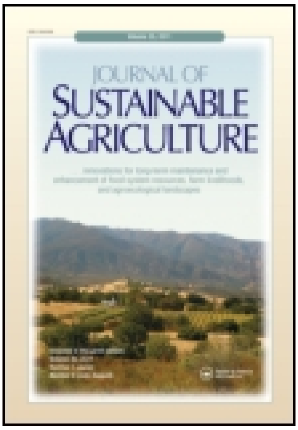

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Analyzing the Design Process of Farming Practices Ensuring Little Bustard Conservation: Lessons for Collective Landscape Management

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Analyzing the Design Process of Farming Practices Ensuring Little Bustard Conservation: Lessons for Collective Landscape Management

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Effective solutions for integrating development of agriculture and conservation of biodiversity at a landscape scale remain to be identified. This article presents a case study on an intensively farmed French cereal plain, where the reintroduction of grasslands has been proposed to protect the Little Bustard, a threatened European bird species. Although this solution may seem trivial at first glance, we analyze the design reasoning from which it resulted in order to highlight the innovative paths it opened. We apply C-K theory, a design theory that distinguishes concepts (i.e., unknown proposals) from knowledge. Our analysis reveals the links between the production of scientific knowledge and the generation of various solutions. It also highlights that specifying the ecological functions of grasslands facilitates their management. In the cereal plain,

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some of these functions give grasslands the status of common goods. This consideration opens new possibilities for managing agricultural landscapes in a way that reconcile agriculture and conservation.

KEYWORDS agroecology, collective action, conservation, design, ecosystem services, landscape, Tetrax tetrax

INTRODUCTION

Despite the increasing awareness of the urgency to halt biodiversity loss and ecosystem degradation all over the Earth, large-scale effective solutions are still missing. Traditionally, conservationists have focused their efforts on natural or semi-natural areas such as forests or wetlands, considered to harbor the greatest biodiversity. Conventional conservation strategies generally use regulatory tools to create protected areas where agricultural activity is officially banned or strictly circumscribed (Scherr and McNeely 2008). However, such strategies may raise conflicts, be very costly, or remain spatially limited. A major stake today is rather to find solutions to reconcile and integrate agricultural practices with the conservation of biodiversity.

Over the past decades the preservation of biodiversity in managed ecosystems, such as agroecosystems, has raised major concerns in Europe. Indeed the agricultural intensification that has occurred in order to meet the increasing demand for food, has led to the rarefaction of many species of plants, insects, birds and mammals (Donald et al. 2001; Kleijn and Sutherland 2003). However the ongoing processes by which agriculture impacts biodiversity remain partly unknown. Indeed, while agricultural ecosystems make up a large proportion of the land area at the European level, they are also the ecosystems in which trophic interactions and community ecology have been least well studied (Bretagnolle, Gauffre, et al. 2011). As solutions to make agriculture and conservation compatible remain largely unknown and as they must be adapted to local situations, European public authorities have opted for contractual tools rather than coercive ones.

The main public policy tools are agri-environmental schemes (AES), and to a lesser extent, a series of incentives and rules such as Natura 2000. AES were integrated into the Common Agricultural Policy (CAP) in the late 1980s (Clark et al. 1997). In France, they are mainly 5-year contracts between volunteer farmers and the government. These contracts are 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. Natura 2000 is a network of protected sites implemented within the framework of the Habitats (1992) and Birds (1979) Directives, which form the cornerstone of Europe's conservation of nature policy. The network now covers 18% of the European Union area. The directives target the conservation of bird species and habitats of importance to Europe.

The European Union’s 2010 objective to halt the loss of biodiversity has not been met, especially in agricultural ecosystems (Kettunen et al. 2010). However, there are cases where Natura 2000 conservation programs have been successful. There is a major interest in analyzing them in order to collectively learn from these experiences and to be able to reproduce them elsewhere. It is important to understand what ecological processes are at stake, how they interact and what levers of management can be activated at a landscape scale.

This article presents a case study of the implementation of Natura 2000 on the cereal plains of Poitou-Charentes (West of France, see Figure 1), where the results in terms of conservation of a threatened bird species are positive even though it is an area subjected to intensive agriculture. Since 2004, following the implementation of AES, an increase in the number of male bustards (five-fold increase in 5 years) has been observed in contrast to their state of decline beginning in 1995. The rise in numbers of Little Bustards (*Tetrax tetrax*) is attributed mainly to local recruitment, that is, the production of chicks from females whose nests are protected by farmers’ contracts or direct protection interventions, but it is also possible that some individuals from areas outside the SPA have migrated in.

At first glance, it seems that the main solution promoted, to integrate grasslands in the agroecosystem, is quite trivial and difficult to implement without large amounts of funding. However, our analysis shows that it would be wrong to stop here. Our claim is that analyzing the design reasoning can reveal that the solution proposed is not as trivial as it seems. It is not just about increasing grassland areas, but rather about managing the landscape by paying attention to how grasslands should be integrated. It also

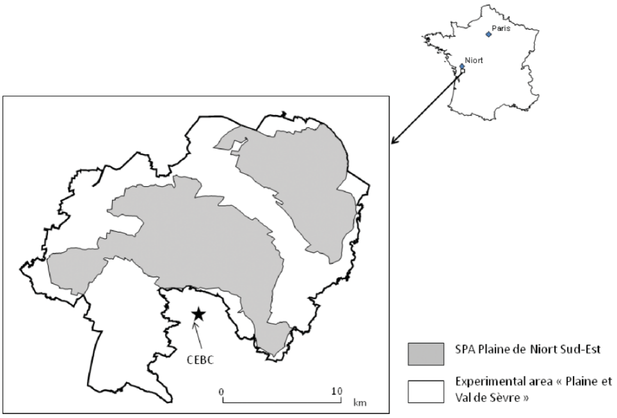

FIGURE 1 Map of the study site: CEBC experimental area and Natura 2000 Special Protection Area (color figure available online).

reveals that in this situation, grasslands can be considered as common goods. Approaching the issue from this point of view opens new possibilities for management at the landscape scale.

After a presentation of the case study, we expound the methodology and the theoretical framework applied to analyze ex post the design process of agricultural practices compatible with the conservation of threatened bird species. We then report the results of our analysis and comment on them. Finally, we discuss how the theoretical approach applied in this article makes it possible to renew the concept of grassland and opens new paths of progress on the issue of sustainable landscape management.

PRESENTATION OF THE CASE STUDY

This article presents a case study of the implementation of Natura 2000 on the cereal plains of Poitou-Charentes. The altitude ranges from 50 to 150 m. Clay-limestone soils with an alkaline pH predominate. The oceanic climate is characterized by an average temperature of 12°C and an annual average precipitation of 850–900 mm. Water deficits are recurrent in summer, with irrigation restrictions almost every year since the 1990s. This has recently led to a shift from irrigated corn production to crops that require less water, such as cereals and semi-perennial crops. The main crops produced are wheat, corn, sunflower, and rape (Agreste 2010). This region has known a strong agricultural intensification and specialization. The number of farmers has halved over the past 30 years, while the average farm size has doubled (Agreste 2010). Although cattle and goat farming remain, mixed farming systems have markedly declined in favor of intensive cereal farming systems over the past 60 years. This change has led to a decrease in semi-perennial forage crops as well as in meadows and grasslands. For example, in 2007, 15% of the cultivated areas were grasslands (artificial, temporary or permanent) compared to 60% in 1970. Agricultural intensification has also led to the elimination of most of the hedges and a 10-fold increase in the average size of cultivated fields since the 1960s. In addition, the use of chemical inputs has increased sharply. However, naturalists have found that the area still supports great biological richness. As an example, the agricultural plains south of the city of Niort (the area studied here) still host 17 bird species endangered at the European level, for nesting, breeding, a stop-over site during migration, or an over-wintering area.

The Special Protection Area (SPA) "Plaine de Niort Sud-Est" (FR5412007), as well as seven other SPAs designated in the cereal plains of Poitou-Charentes, have been delineated mainly on the basis of the distribution of the Little Bustard (Inchausti and Bretagnolle 2005). It is considered an *umbrella species* (its presence coincides with that of many other bird species of conservation interest), as well as an *indicator species* (its presence indicates proper functioning of the food web) and a *flagship species* (it is emblematic of the cereal plains of the region). In France, the Little Bustard is now red listed; indeed the number of breeding males in agricultural habitats has been reduced by 92% over the last 20 years (Bretagnolle and Inchausti 2005).

We chose the SPA Plaine de Niort Sud-Est as our study area for several reasons. First, it is one of the few Natura 2000 sites that have been designated in areas of intensive agriculture. The challenge is, thus, to find a compromise between the conservation of biodiversity and agricultural production. Second, the site is located in an area of large-scale and long-term experimentation, called Zone Atelier Plaine et Val de Sèvre (see Figure 1), which is managed by the ecology lab of the Centre for Biological Research of Chizé (CEBC-CNRS). This laboratory is also involved in the SPA management, coordinating AES implemented within the framework of Natura 2000. A representative of CEBC promotes contracts with volunteer farmers on behalf of public authorities. In our case study, a research center in ecology was, thus, collaborating both with farmers for experimentation and with local authorities for funding and co-construction of AES. Such a configuration has facilitated the implementation of a pioneering research–action program.

Solutions for reconciling agriculture and conservation of the Little Bustard in the cereal plain were not known at the beginning of the project. When the first program of conservation of the Little Bustard was launched in 1997, little was known about the biology and ecology of this species. If the decline of this species in the region was concomitant with the intensification of agriculture, the processes by which the latter generated the decline were poorly understood. Moreover, at that time, preservation of biodiversity in areas of intensive agriculture was almost nonexistent and, according to naturalists as well as farmers, seemed incompatible with agricultural production. Yet, although farming is still the major land use, the number of Little Bustard males has been increasing since 2004. The number of displaying males in the study area declined from 55 in 1995 to only 6 in 2003. Thereafter, male numbers started to increase, reaching 27 in 2008 (Bretagnolle, Villers, et al. 2011). The solutions proposed to reach such results have been designed progressively according to the local situation and knowledge produced by the stakeholders involved. The aim of this article is to understand this design process.

METHOD AND CONCEPTUAL FRAMEWORK APPLIED TO ANALYZE A DESIGN REASONING

Our study was carried out between May and August 2010. It was primarily based on a review of 1) scientific papers in social sciences, conservation biology, and agroecology; 2) administrative documents dealing with Natura 2000; and 3) scientific papers, theses, or research projects produced by

CEBC researchers. We also conducted 23 interviews with researchers at CEBC and other key players in the implementation of Natura 2000 in the region: government bodies, environmental nongovernmental associations, local authorities, farmers, and related organizations. One of the coauthors on this article is a researcher at CEBC. The range of interviews made it possible to cross various points of view regarding the process of landscape design aimed at integrating agriculture and conservation in the study area. The interviews were conducted in order to understand the sequence of obstacles met and the variety of solutions devised by local conservationists (CEBC and environmentalists). More precisely, both reviews and interviews were aimed at reconstructing the design of conservation initiatives for the Little Bustard, which was the main species targeted by the implementation of Natura 2000 in these areas.

As mentioned earlier, there were no solutions a priori making it possible to keep on intensive farming without threatening Little Bustards. This is typically the initial situation of a design process, which is difficult to report as it brings into play reasoning about unknown proposals. Indeed, different paths were explored, some were abandoned, knowledge has evolved, and so forth. A theoretical framework makes it possible to analyze a design process as it takes account of the specificities of such reasoning: the Concept-Knowledge (C-K) theory (Hatchuel and Weil 2003, 2009). The distinction between concepts and knowledge highlights the singularity of “design” as compared to problem-solving approaches or other standard forms of reasoning. Indeed, unlike decision theory, which responds to a logic of optimization among a set of solutions already known, the C-K theory makes it possible to analyze a reasoning that starts with an unknown object and it highlights the generation of new alternative solutions. The C-K theory has been developed in the field of engineering design and has not been used yet in landscape ecology or agroecology. In these disciplines, problem-solving approaches are more widely used. However in the problem-solving approach described by McAlpine et al. (2010) for instance, the authors assumed that the list of landscape management options was already known given ecologists’ knowledge. In our case study, as solutions did not exist at the beginning of the design process, we applied the C-K theory to understand how new management options were created.

It is not the purpose of this article to explain the foundation of the C-K theory in detail, so we will present it briefly. The central proposition of the theory is a formal distinction between:

- “Concepts” (C), that is, proposals that are still partly unknown and that require a design process. We cannot say that they are impossible to achieve, but we do not know how to achieve them in the current state of knowledge.

- "Knowledge" (K), that is, proposals that have a logical status, which means that they can be assessed by anyone as being true or false. Knowledge is what designers already know before the design process or what they learn progressively.

A central finding of the C-K theory is that a concept is the necessary departure point of a design process (Hatchuel and Weil 2003). A concept asserts the existence of an unknown object that presents certain properties desired by the designer. Hence, the C-K theory is a theoretical framework that makes it possible to start with an unknown object and analyze the reasoning carried out to obtain a feasible object ultimately. From a formal point of view, the theory requires work to be carried out simultaneously with both concepts and knowledge to formalize the design reasoning.

The formalism proposed by the theory is a kind of map of design reasoning. We thus applied this formalism to analyze ex post the design reasoning that was developed by scientists in the case study, but that today is implicit. This is worthwhile for various reasons: first, the outcome is a didactic flow diagram that represents key steps of a design process. It shows when choices have been made, implicitly or not. It links these decisions to their context: state of knowledge, constraints, and so on. Second, the flow diagram reveals the variety of solutions explored. It highlights paths abandoned for specific reasons at specific times and which could be further explored in a new context.

The flow diagram we display in this article (see Figure 2) is a summary of the original one. It highlights only key issues and does not intend to reflect in an exhaustive way all the reasoning steps of stakeholders over the past 15 years of the project, or to be chronological. It is an interpretation from the surveys and the literature review conducted. Its construction was iterative and took into account feedback from the people involved in the design process. It might be necessary to add that the conservationists did not use the C-K theory in the case that we study.

ANALYSIS OF THE DESIGN REASONING TO INTEGRATE INTENSIVE AGRICULTURE AND CONSERVATION

In order to protect the Little Bustard, conservationists could have promoted a traditional approach such as excluding agricultural activities and establishing a nature reserve. However, as the region had become an area of intensive cereal production, economic interests were such that excluding farming was impossible. In addition, vast areas would have been necessary to protect populations of Little Bustards, given their extensive geographical range and large individual home ranges. Therefore, the solution of the nature reserve was soon abandoned. The conservationists had to imagine more innovative approaches to integrate farming and bird conservation at a large scale. As a

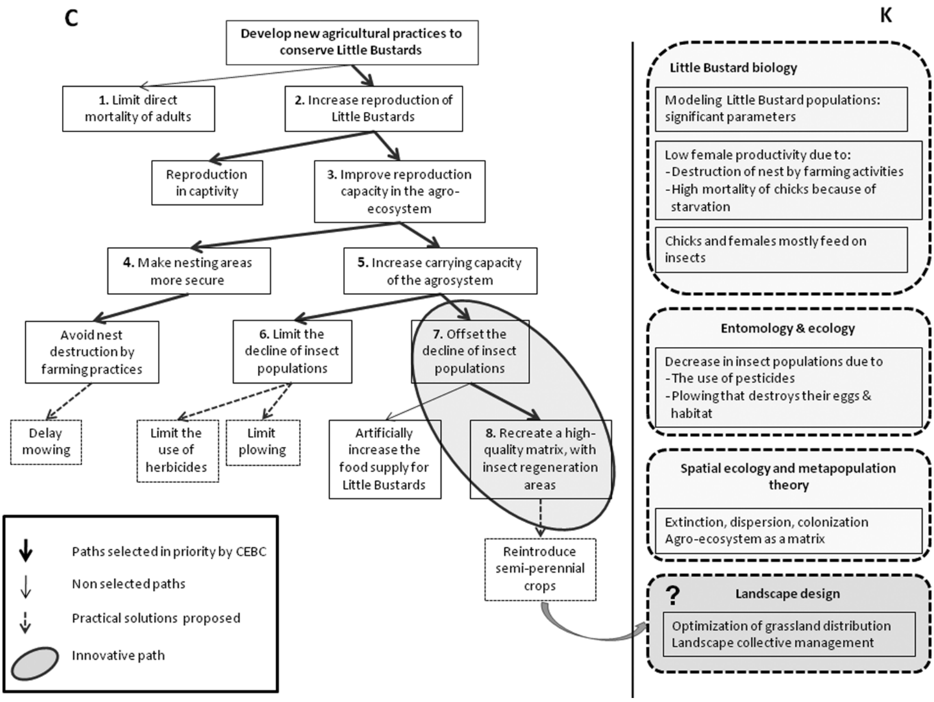

FIGURE 2 C-K flow-diagram of the design of new agricultural practices ensuring Little Bustard conservation. On the left hand side features the Concept space (C) and on the right hand side the Knowledge space (K). According to Hatchuel and Weil (2003, 2009), the progress of the design reasoning and the specification of concepts is represented by a tree structure, while knowledge is grouped by subjects. We also see in this picture that new concepts appear thanks to the production of knowledge and these concepts conduce to looking for new knowledge. (See core text for additional information on the figure.)

consequence, the starting point of the design process was to develop new agricultural practices that would make it possible to conserve the Little Bustard on the cereal plain. Solutions were initially largely unknown, and there were no obvious or satisfactory ones guaranteeing that reconciling these a priori antagonistic objectives was possible. Therefore, the proposal to develop new agricultural practices to conserve Little Bustards in the cereal plain is what, in the framework of the C-K theory, we qualify as an initial concept: an unknown proposal that one wants to reach and which is the starting point of a design process. This is the first step of our flow diagram (see Figure 2).

1) Improving the Knowledge About Little Bustard Biology to Identify New Concepts

To begin with, CEBC researchers sought to understand the causes of mortality of the Little Bustard. During the first conservation program, they used population viability analyses to test the effect of several demographic parameters on the survival of Little Bustard populations, measured by population growth rate (λ; a negative growth rate leads to extinction; Bretagnolle and Inchausti 2005). The first parameter analyzed was adult survival. The causes of direct mortality of adults are mainly collisions with power lines, predation, poaching, and exhaustion during migration that can be caused by poor nutrition during the postnuptial gatherings in autumn. However, improving adult survival, including limiting the direct mortality of adults (see Figure 2, path 1), was not considered as the most decisive parameter by these biologists. Apart from the fact that it is very difficult to control, it is not a parameter that strongly affects population growth rates and hence population dynamics (Inchausti and Bretagnolle 2005).

According to their studies, these biologists identified two other parameters as being more significant than adult survival in terms of conservation strategy: carrying capacity and female productivity (Bretagnolle and Inchausti 2005). Indeed, decreasing mortality required a considerable effort for a low impact, while improving reproduction had potentially greater impact. They, therefore, aimed at a new concept: improving the reproduction capacity of Little Bustards (see Figure 2, path 2).

Given the rapid decline of the Little Bustard in agricultural areas (over 13% per year between 1997 and 2002; Bretagnolle, Villers, et al. 2011), both reproduction in captivity and in the agroecosystem were aimed at. A reinforcement program was launched to increase population size in addition to other conservation actions (Inchausti and Bretagnolle 2005). The LIFE Program "Strengthening the populations of migratory Little Bustard," coordinated by LPO France (Ligue pour la protection des oiseaux, French representative of Birdlife international) ran from 2005 to 2009. Both protection of nests and captive breeding allowed conservationists to keep or reintroduce into the Poitou-Charentes region 353 Little Bustards at the egg stage or fledgling stage. The observed survival rate of 190 released birds was above 50%, a value higher than the estimated survival rate of wild fledglings. The LIFE program helped to establish a breeding conservatory stock. Its actions are currently being pursued through a national action plan for the Little Bustard.

However, the main conservation efforts carried out by CEBC targeted the concept for improving reproduction capacity in the agroecosystem (see Figure 2:, path 3). This concept required the production of new knowledge regarding Little Bustard reproduction. Very little information was available about where and when this species bred, laid eggs, how chicks were fed, an so on. Based on a sample of 80 nests for which data was recorded between 1997 and 2001, researchers found that half of the clutches could not hatch, 40% of which was due to the destruction of nests by farming practices. In addition, nearly 40% of clutches arriving at hatching failed because of food shortage during the early chick rearing period, when chicks rely solely on insects (Orthoptera and Coleoptera; Jiguet 2002) for their first

15 days (Inchausti and Bretagnolle 2005). Hence, to improve female productivity, the ecologists explored how to limit the destruction of nests by farming activities. This led to another concept: to make nesting areas more secure in the agroecosystem (see Figure 2, path 4). The first solutions proposed came from conservation measures formerly developed for other bird species, then adapted to the Little Bustard. However the conservationists aimed at identifying effective agricultural practices of which the restrictive nature was as limited as possible for farmers. A thorough knowledge about nest location, as well as laying dates was needed. CEBC researchers and their partners identified that the most common plant covers for nesting were grasslands and fallows, followed by legume fields (alfalfa). Female bustards very markedly prefer perennial or semi-perennial plant covers. Egg laying lasts over 4 months, from May to August. As mowing traditionally occurs between May and July, and fallow mulching in June, ecologists identified the period from mid-May to late July to be the most critical for nest protection. Farmers were, therefore, requested (through contractual agreement) not to mow their grasslands during this period estimated as such in order to protect 90% of the clutches while allowing farmers to keep on producing fodder. However, as there was a correlative yield decrease, farmers received financial compensation. To a lesser extent, some less destructive mowing techniques were also applied, such as maintaining non-mowed strips, or mowing from the center to the periphery so that the female bustards and their chicks could escape.

2) The Use of Metapopulation Theory to Understand the Whole Agroecosystem Ecological Functioning: Opening an Innovative Path

CEBC research programs highlighted that failure rate during rearing was another factor for low female productivity. Field observations revealed that Little Bustard chicks fed exclusively on insects, and that on average, nearly half of them died of hunger due to lack of sufficient prey (Bretagnolle, Villers, et al. 2011). This finding made it possible to define a new concept for conservationists: increasing the carrying capacity of the agroecosystem (i.e., maintaining a sufficient quantity of insects; see Figure 2, path 5).

To achieve this goal, various solutions were explored to decrease the impact of farming practices on insect populations (see Figure 2, path 6). First, results showed that the repeated application of pesticides, particularly herbicides that deprive insects of food and to a lesser extent insecticides, was a major problem. Second, plowing was found to destroy habitats and insect eggs laid in the soil. Another concept explored was to offset the destruction of insects in the agroecosystem (see Figure 2, path 7). A possible solution here would have been to artificially increase the food supply of

Little Bustards through the release of insects or food compounds. However, researchers looked at ways to restore insect pools more "naturally" (see Figure 2, path 8), through the application of spatial ecology principles.

Population dynamics in an ecosystem are governed by phenomena of extinction, dispersal and colonization. When there is local extinction of a population, it can be compensated for by a mechanism of recolonization, provided that an adequate regional supply of this population exists and that individuals can disperse to and colonize the local habitat where the population went extinct (Levins 1969; Hanski 1999). This approach can be applied in agricultural areas. From an ecological point of view, an agroecosystem is a discrete spatio-temporal habitat because of the irregular distribution of agricultural plots and crop rotations. This discontinuity is stochastic for the organisms living in these ecosystems, at least for smaller species (e.g., insects, small mammals), that is, it is unpredictable for them, as it is governed by human activities. Ecological disturbances related to agricultural activities usually lead to local extinctions of insect populations. For instance, if annual crop fields experience local and temporary insect extinctions, surfaces with multi-annual vegetation (at least 3 years), such as perennial crops and edge habitats, differ in terms of level and frequency of these disturbances. Therefore, these areas act as refuges to host the reproduction of a majority of insects, especially those part of the Little Bustard food web (Badenhausser et al. 2009).

The metapopulation theory provides ways and means to analyze the biodiversity of agroecosystems. It predicts that the presence, abundance and distribution of perennial habitats may have strong impacts on metapopulation and metacommunity dynamics of various organisms (Hanski 1999). The spatial phenomena of dispersion/colonization mainly depend on the distance between source populations and on the structure of the landscape that affects the movement of individuals between habitat patches (Kareiva and Wennergren 1995; Nee et al. 1997; Akçakaya 2000). The agroecosystem can be modeled as a matrix, composed of natural areas and cropped areas (Perfecto et al. 2009). This matrix is considered of high quality if it allows for migration rates balancing the rate of local extinctions. Hence, in order to offset the decline of insects on the cereal plain, the scientists aimed at recreating insect regeneration areas and distributing them adequately to obtain a high-quality matrix (see Figure 2, path 8).

An assumption made by ecologists at CEBC was that biodiversity in agroecosystems was intimately linked to the presence of grasslands (used here as a generic term for semi-perennial grass and legume covers). Indeed, grasslands are areas less disturbed by farming activities than other fields: They are not plowed every year and they require fewer pesticides than crops. However, a new bundle of knowledge was needed: how to distribute such areas across the cereal plain? CEBC researchers analyzed in a spatially explicit way metapopulation dynamics of insects predated by

Little Bustards on the cereal plain, especially grasshoppers (Orthoptera: Acrididae). To assess the required frequency of population sources, they used as a model the grasshopper *Calliptamus italicus*, one of the main preys of Little Bustards (Jiguet 2002). This grasshopper disperses by flight and, therefore, has a rather high colonization potential. Its colonizing ability was assessed by Louveaux et al. (1991) to be approximately 600 m. The ecologists used a model to simulate theoretical landscapes composed of grasslands and crops. Threshold values of 10–20% of the landscape as grasslands were found to be necessary to preserve of grasshopper populations. Based on these results, the scientists set a target of 15% of agricultural land as grasslands, preferably randomly scattered across the landscape.

3) Reintroducing Grasslands in the Agroecosystem: An Issue of Landscape Matrix Management

Since the mid-2000s the main objective of the Little Bustard conservation and research project has been to maintain or restore the semi-perennial crops on the cereal plain. Grasslands have been given priority by the ecologists at CEBC compared to linear infrastructures (hedges, grass strips), first, because they are a production asset for farmers and, second, because they are nesting areas for Little Bustards. Moreover, grasslands are a key element of the landscape mosaic to meet often-contrasting ecological requirements of Little Bustard males and females: Males look for open areas for mating purposes; females, by contrast, will only nest in 30–50 cm vegetation height grasslands.

The concept of recreating a high-quality matrix initiated another design process: the landscape design aimed at integrating agriculture and Little Bustard conservation (see Figure 2). A key issue is to control the spatial distribution of grasslands. Researchers of the Center for Biological Studies of Chizé have played the role of designers of conservation actions first at the field level, then at the landscape level. Indeed the solutions they designed at the field level such as mowing delay were validated by local authorities and implemented in local AES. Moreover, thanks to their role as AES operators for the SPA Plaine de Niort Sud-Est, they have progressively become designers and organizers of the landscape matrix through the reintroduction of grasslands (see Figure 3). Indeed, since 1995, the researchers have compiled a database of the location of males, females and nests of Little Bustards. This base makes it possible for them to develop target schemes as a function of field location and to monitor the effectiveness of the schemes. It is important to underline that the CEBC operator negotiates with each farmer about the localization and area of grasslands created under AES. This position made it possible for the CEBC to test various strategies to achieve the

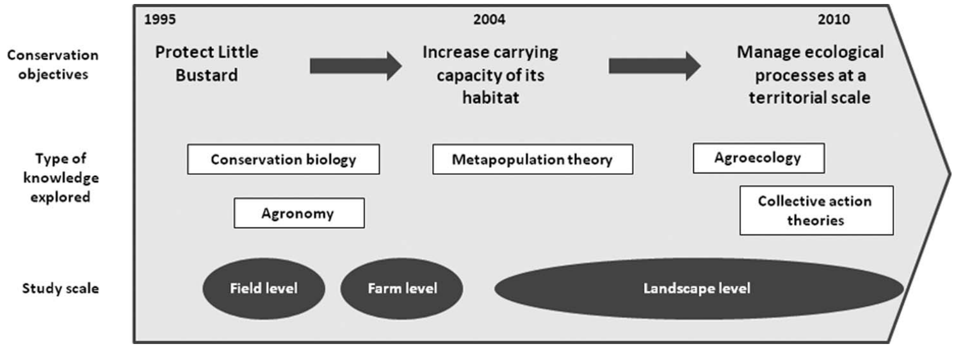

FIGURE 3 Change of conservation objectives, scientific disciplines, and study scales throughout the design process. This figure synthesizes the change of conservation objectives addressed over the 15 years of the project, related to scientific disciplines and study scales used by researchers.

conservation objectives of the Little Bustard and to produce further knowledge about it. For example, many AES have been contracted near Little Bustard leks (gathering of males for competitive mating display). In areas with large cereal fields, another objective was to reconstruct a mosaic of varied fields in order to break up the uniformity of the landscape. AES contracts could also be signed with neighboring farmers in order to increase the effectiveness of an earlier contract. In 2009, 2360 ha (>10% of the eligible area) entered agri-environmental schemes targeting biodiversity, and about 4000 ha more entered AES targeting water quality. Areas under AES have increased exponentially during the last two years. Consequently, the areas with alfalfa and other grasslands increased nearly 5-fold in 3 years.

DISCUSSION

Reporting the Variety of Solutions and Knowledge Produced

In this article, we analyze ex-post the design reasoning that led to the proposal of grassland reintroduction in the cereal plain in order to preserve the Little Bustard. The analysis of the design reasoning highlights results that go further than this mere solution: this solution actually hides a variety of concepts and knowledge produced over the 15 years.

First, the step-by-step reconstruction of the design process highlights the links between research progress and the gradual change of objects targeted by the design process. The design flow diagram, applied to knowledge-based conservation actions, shows that the method used was not problem-solving (i.e., trial and error), but a gradually targeted process where the production of knowledge made it possible to formulate new concepts, which then guided knowledge production. The first research carried out on the study area between 1994 and 1998 focused on the ecology of different bird species. As ecologists aimed at understanding the impact of farming disturbances on bird population dynamics and habitat selection, they collaborated with farmers and agronomists to analyze agricultural practices. From 2000 onward, research efforts targeted the agroecosystem food web as well as the animal and plant communities therein. By using metapopulation concepts, researchers developed an impact analysis of agricultural practices on trophic availability at the scale of the entire agroecosystem. Retrospective analysis shows that there has been a disciplinary transition from fundamental ecology and conservation biology to agroecology associated with the formulation of new concepts.

Second, the analysis reveals that there has been a large range of solutions proposed. Indeed, in 2010, 13 local agroenvironmental schemes were proposed to farmers. These schemes can be divided into five categories: 1) four schemes aimed at a less intensive production of field crops (cereals, oilseeds and protein crops); 2) two aimed at the development of organic farming; 3) four aimed at the conversion of crop fields into grasslands; 4) two aimed at the management of the existing grasslands in a way favorable for the avifauna; and 5) one dealt with the management of fallows. We can see that the reintroduction of grasslands was not the unique solution proposed to farmers and that it encompassed a range of various practices.

Third, our retrospective analysis shows that in the case studied the word "grassland" has various meanings. Indeed, grassland refers to a traditional management unit in agriculture used for cattle breeding, it also refers to different functions for ecologists. There is a need to specify its ecological and agricultural functions, which actually open a range of solutions for biodiversity conservation as well as for other environmental issues. Grasslands are the support of various ecosystem services as many ecological and physicochemical processes occur in these habitats. For instance, grasslands are nesting zones and food sources for threatened species. They also play a regulatory role in the qualitative and quantitative management of water, as well as for soil quality. The soil organic matter accumulated in grasslands contributes to capturing carbon dioxide (CO_2) from the atmosphere (Casella and Soussana 1997). Temporary grasslands may both contribute to the regulation of weed populations that are most harmful in annual crop fields while favoring other plant species that are less harmful (Badenhausser et al. 2009; Meiss et al. 2010). There is a need to clarify the ecological processes at stake in order to design grasslands in such a way as to preserve and maximize certain functions that are expected. Indeed, according to the way they are managed, all functions cannot be optimized at the same time. For example, intensive management of grasslands, with a high use of fertilizer and frequent mowing, promotes the function of forage production, but decreases the reproduction of insects. Highlighting the antagonisms between these functions facilitates the management of grasslands.

Toward the Collective Management of Grasslands in a Cereal Plain: New Insights for Landscape Management

The issue of grassland management at the landscape scale opens up a new design field, for which a concept (in the meaning given by the C-K theory) can be: managing grasslands as areas for the regeneration of biodiversity. This raises several questions. What should the size of grassland areas be? How should they be located across the agricultural landscape? How should they be managed?

Ecosystem services rely on ecological processes that exceed the field scale and thus have to be managed at a landscape scale (Chan et al. 2006; Bennett et al. 2009). Hence, the focus on ecosystem services provided by grasslands creates new interdependencies among farmers. For instance, in our case study, when a farmer establishes grassland, the latter is an area for regeneration of biodiversity enabling insects to recolonize nearby fields. To a certain extent, the farmer provides ecosystem services to his neighbors.

Grasslands, as sources of regulation of the agroecosystem food web as well as soil and water quality, can be considered as common goods. Common goods refer to a field of the economy for which it is difficult to develop physical or institutional means for excluding beneficiaries although these goods are in limited quantity. An abundant literature has tackled this problem since the publication in 1968 of “The tragedy of the commons” by Hardin (1968). The author denounced the irreversible exhaustion of scarce resources in situations of open access. This feature of “common” property is for many authors considered as a source of problems (overuse, pollution, and potential loss of these goods) for which the only solutions considered for years where the authoritarian public control of such goods or the establishment of private property rights (Ostrom 1990). Here, on the contrary, the designation of grasslands as common goods may provide solutions allowing local people to overcome the current situation of “tragedy”, that is, the destruction of biodiversity on the cereal plains. In our case study, the transition from the field to landscape scale gave an opportunity to look for a new optimum for the increase of areas under grasslands. Rather than trying to obtain a 15% ratio of the farm under grasslands from each farmer, the 15% ratio was targeted at the landscape scale (see also Bamière et al. 2011). This allowed for greater freedom in the negotiation process in order to achieve better adoption by farmers and therefore a more effective preservation of the Little Bustard. However, further knowledge is required today to specify how to properly organize the agricultural matrix according not only to Little Bustard needs but also to larger considerations of biodiversity and the environment. AES is a possible instrument to use in managing landscape design, but it requires high amounts of public funding. This perspective leads to exploring new management and economic models that may help to reconcile biodiversity and agriculture and that should include various stakeholders such as food industries and local authorities. New instruments or organizations deserve further multidisciplinary research, bringing together ecologists, agronomists, agroecologists, economists, and sociologists.

The case of grasslands is interesting because it leads to thinking in terms of design of common goods. So far, several strategies proposed to safeguard common goods have been identified, including those developed by local communities, and analyzed by Ostrom (1990, 2000). Ostrom identified several design principles that help communities sustain and build their cooperation over long periods of time; however, she considers common goods as an existing collectively owned stock to manage. In our case, grasslands are private goods, but as soon as they are managed as common goods they have to be designed, as do also new farming practices and new modes of collective action. Here, on the basis of our observations, it now appears likely that the action of designating private goods as commons can help achieve a collective interest and that the collective characteristic of these goods is not a problem but a solution. It opens up the way to collective design processes of new modes of governance to manage sustainably agricultural landscapes.

CONCLUSION

In the case studied, the use of the C-K theory highlights how a design effort can develop innovative ways of reconciling a priori antagonist objectives. While ex post solutions seem trivial, they should not overshadow the effort of knowledge production that made them emerge. The results of the work carried out in Poitou-Charentes are not only about the number of Little Bustards saved, nor about the unique grassland solution that is highlighted today. The results are rather about the body of knowledge that makes it possible to reconsider the conditions for conservation of biodiversity. In the case study, the initial dilemma was solved thanks to a collective but centralized management of grasslands at the landscape scale.

Such efforts of design and knowledge production should not be underestimated for the implementation of public policies such as Natura 2000 that deal with highly complex issues. Public authorities might have to help landscape managers steer a design process by developing networks to reinforce the transfer of knowledge, or develop training courses about design management. As Nassauer and Opdam (2008) state, design is a "common ground for technology transfer" (635). where practitioners and scientists agree on concepts and progress together in the production of knowledge. In light of our case study, we are presently convinced that design skills are particularly important in the field of agroecology, where methods of trial-and-error are not appropriate since experiments are not easy. The ecological processes studied often occur at large spatial and temporal scales and, to some extent, time is short.

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