (AES), i.e. contracts with farmers funded through the CAP (EU Common Agricultural Policy) and intended to promote the implementation of environmentally friendly agricultural practices in return for an annual subsidy to offset the costs involved and possible income reductions. Such AES could be implemented as the study site had been designated as a NATURA 2000 Special Protection Area (SPA), at the request of the CEBC scientists and NGOs. Local, national then European authorities validated the scheme, and the CEBC became the AES operator in this SPA. Such an approach relied on collaboration between scientists, local farmers and legal representatives of government authorities (Fig. 2). As the scientists were simultaneously the designers of these schemes and the facilitators for their implementation, they met with the farmers and negotiated with them the implementation of grasslands at targeted locations considered to be strategic from an ecological point of view. Hence, scientists eventually became landscape matrix designers as they were instrumental in reintroducing grasslands, using their GIS database, in allowing targeted schemes to be developed with regard to Little Bustard distribution, and also in monitoring their effectiveness (e.g. Caro et al., 2016). This strategy had positive impacts as areas of alfalfa increased by 50% in seven years in the eligible zone, reaching 2,200 ha in 2012 (Bretagnolle et al., 2011a). The improvement of habitat, together with a programme of Little Bustard reintroduction (with captive breeding and population reinforcement through releases of captive reared chicks), led to a significant increase in its population (Bretagnolle et al., 2019, 2011b).

Such a centralized management strategy however presented various shortcomings. As AES are very costly (compensations to farmers can reach €500/ha/year), their spatial scope is limited. They are also limited in time (5 years), and cannot be extended outside the SPA delineation (with a buffer of 2 km allowed in this precise case). Above all, the contribution of farmers to defining the stakes, producing knowledge or designing management measures and policy instruments was very limited in this case. The scientists, also AES operators, would determine the best location for alfalfa plots according to their knowledge of bird population dynamics, and farmers then only had the option of accepting or refusing the proposed contracts. As alfalfa production is not particularly profitable for farmers compared to cereal and oilseed crops, the success of the initiative was highly contingent on public spending and cereal prices. Since 2013–2014 (and the CAP reform), areas under AES have sharply declined, returning to the 2005 levels, with the Little Bustard population following the same trend (Bretagnolle et al., 2019). Here, the researchers did not consider the ecological fund i.e. “the landscape mosaic comprising ca15% grassland areas” as a “common unknown”, as the departure point of a participatory design process. Rather it was considered as a target for which solution pathways have to be found. Other attempts aimed at restoring grassland areas have therefore been sought, as an alternative to this centralized strategy, to government-funded economic compensation and to individual economic incentives for farmers.

## 5. Second step: Highlighting the role of grassland in ES delivery and initiating the collective design of an agroecosystem delivering multiple ES.

### 5.1. *Highlighting the role of grasslands in intensive cropping systems, for the provision of multiple ecosystem services*

In the 2000s, the ZA PVS researchers started exploring further values that could be attributed to grasslands. Initially, reintroducing grasslands in the arable plain was intended to reconcile two antagonistic ecosystem services: flagship species conservation, and agricultural production. Scientific knowledge (both internal and external to the ZA PVS) showed that increasing grassland areas in the landscape and managing their location could be a solution not only for reconciling both ecosystem services, but also for other ecosystem services (see Table 1). Grasslands were shown to benefit not only biodiversity, but a whole set of ecosystem services (pollination, preservation of water quality, weed management, and carbon sequestration; Gaba et al., 2020). The multiple ES delivered by grasslands then became the subject of several research programmes in the ZA PVS (Fig. 2), shifting from flagship species conservation aims to the quest for solutions to halt biodiversity loss and allow the delivery of a bundle of ecosystem services in this agroecosystem.

This gradual shift in the research programme fostered interactions with an ever-wider range of stakeholders. In the 1990′s, when research focused primarily on flagship species, scientists interacted only with naturalists and environmental NGOs, who designed the first agri-environmental scheme contracts targeting bird conservation (which became AES). This led to contacts with farmers, though such collaboration was initially quite marginal. By developing research within the field of spatial ecology on the role of grasslands in maintaining birds’ trophic webs, interactions with farmers steadily increased, especially because scientists became AES operators on the site. About 200 farms were engaged in AES schemes between 2004 and 2017, which allowed for large-scale experiments to be designed, aimed at exploring the effect of grasslands (and other semi-natural elements) on biodiversity and ES. Further research collaboration with agronomists, weeds scientists or entomologists led to investigations of grasslands’ multifunctionality, i.e. their ability to deliver a wide range of ecosystem services, especially when maintained in an intensive arable plain (Gaba et al., 2020). At the same time, research projects were also developed with beekeepers, for example to promote collective discussions with farmers and citizens on the design of multifunctional agricultural landscapes (see (Bretagnolle and Gaba, 2015) for a conceptual framework linking farmers and beekeepers).

### 5.2. *Initiating a landscape-scale co-design process involving ecologists and a farmer cooperative*

Among the possible semi-perennial crops or “grasslands” targeted, alfalfa was prioritized for ecological, agronomic and economic reasons (Bretagnolle et al., 2019). In 2010, a local farmers’ cooperative contacted the research team to build a project fostering agroecology at a territorial scale. They combined their efforts to launch a collaborative initiative, in which both seemed to agree on the importance of generating new momentum for alfalfa production in the region. Their idea was to set up a local alfalfa supply chain, with cereal farmers growing alfalfa and selling it to local cattle or goat breeders. They aimed to elaborate a business model that was economically viable and not reliant on individual economic incentives, seeking instead to foster self-organization among stakeholders pursuing a common purpose (Berthet et al., 2016). The project actually drew on a prototypal project initiated in 2005, in which scientists from various disciplines (ecologists, agronomists and economists) had set up a network of 24 farms, including cereal growers and breeders, whose technical choices were monitored over 3 years. The project suggested that reintroducing alfalfa cultivation in cereal rotations would be feasible if a local alfalfa market was established between cereal farmers and goat breeders. The former would diversify their crop succession and the latter would have better access to food at a lower cost than the current dehydrated alfalfa purchased on a national or even European market. This prototypal project served to build scenarios and economic simulations of the reintroduction of alfalfa, to design a market instrument, and to transfer this innovation to farmers. Yet the *ad hoc* farmer network set up was dissolved at the end of the project, no local alfalfa supply chain was created, and the surface areas of alfalfa cultivation did not increase. The fact that the network was not set up on the initiative of farmers, along with the project's temporal limitation, hindered trust building among farmers.

The new collaborative project between the farmers' cooperative and the research lab paved the way for new interactions between ZA PVS ecologists and local stakeholders. A management scientist involved in the project pointed out that despite the apparent synergies between the stakeholders involved in this initiative, a major difficulty lays in the fact that farmers, citizens, naturalists and scientists did not share common goals with regard to alfalfa production. Farmers saw alfalfa as a fodder crop whose production was to be maximized at the field scale; naturalists saw it as an ecological habitat that should be minimally disturbed, and with a high value if managed at the landscape scale; and citizens saw only meadows for flower collecting and recreational activities. The project leaders (two scientists and two cooperative leaders) thus decided to initiate a collective design process that called into question the very identity of alfalfa by collectively exploring its potential to act as an agroecological infrastructure while also acknowledging its indeterminate properties. A collective design process was conducted combining a workshop with further meetings (Berthet et al., 2014). The workshop, held in May 2011, was attended by 30 participants: cooperative board members, technicians and member farmers, scientists in the fields of ecology and agronomy, local authorities' representatives, and extension services.

The knowledge gathered during this workshop extended the list of properties of alfalfa by widening its range of agronomic and ecological functions, and by exploring the feasibility of new design / production parameters. Knowledge gaps were also identified, for example in the relationship between production parameters and ES delivered by alfalfa. It also highlighted intermediate pathways between the intensive management of alfalfa, which was seen as detrimental to biodiversity, and more extensive management such as in AES, seen as detrimental to farmers because of lower production. For example, mowing the alfalfa during appropriate periods was identified as relevant for weed control, thereby limiting herbicide use, and for protecting pollinating insects, while also maintaining acceptable levels of production. Importantly, this exploration revealed the importance of collective management parameters, including the coordination of mowing dates to improve not only pollination but also fodder production for goats. In the former case, mowing alfalfa before flowering is better for forage quality, but unfavourable to bees because it decreased the amount of floral resources especially during food deficit periods (Requier et al., 2015). The workshop participants sought leeway to overcome ES antagonisms: for example, for the second and third harvests of alfalfa, which take place in July and September respectively, waiting for flowering is less problematic than with the first harvest because alfalfa grows more slowly; moreover, it allows the plant to build up more reserves and therefore have a longer lifespan.

The scientists presented the results to all workshop participants, who explored various configurations of the agroecosystem in relation to alfalfa management and spatial distribution within the landscape. They did not agree *a priori* on the ecosystem services to maintain, but instead explored the potential ES delivered by different landscape configurations, for example, how staggering alfalfa harvest dates could enhance pollination, or how concentrating grasslands around drinking water catchments could improve water quality. This highlighted some neglected interdependences between agroecosystem stakeholders (as pointed out by Barnaud et al. (2018)), especially when considering the regulation functions of grasslands that most of them were not aware of. Interestingly, the participants explored various alfalfa production modalities that were not focused on trade-offs between fodder production and nature conservation, but rather on the identification of new ES or new ES values that could be collectively created. Since various spatial configurations of grasslands result in different ecological and productive properties of the ecosystem, the stakeholders need to collectively rank and select the ecosystem services to maintain, pointing out that the agroecosystem and the ES it delivers could become an object of collective design.

Following this, a research-action project funded by local authorities and steered by the cooperative and the ZA PVS was carried out between 2012 and 2014 to address the identified knowledge gaps. In parallel, an economic feasibility study was conducted with the support of public funding to facilitate the establishment of a local alfalfa supply chain. The cooperative then worked to set up the alfalfa supply chain, but by 2014 they had sowed only 150 ha of their initial target of 500 ha of alfalfa. The cooperative considered this scaling-back as resulting from a need to identify suitable markets, ways of dealing with climatic events likely to decrease yields, and technical solutions for achieving stable and standardized forage quality. They also did not want to impose field location constraints on farmers, despite the recommendations of scientists, for fear of dissuading farmers from participating. Additionally, the cooperative decided to avoid limiting the use of herbicides and to encourage the production of alfalfa for seed reproduction (a secured market), which requires chemical treatments. Within three years, due to internal tensions related to the strategy of the cooperative, the board completely changed and the project was eventually abandoned. Although a co-design process had been initiated, it was too limited (a single day design workshop) and the range of stakeholders involved was too narrow (as the participants were mainly cooperative members or employees). This reveals that increasing our understanding of ecosystem functioning is a key step in sustainable management of ecosystem services, but it is not sufficient. Even the active involvement of researchers (e.g. for the design of conservation protocols or AES schemes), the establishment of collaboration with policy or economic actors, or experimentation with farmers, cannot guarantee success. New solutions and new thinking to foster agroecological transition therefore remain to be explored, in particular to enable the contribution of a larger range of stakeholders in the collective design process of a social-ecological system delivering multiple ES.

## 6. Third step: co-building knowledge in agroecosystem functioning with farmers to foster agroecological transition at the field and farm scales

In response to a growing societal demand for innovative solutions to enhance agriculture sustainability, the French government launched in 2007 the Ecophyto Plan, with the aim of identifying, inventing and disseminating the best agricultural practices to reduce the use of pesticides. Pesticides effects on biodiversity and related ecosystem services are increasingly highlighted (Desneux et al., 2007, Gill et al., 2012, Gaba et al., 2016). In this context, the ZA PVS research team initiated a new type of experiments, social-ecological experiments (Gaba and Bretagnolle, 2020). First, these experiments were set up in real conditions (i.e., in farmers' fields, with and for farmers). The researchers asked volunteer farmers to reduce their use of nitrogen fertilizers and herbicides on small-scale plots located in their fields, all other practices remaining constant. The scientists performed several measurement with experimental and control plots, the control plots being the rest of the field in which farmers had a "business as usual" management. Surprisingly, the reduction in the use of herbicides and nitrogen fertilizers did not systematically lead to a significant decrease in crop yield (Catarino et al., 2019). Therefore, when margins were calculated (by subtracting operational costs -such as fertilization or weeding- to yield, multiplied

**Table 1**
Temporal dynamics of the research programme, and presentation of the ES taken into account, the design and the stakeholders targeted or integrated into the research.

| Time period | Object (or good) targeted by collective action | ES at stake | Initiators of the design process | Knowledge produced | Objects designed | Stakeholders involved in the design process | Instruments or approaches developed to involve stakeholders | Private, public or common goods |
|---|---|---|---|---|---|---|---|---|
| ~1992-2002 | Flagship species | **Cultural ES** (preserving threatened species) and **provisioning ES** (food production) | Ecologists (researchers) and naturalists | • Species population monitoring<br>• Bird ecology<br>• Ecology of preys<br>• Impacts of farming practices on the trophic web | • Solutions to protect birds (infra field scale)<br>• Farming practices that reconcile both ES (farm scale) | The design process is largely centralized, but researchers, naturalists and farmers are involved | Experimental contracts between the research team and farmers | Farmers do not consider flagship species as commons. |
| ~2000-2010 | Agroecosystem as the support of multiple ES | **Cultural ES** (preserving threatened species; scientific education); **provisioning ES** (food and fodder production); **regulating ES** (pollination, pest regulation, habitat, water purification and regulation, carbon sequestration, etc.) | Ecologists and policy-makers | Landscape design and impacts on biodiversity dynamics | • AES Landscape mosaic<br>• (landscape scale) | • Farmers<br>• Policy-makers<br>• Researchers from various disciplines | AES (public funding – contracts) | Grasslands are managed as both private and public goods providing multiple ES |
| 2010-2015 | | | Ecologists and a local cooperative | • Alfalfa farming practices and their impacts on ES<br>• New roles for a local farmer cooperative | Local alfalfa supply chain(landscape scale) | • Researchers from various disciplines<br>• Members of a local farmer cooperative | • Collective design workshop<br>• Local alfalfa market | The agroecosystem is presented as a common unknown, yet to a limited range of stakeholders |
| 2013's onward | Knowledge production on agroecology | **Provisioning ES** (food and fodder production); **Regulating ES** (pollination, pest regulation, habitat, water purification and regulation, carbon sequestration, etc.) | Ecologists and farmers | • Impacts of farming practices on the provision of various ES<br>• Role of biodiversity and ES for food production and farmers' incomes | Nature-based solutions(field and farm scale) | Ecologists, farmers, beekeepers | • Social-ecological experiments<br>• Bioeconomic models | Farmers, together with researchers, explore acceptable solutions at the field scale to maintain various ES for private interests; these strategies may also be beneficial to other stakeholders. |
| 2018 onward | Resilient agri-food system | **All potential ES** provisioned by an agri-food system | Researchers and social and solidarity economy actors | • Food system resilience factors and indicators<br>• Human-Nature relationships<br>• Solidarity within food systems | New forms of solidarity and collaboration between humans and between humans and non-humans | Local stakeholders: farmers, citizens, local authorities, researchers, facilitators, etc. | • Transdisciplinary research<br>• Local events to foster mutual knowledge and trust, facilitate dialog, and share expectations<br>• Collective design workshops | Diverse stakeholders are engaged in the exploration of common unknowns to generate new forms of collective action. |

by selling price), results showed that the most intensively managed plots had a lower gross margin compared to low inputs plots (Catarino et al., 2019). From the results of the two-year experiment conducted in 56 winter cereal fields, it was even possible to suggest an optimal combination of nitrogen inputs and herbicide treatments to optimize yields and gross margin, which, in this area, appeared to be 25–30% lower than current levels of both nitrogen and herbicide use.

Further experiments were conducted in rapeseed and sunflower, crops whose pollination is largely dependent on insects. The impact of insect pollination on these two mass-flowering crops yields was quantified using exclusion cages that allowed to investigate and differentiate the efficiency of the different pollination processes, namely wind-, self- and insect-pollination (honeybees and wild bees) (Perrot et al., 2018, Perrot et al., 2019). As experiments were set up in real farming conditions, researchers could also compare the respective contribution of insect pollination and agro-chemicals to yields and farmers' margins. In rapeseed, levels of nitrogen fertilization and pesticide use had little correlation with yield in contrast to phosphorus input. Most importantly, insect pollination increased yields by an average of 37.5% (or 1 ton/ha) when bee species diversity was multiplied 10 fold (Perrot et al., 2018). In sunflower, insect pollination increased yields by an average of 40% (about 0.7 t/ha) when honeybee abundance was increased 100 fold. The economic gain of insect pollination was estimated at, on average, 110€/ha overweighting the gain obtained with agrochemicals (Catarino et al., 2019), underlining the importance of this regulating service for agriculture. These studies further confirmed the importance of maintaining both domestic and wild bees, highlighting the need to maintain semi-natural habitats in agricultural areas as well as to reduce the use of insecticides and herbicides to avoid direct and indirect (through the decline of wild flora) bees mortality.

To date, more than 100 farmers have taken part in these social-ecological experiments. Initially, researchers approached farmers during either workshops or face-to-face meetings. This has been successful as the positive response rate of farmers was c.90% (constant over years). In 2018, some farmers directly contacted the researchers to be part of the research programme. Regardless of how they joined the programme, the experimental protocol set up in each field was discussed with the farmers, who adapted it according to their own management practices, to the pedoclimatic conditions of their fields, and to their own specific interests. The researchers' representations of farmers therefore moved from farmers being exogenous drivers of change in the ecological systems, to essential partners for exploring agroecological solutions.

## 7. Fourth step: Exploring pathways to involve an increasing range of stakeholders in the design of an agri-food system delivering multiple ES

In 2018, the ZA PVS researchers, together with actors of the Social and Solidarity Economy (SSE), launched a new research-action project, "Aliment'Actions" (Berthet et al., 2020), planned to be run over ten years or more. The project is based on the assumption that agroecological transition can be generalized and accelerated only if food systems are redesigned as a whole. Indeed, today, most food systems are globalized and structured around very large industrial firms. They tend to maximize food production services at the expense of other ecosystem services and healthy ecosystem functioning (Godfray et al., 2010). The quest for profit has favoured chemicals and technologies over natural regulation, and maximum sustained yields over balanced ecological cycles. In many situations, such food systems lead to the pauperization of farmers, the degradation of natural resources, and poor-quality food. Relocation of food systems can solve many of these problems (Rotz and Fraser, 2015) by supporting the development of more environmentally- and health-friendly production and consumption models that reduce waste throughout the food chain, promote local products and producers, and allow better sharing of costs and risks linked to agroecological transition.

While some factors enhancing food system resilience have been put forward in the literature (Stone and Rahimifard, 2018), food system trajectories towards resilience are still mostly unknown. The project Aliment'Actions recognizes the issue as complex and open-ended with

**Table 2**
Advantages, limits and lessons learned from the different steps of the research-action programme.

| Steps | Description | Advantages | Limits | Lessons learned |
|---|---|---|---|---|
| 1 | **From flagship species conservation to landscape multifunctionality: a centralized implementation strategy** | A lot of knowledge has been produced on agricultural impacts on biodiversity. Researchers are also the landscape managers with AES: the management strategy is thus efficiently elaborated. Public funding is important. | Farmers' only motivation to implement AES is monetary. Their involvement in the design of solutions is limited. A trade-off between two ES only is considered. | Thanks to ecological knowledge on threatened bird species, an innovative landscape management strategy has been proposed by the researchers. Such an approach seems efficient at first glance, but is not sustainable in the long term as it does not foster farmers' adhesion to the ES management project. |
| 2 | **Highlighting the role of grasslands in ES delivery and initiating the collective design of an agroecosystem delivering multiple ES** | The range of ES considered is extended and the multiple roles of grasslands are highlighted. Stakeholders of the agricultural sector are involved in the design process. | The design process resulted in a single workshop. The range of stakeholders involved in the collective design process is limited. This raises an issue of legitimacy and capacity to change the system. | A strategy to use ecological knowledge in a collective design process has been proposed. Such a process fosters social learning. Yet, the design process was too short and the range of actors involved too limited. The implementation of the system transformation has not been achieved. |
| 3 | **Co-building knowledge in agroecology with farmers and studying levers for agroecological transition at the field and farm scales** | A strong collaboration is set up between farmers and researchers. Nature-based solutions for sustainable food production are tested in real farming conditions. | The solutions are tested at the field or farm scale; collective action is not considered. | This experimental approach is ongoing. Promising results on the advantages of nature-based solutions for both biodiversity and farmers' income have been produced. It could be interesting to explore the impacts of these experimentations on collective action. |
| 4 | **Exploring pathways to involve an increasing range of stakeholders in the design of an agri-food system delivering multiple ES** | Various strategies to involve heterogeneous agri-food system stakeholders in a collective action/design process are tested and compared. Researchers collaborate with facilitators and develop a place-based research on the LTSER ZAPVS. A large range of ES and of stakeholders are taken into account and new ES are sought. | Such an endeavor is challenging and time-consuming, with many trials and errors. A project of this kind requires coordination between researchers from multiple disciplines and institutions, and with a large range of stakeholders. | The project is in its infancy and is planned for at least ten years. Its success will depend on the project members' ability to involve a large range of stakeholders. |

competing views and value frameworks. Therefore, rather than being based on a process of solution-seeking with a top-down transfer of empirical knowledge or expertise-based solutions, the project is based on the collective design and implementation of transformative pathways toward a resilient food system. The project's ambition is to strengthen, or renew, relations between consumers and farmers within the territory, and to develop an adaptive and participatory mode of governance that could make the food transition a lever for transforming agricultural practices. To that end, the project is structured around four pillars: (1) to co-produce knowledge on the local social-ecological system; (2) to contribute to individual and collective awareness of the issues surrounding food, agriculture and the environment; (3) to foster collective design processes and actions facilitating food and agroecological transitions, and catalysing these actions at individual or collective levels; and (4) to ensure the follow-up of actions and a wide dissemination of knowledge. The project activities are set at the municipality level, and the presence of 24 such municipalities in the ZA PVS allows comparisons between pathways to collective design of a resilient agri-food system.

This project brings together academic and non-academic partners with complementary approaches, such as facilitation of citizen events, surveys and collective design workshops. All aim to involve local stakeholders, to contribute to collective learning, to turn ideas into actions and to test levers of transformation. The notion of "ecosystem services" is not necessarily mentioned during interactions with local stakeholders, but the ES potentially provided by agri-food systems can be discussed, integrated as part of the study or even the subject of the study (see Table 1). Aliment'Actions places particular emphasis on the psycho-cognitive phenomena at work in the processes of transition and transformation: issues of individual and collective awareness, imaginaries, trust, ability to generate innovative ideas and projects, etc. These phenomena are studied for a variety of stakeholders: consumers, producers, economic actors, associations or politicians, adults, children and adolescents. The project also includes the analysis of processes of emergence and development of initiatives, be they citizen, associative, political or from the corporate world, in favour of increasing the resilience of the food system. Aliment'Actions focuses on scales ranging from individual to territorial scales, encompassing collective ones (e.g. municipality scale). It also considers the impacts related to processes occurring at larger scales (national, European or international). Aliment'Actions takes into account the uncertain nature of the trajectory of the food system in response to climate change, erosion of biodiversity and the complex socio-economic disturbances. The research carried out is transdisciplinary, in the sense that it involves the non-scientific actors concerned by these issues. Scientists adopt a post-normal stance, appropriate according to Funtowicz and Ravetz (1993) for cases where "facts are uncertain, values under debate, stakes high, and decisions urgent". Aliment'Actions is embedded in the ZA PVS research programme that addresses the levers of transformation of the social-ecological systems towards resilience and global health (Ecohealth concept).

## 8. Discussion: Unveiling the role that researchers can play to foster the collective design of a social-ecological system delivering multiple ecosystem services

### *8.1. Coevolution of the research agenda and the objects of collective action*

In an agroecosystem, unlike common pool resource situations (Ostrom, 1990), collective action is hampered by two main difficulties: (i) there are multiple resources and ES at stake for which local stakeholders do not share the same interest; and (ii) there is no community in charge of its management. Here, to initiate collective action toward agroecosystem sustainability, naturalists and ecologists first tried to present flagship bird species as common goods to preserve (see Table 1). Yet these flagship species had no particular value for most farmers, who therefore did not engage in collective action toward nature conservation. Flagship species rather appeared as a public good that should be managed with public funding. This is actually what happened until the years 2010: only EU, national or regional funding was used to maintain this cultural service.

As their knowledge about agroecosystem ecology grew, the scientists identified what could be considered as an ecological fund, i.e. as a minimal condition to allow the social-ecological system to deliver multiple ES: designing a landscape mosaic comprising ca15% grassland areas. They explored two strategies to implement it: (i) agri-environmental schemes, or the centralized design and management of the landscape mosaic; and (ii) a partnership with a local cooperative, or the co-design of the landscape mosaic considered as common unknown but to a limited range of stakeholders. For the first time, private funds were used, with the contribution of the farmer cooperative; yet the cooperative did not consider the business model of the alfalfa supply chain as satisfactory.

Envisioning the agroecosystem as a common unknown, for the design of which the range of stakeholders extends further afield than farmers and naturalists alone, seems promising. This, together with the incorporation of stakeholder's perception, knowledge and beliefs regarding their food consumption impacts and their engagement in the process, is the core of the current research project Aliment'Actions. This project also explores to what extent local stakeholders can create new forms of solidarity within the agri-food system and create an agricultural model that provides a larger range of ecosystem services than conventional agriculture. Various actions have been set up to establish a large and progressive collective design process of what could be a resilient agri-food system, giving ways to new knowledge regarding the key role of biodiversity in productive socio-ecosystems while generating individual and collective actions to foster the agroecological transition of the whole local agri-food system. Such an approach might also raise issues that addressed in Aliment'Actions. Involving diverse and autonomous stakeholders in collective design processes over a long period is not straightforward and required frequent contact and adaptation to raise awareness. Such program questions the type of stakeholders to involve for ensuring representation and legitimacy of the process. Transdisciplinary research also raises the question of the place of researchers and facilitators with respect to the inhabitants, as well as the duration of their commitment in emerging collective initiatives. Table 2 features the main interests, limits and lessons learned from the four strategies implemented in the LTSER ZA PVS over the past 28 years.

### *8.2. The multiple expansions of the research agenda as a support for collective action*

This retrospective of the research programme conducted in the LTSER Zone Atelier Plaine & Val de Sèvre highlights the multiple expansions it underwent to reach its ultimate goal: increasing the resilience of this social-ecological system. The research programme has been generative (Hatchuel et al., 2011) insofar as it has expanded at once the range of disciplines involved, the protocols, the ES taken into account, and the stakeholders. This generative research has also explored other concepts than the ES concept, such as Nature-based solutions and social-ecological resilience indicators and levers. As knowledge about the social-ecological system has increased and research questions have been refined, the design objects at stake have evolved, from solutions to overcome trade-offs between ES (landscape mosaic, alfalfa supply chain…), to Nature-based solutions and also to new forms of solidarity and collaboration between humans (farmers and consumers; academic and non-academic actors…) and between humans and non-humans. Relations between researchers and local stakeholders have indeed evolved significantly: the researchers have broadened the range of collaborators and have fostered specific relations with local stakeholders to both advance their research and better meet local expectations.

This retrospective analysis is interesting to identify the evolving research stances (Hazard et al., 2020) adopted by the ZA PVS researchers since the 90′s to produce scientific knowledge for sustainable transitions. Pointing at the identification of ecological funds and common unknowns highlights an interesting role for researchers willing to contribute to open design processes addressing societal issues. In addition to the production of knowledge, it points at the advantages of formulating operational concepts to open design spaces and thereby enhance both generativity and the engagement of diverse potentially key stakeholders. In this view, science thus does not "make" decisions but rather "builds" decisions (Cortner, 2000). This standpoint might not be easy and obvious for researchers whose practices are traditionally very different. It may also require a renewal of research governance, giving more space to participatory processes and allowing research to adopt a new position in the setting of societal goals. Involving various stakeholders such as farmers, beekeepers, hunters, naturalists or inhabitants, has changed the scientists' perspectives, as they need to build a systemic representation of the various stakeholders' perceptions of their environment, beliefs and values. Engaging stakeholders in the process, accounting for the diversity of stakeholders involved, and creating shared understanding about the problems are changing the way researchers learn about social-ecological systems, shifting from a rather "positivist" approach to a more "constructivist" and holistic approach, and from a knowledge-transfer perspective to a post-normal science perspective (Ainscough et al., 2018), in which social-ecological systems are considered as open-ended items that can be collectively designed and transformed.

As we have highlighted throughout this paper, the research conducted in the ZA PVS is closely related to various design processes. As Le Masson and Weil (2016) underline, a generative research leads to both conceptual expansions (imagining new products or systems, new uses, new technologies, etc.) and knowledge restructuring (new interdependences, new laws, new disciplines, etc.). Such a generative science requires that specific attention be paid to instruments that monitor emerging properties of SES. Today, the LTSER ZA PVS is home to pioneering research seeking to reconcile human well-being, agriculture and the environment, as a collaborative platform where interdisciplinary research teams, with expertise in ecology, agronomy, environmental sciences, sociology, and economic sciences, collaborate with local stakeholders. Such an infrastructure is close to what Schäpke et al. (2018) or Bergmann et al. (2021) name "labs in the real world". Using approaches such as monitoring, experimentation and inquiries (and to a lesser extent, modelling), the ZA PVS supports place-based knowledge production (Bretagnolle et al., 2019). It combines long-term monitoring of each component of the SES and their relations, where the coupling between the social and ecological templates is represented by two loops – the "Ecosystem Services interface" (Haines-Young and Potschin, 2010) and the "Adaptive Management interface" (Cumming et al., 2015) –, supports interdisciplinary research, and engages stakeholders in transdisciplinary approaches (Bretagnolle et al., 2018). The development and funding of such infrastructures and the recognition of post-normal research in academic institutions are both crucial if research wants to cope with the greatest environmental challenges of our time.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

Ainscough, J., Wilson, M., Kenter, J.O., 2018. Ecosystem services as a post-normal field of science. Ecosyst. Serv. 31, 93–101.
Badenhausser, I., Amouroux, P., Lerin, J., Bretagnolle, V., 2009. Acridid (Orthoptera: Acrididae) abundance in Western European Grasslands: sampling methodology and temporal fluctuations. Journal of Applied Entomology 133 (9–10), 720–732.
Barnaud, C., Corbera, E., Muradian, R., Salliou, N., Sirami, C., Vialatte, A., Choisis, J.-P., Dendoncker, N., Mathevet, R., Moreau, C., 2018. Ecosystem services, social interdependencies, and collective action. Ecol. Soc. 23 (1).
Bergmann, M., Schäpke, N., Marg, O., Stelzer, F., Lang, D.J., Bossert, M., Gantert, M., Häußler, E., Marquardt, E., Piontek, F.M., Potthast, T., Rhodius, R., Rudolph, M., Ruddat, M., Seebacher, A., Sußmann, N., 2021. Transdisciplinary sustainability research in real-world labs: success factors and methods for change. Sustain. Sci. 16 (2), 541–564.
Berthet, E., Bretagnolle, V., Segrestin, B., 2014. Surmonter un blocage de l'innovation par la conception collective. Fourrages 217, 13–21.
Berthet, E.T., Segrestin, B., Hickey, G.M., 2016. Considering agro-ecosystems as ecological funds for collective design: New perspectives for environmental policy. Environ. Sci. Policy 61, 108–115.
Berthet, E.T.A., Bretagnolle, V., Segrestin, B., 2012. Analyzing the Design Process of Farming Practices Ensuring Little Bustard Conservation: Lessons for Collective Landscape Management. Journal of sustainable agriculture 36 (3), 319–336.
Bretagnolle, V., Gaba, S., 2015. Weeds for bees? A review. Agron. Sustainable Dev. 35 (3), 891–909.
Bretagnolle, V., Gauffre, B., Meiss, H., Badenhausser, I., 2011a. The role of grassland areas within arable cropping systems for the conservation of biodiversity at the regional level. Grassland Productivity and Ecosystem Services. CABI Publishing, pp. 251–260.
Bretagnolle, V., Villers, A., Denonfoux, L., Cornulier, T., Inchausti, P., Badenhausser, I., 2011b. Rapid recovery of a depleted population of Little Bustards Tetrax tetrax following provision of alfalfa through an agri-environment scheme. Ibis 153 (1), 4–13.
Bretagnolle, V., E. Berthet, N. Gross, B. Gauffre, C. Plumejeaud, S. Houte, I. Badenhausser, K. Monceau, F. Allier and P. Monestiez (2018). "Towards sustainable and multifunctional agriculture in farmland landscapes: lessons from the integrative approach of a French LTSER platform." Science of the Total Environment 627: 822-834.
Bretagnolle, V., M. Benoît, M. Bonnefond, V. Breton, J. Church, S. Gaba, D. Gilbert, F. Gillet, S. Glatron and C. Guerbois (2019). "Action-orientated research and framework: insights from the French long-term social-ecological research network." Ecology and Society 24(3).
Caro, G., Marrec, R., Gauffre, B., Roncoroni, M., Augiron, S., Bretagnolle, V., 2016. Multi-scale effects of agri-environment schemes on carabid beetles in intensive farmland. Agriculture, Ecosystems & Environment 229, 48–56.
Catarino, R., Gaba, S., Bretagnolle, V., 2019. Experimental and empirical evidence shows that reducing weed control in winter cereal fields is a viable strategy for farmers. Sci. Rep. 9 (1), 1–10.
Cortner, H.J., 2000. Making science relevant to environmental policy. Environmental Science & Policy 3 (1), 21–30.
Cumming, G.S., Allen, C.R., Ban, N.C., Biggs, D., Biggs, H.C., Cumming, D.H., De Vos, A., Epstein, G., Etienne, M., Maciejewski, K., 2015. Understanding protected area resilience: a multi-scale, social-ecological approach. Ecological Applications 25 (2), 299–319.
Cumming, G.S., Cumming, D.H., Redman, C.L., 2006. Scale mismatches in social-ecological systems: causes, consequences, and solutions. Ecol. Soc. 11 (1).
Daily, G.C., Matson, P.A., 2008. Ecosystem services: From theory to implementation. Proc. Natl. Acad. Sci. 105 (28), 9455–9456.
Desneux, N., Decourtye, A., Delpuech, J.-M., 2007. The sublethal effects of pesticides on beneficial arthropods. Annu. Rev. Entomol. 52, 81–106.
Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour. 30, 441–473.
Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25 (7), 739–755.
Furness, R., Greenwood, J., Jarvis, P., 1993. Can birds be used to monitor the environment? Birds as monitors of environmental change. Springer, pp. 1–41.
Gaba, S. and V. Bretagnolle (2020). "Social–ecological experiments to foster agroecological transition." People and Nature 2(2): 317-327.
Gaba, S., Gabriel, E., Chadœuf, J., Bonneu, F., Bretagnolle, V., 2016. Herbicides do not ensure for higher wheat yield, but eliminate rare plant species. Sci. Rep. 6 (1), 1–10.
Geiger, F., Bengtsson, J., Berendse, F., Weisser, W.W., Emmerson, M., Morales, M.B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L.W., Dennis, C., Palmer, C., Oñate, J.J., Guerrero, I., Hawro, V., Aavik, T., Thies, C., Flohre, A., Hänke, S., Fischer, C., Goedhart, P.W., Inchausti, P., 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl. Ecol. 11 (2), 97–105.
Georgescu-Roegen, N., 1966. Analytical economics: issues and problems. Harvard University Press Cambridge.

Gill, R.J., Ramos-Rodriguez, O., Raine, N.E., 2012. Combined pesticide exposure severely affects individual-and colony-level traits in bees. Nature 491 (7422), 105–108.
Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. Science 327 (5967), 812–818.
Haines-Young, R., Potschin, M., 2010. The links between biodiversity, ecosystem services and human well-being. Ecosystem Ecology: a new synthesis 1, 110–139.
Hanski, I., 1999. Habitat connectivity, habitat continuity, and metapopulations in dynamic landscapes. Oikos 87 (2), 209–219.
Hatchuel, A., Weil, B., 2009. CK design theory: an advanced formulation. Research in engineering design 19 (4), 181.
Hatchuel, A., P. Le Masson, Y. Reich and B. Weil (2011). A systematic approach of design theories using generativeness and robustness. International conference on engineering design (ICED). Copenhagen, Denmark.
Hazard, L., Cerf, M., Lamine, C., Magda, D., Steyaert, P., 2020. A tool for reflecting on research stances to support sustainability transitions. Nat. Sustainability 3 (2), 89–95.
Inchausti, P., Bretagnolle, V., 2005. Predicting short-term extinction risk for the declining Little Bustard (Tetrax tetrax) in intensive agricultural habitats. Biological Conservation 122 (3), 375–384.
Kronenberg, J., Hubacek, K., 2016. From poverty trap to ecosystem service curse. Sustainability Science 11 (6), 903–907.
Le Masson, P., Weil, B., 2014. Réinventer l'entreprise: la gestion collégiale des inconnus communs non appropriables. In: Segrestin, B., Roger, B. (Eds.), L'entreprise, point aveugle du savoir. Sciences Humaines.
Le Masson, P., Weil, B., 2016. Fayol, Guillaume, Chevenard–la science, l'industrie et l'exploration de l'inconnu: logique et gouvernance d'une recherche conceptive. Entreprises et histoire 2, 79–107.
Lopes, R., Videira, N., 2015. Conceptualizing Stakeholders' Perceptions of Ecosystem Services: A Participatory Systems Mapping Approach. Environ. Clim. Technol. 16 (1), 36–53.
Millenium Ecosystem Assessment, MEA, 2005. Ecosystems and Human Well-being: Synthesis. C. Island Press, Washington (DC).
Muradian, R., 2013. Payments for ecosystem services as incentives for collective action. Soc. Nat. Resources 26 (10), 1155–1169.
Norgaard, R.B., 2010. Ecosystem services: From eye-opening metaphor to complexity blinder. Ecol. Econ. 69 (6), 1219–1227.
Ostrom, E., 1990. Governing the Commons. The Evolution of Institutions for Collective Action. Cambridge University Press.
Ostrom, E., 2009. A General Framework for Analyzing Sustainability of Social-Ecological Systems. Science 325 (5939), 419–422.
Ostrom, E., Gardner, R., Walker, J., Walker, J.M., Walker, J., 1994. Rules, games, and common-pool resources. University of Michigan Press.
Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., Taillieu, T., 2007. Social learning and water resources management. Ecol. Soc. 12 (2).
Perrot, T., Gaba, S., Roncoroni, M., Gautier, J.-L., Bretagnolle, V., 2018. Bees increase oilseed rape yield under real field conditions. Agric. Ecosyst. Environ. 266, 39–48.
Perrot, T., Gaba, S., Roncoroni, M., Gautier, J.-L., Saintilan, A., Bretagnolle, V., 2019. Experimental quantification of insect pollination on sunflower yield, reconciling plant and field scale estimates. Basic Appl. Ecol. 34, 75–84.
Prager, K., Reed, M., Scott, A., 2012. Encouraging collaboration for the provision of ecosystem services at a landscape scale—rethinking agri-environmental payments. Land use policy 29 (1), 244–249.
Requier, F., Odoux, J.-F., Tamic, T., Moreau, N., Henry, M., Decourtye, A., Bretagnolle, V., 2015. Honey bee diet in intensive farmland habitats reveals an unexpectedly high flower richness and a major role of weeds. Ecological Applications 25 (4), 881–890.
Rotz, S., Fraser, E.D., 2015. Resilience and the industrial food system: Analyzing the impacts of agricultural industrialization on food system vulnerability. J. Environ. Stud. Sci. 5 (3), 459–473.
Schäpke, N., Bergmann, M., Stelzer, F., Lang, D.J., 2018. Labs in the real world: Advancing transdisciplinary research and sustainability transformation: Mapping the field and emerging lines of inquiry. GAIA-Ecol. Perspect. Sci. Soc. 27 (1), 8–11.
Spangenberg, J.H., Görg, C., Settele, J., 2015. Stakeholder involvement in ESS research and governance: between conceptual ambition and practical experiences–risks, challenges and tested tools. Ecosyst. Serv. 16, 201–211.
Stallman, H.R., 2011. Ecosystem services in agriculture: Determining suitability for provision by collective management. Ecol. Econ. 71, 131–139.
Stone, J., Rahimifard, S., 2018. Resilience in agri-food supply chains: a critical analysis of the literature and synthesis of a novel framework. Supply Chain Manage.: Int. J.