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Methods

Bio economic modeling for a sustainable management of biodiversity in agricultural lands

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ABSTRACT

For several decades, significant changes in farmland biodiversity have been reported in Europe. Agriculture is a major driver of these modifications. Taking into account these environmental impacts, agriculture nowadays aims at a more sustainable way of producing which would reconcile its economic and ecological functions. The objective of this paper is to give insights into the impact of public policies on both conservation of biodiversity and farming production. We develop a macro-regional model combining community dynamics of 34 bird species impacted by agricultural land-uses and an economic decision model. The ecological dynamic model is calibrated with the STOC (French Breeding Bird Survey) and AGRESTE (French land-uses) databases while the economic model relies on the gross margins of the FADN (Farm Accountancy Data Network). We investigate the scenario based on subsidies and taxes. We show that simple economic instruments could be used to establish scenarios promoting economic performances and bird populations. It is pointed out how the sustainability of the policies is sensitive to the ecological and economic indicators used by the planner. The bio-economical analysis shows several solutions for the ecology-economy trade-off. These results suggest that many possibilities are available to develop multi-functional sustainable agriculture.

1. Introduction

We observe in recent decades a biodiversity decline in Europe. The pressure is particularly strong on bird populations which have undergone severe and widespread decline (Chamberlain et al., 2000; Jiguet, 2009; Krebs et al., 1999). Such erosion is mainly due to a combination of habitat loss and degradation of habitat quality altering the nesting success and/or survival rates (Benton et al., 2003). Global changes in European agriculture, including intensification and land abandonment, have significantly modified farmland bird (Donald et al., 2001, 2006). In this context, the European Union, aiming at halting biodiversity loss, has adopted the Farmland Bird Index as an indicator of structural changes in biodiversity (Balmford et al., 2005). In this perspective, the need to reconcile agricultural production and biodiversity is of particular interest (Jackson et al., 2005).

Since the early 90's, several public policies have been developed to limit the negative impacts and externalities of agriculture on biodiversity. Typically, agri-environment schemes have been introduced in which farmers receive support for adopting environmentally friendly agricultural practices. There is an extensive and increasing volume of literature concerning agri-environmental schemes and policies for multi-functional agriculture (Alavalapati et al., 2002; Dobbs and Pretty, 2004; Dreschler and Wätzold, 2007; Münier et al., 2004; Pacini et al., 2004; Shi and Gill, 2005). However, after 15 years of implementation of such instruments, the question whether providing habitat quality conflicts with management for agricultural production remains controversial (Butler et al., 2007; Kleijn et al., 2006; Vickery et al., 2004). To address agro-environmental sustainability, both economic and ecological criteria must be considered. As pointed out by Hughey et al. (2003) and Perrings et al. (2006), there is an urgent need for approaches that integrate economic criteria in conservation problems. Reinforcing such analyses and examining forms of farming allowing for the joint sustainability of biodiversity and agricultural production require interdisciplinary research. Such work relies upon the development of interdisciplinary concepts, quantitative methods and integrated models that adequately incorporate the complex interdependencies between farmland ecosystems and economic systems.

The present paper deals with such modeling issues regarding agro-environmental sustainability. A bio-economical model is developed to study the joint sustainability of agricultural land-use and bird biodiversity. To address agro-environmental sustainability, numerous modeling frameworks are proposed in the literature. They include Cost–Benefit (Dreschler and Watzold, 2001; Rashford et al., 2008) and Cost–Effectiveness (Holzkamper and Seppelt, 2007) approaches. A major criticism of Cost–Benefit analysis for conservation issues is that benefits related to biodiversity and habitat quality are usually non-market goods,

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and by definition difficult to quantify in monetary terms (Rees, 1998). Although pricing techniques such as contingent valuation are available, their suitability for complex biodiversity issues is disputed, notably in anthropogenic systems (Diamond and Hausman, 1994). Cost–Effectiveness analysis can be used to reveal a minimal cost policy among those satisfying the given goals of conservation and production (MacMillan et al., 1998). This approach, based on optimization under constraints, avoids monetary evaluation of environmental goods (Gatto and Leo, 2000). As far as agricultural economics is concerned, most models rely on mathematical programming and optimization under constraints. The joint production of an agricultural commodity and grassland biodiversity is examined for instance in Havlík et al. (2005) where the environmental service is approximated by the number of hectares managed in a prescribed environmentally friendly way. The real impacts on biodiversity and ecological services are more explicitly considered in Van Wenum et al. (2004) or Polasky et al. (2003). To deal with sustainability, approaches such as ecological economics (Dreschler and Wätzold, 2007) suggest studying environmental and economic effectiveness simultaneously, stressing the relevance of multi-criteria approaches. However, few economic studies cope with the spatial and temporal dynamics of biodiversity in this context (Hammack and Brown, 1974). In this vein, a range of spatially explicit models exist that aim at assessing consequences of different land use patterns for various environmental and economic criteria (Irwin and Geoghegan, 2001; Swihart and Moore, 2003). Nevertheless, most of these models are static, which restricts the ecological processes taken into account. Moreover, they usually do not incorporate important economic drivers (e.g. agricultural prices, and subsidies) that affect the returns of different land-use patterns. Some recent approaches overcome these limitations by integrating biological and economic models that demonstrate (Pareto-) efficient land-use patterns (Groot et al., 2007; Polasky et al., 2003).

The bio-economic model proposed in the present paper is in direct line with these considerations. First the model is dynamic. Furthermore it articulates ecological and economic compartments and adopts a multi-criteria perspective. Moreover, it offers a spatialized perspective as it is built up at a macro-regional scale and its calibration relies on French regional data of both land-use and bird abundance. The model allows us to analyze how we can significantly drive the bio-economic performances with financial incentives. This model questions the way to evaluate the ecological and economic dimensions and to rank habitat management decisions in order to assess the relevance of different policies, notably with respect to sustainability. In particular we study the influence of different ecological and economic indicators on the sustainability of scenarios.

The paper is organized as follows. The second section presents our bio-economical model and its calibration. The third section describes the results. The fourth section is devoted to the discussion.

2. The Bio-economic Model

2.1. The Ecological Model

Regarding the model for bird populations, we choose a dynamic framework. We adopt the Beverton–Holt model (Beverton and Holt, 1957) which accounts for the intra-specific competition for the resources and the density dependence as follows:

$$N_{s,r}(t+1) = N_{s,r}(t)\cdot\frac{1+R_s}{1+\frac{N_{s,r}(t)}{M_{s,r}(t)}} \tag{1}$$

where $N_{s,r}(t)$ stands for the bird abundance of species s in region r at year t. The R_s coefficient corresponds to the intrinsic growth rate specific to a given species s which is assumed to remain stable over France. This parameter takes into account the characteristics of each species such as the clutch size, mean reproductive success, or the number of clutches per year. The product $M_{s,r}(t)^*R_s$ represents the carrying capacity of the habitat r and the value $M_{s,r}$ captures the ability of the habitat to host the species. For computing the abundance at year $t+1$, we have chosen to involve the $M_{s,r}$ coefficient at year t, which shows a delay between the time when the habitat is modified and the time when the change affects the species. Habitat index $M_{s,r}$ is assumed to depend on land-uses as follows:

$$M_{s,r}(t) = b_{s,r} + \sum_k a_{s,r,k}\cdot A_{r,k}(t) \tag{2}$$

where $A_{r,k}(t)$ represents the share of the region r dedicated to land use k at time t. The a and b coefficients, specific to each species, show how such a species s responds to the various agricultural uses in a given region r. The $b_{s,r}$ coefficient can be interpreted as the mean habitat coefficient for a species s in a region r. Hence, one feature of this ecological model is that the abundances depend on the land-uses. It is noteworthy that the model is not explicitly spatialized. In terms of birds biodiversity, this is not a too restrictive hypothesis: their repartition areas are wider than those of other taxa and so they are less sensitive to spatial arrangements.

2.2. The Economic Model of the Farmer

We consider the 21 regions of metropolitan France. Each region r is managed by a representative farmer who selects farming land-uses along time. It is assumed that forests and no agricultural land-uses are kept fixed. The farmers make their choice in order to maximize their income given rigidity and technical constraints. Thus this income depends on two economic parameters–unit gross margin and public incentives–and the current land-uses. The program of the regional agent is defined by:

$$\max_{A_{r,k}} \mathrm{Income}_r(t) = \sum_{\text{farming } k} \widehat{mb}_{r,k}\cdot A_{r,k}(t)\cdot(1+\tau_k(t)) \tag{3}$$

$$|A_{r,k}(t) - A_{r,k}(t-1)| \leq \varepsilon\cdot A_{r,k}(t-1) \tag{4}$$

$$\sum_k A_{r,k}(t) = A_r \tag{5}$$

For each use k, the farmers get a direct income derived by the mean gross margin per surface unit $\widehat{mb}_{r,k}$ of this use k in region r and the surface dedicated to such a use $A_{r,k}(t)$. This income is affected by public incentives τ_k on different uses k which take the form of taxes ($\tau_k<0$) or subsidies ($\tau_k>0$). It is computed as a rate τ of mean gross margin per surface unit. This rate represents the economic lever of public decision makers to steer the uses. We choose gross margins as economic data because it was the only one available for each region. In addition, this kind of indicator has been already used in bio-economic modeling (Berge ten et al., 2000; Pacini et al., 2004). Implicitly the gross margin is computed from the regional output of each activity and its sale price. When maximizing their income, the standard agents must comply with two constraints at every time. The first constraint (Eq. (4)) corresponds to a technical constraint where the coefficient ϵ stands for the rigidity in changes (for example, $\epsilon=0$ means the surfaces remain constant). The second constraint (Eq. (5)) ensures merely that the total surface per region is kept fixed.

For any region, representative farmers define the share of their farming land which they dedicate to the various practices relying on a linear optimization under constraints. Certain hypotheses underlie this model. We assume that the economic system is at equilibrium and that the farmer's choice does not alter such equilibrium. First, we consider the farmers as price-takers. Second, we admit that the food demand remains constant. Third, the technological level does not evolve: there is neither improvement from research nor the quest for improved productivity from the farmers. The mean yield (which this income per surface unit depends on) is kept flat. Finally, the agricultural surface is assumed constant.

2.3. Model Coupling and Public Decisions

Ecological and economic models described previously are linked by the land-uses as depicted by Fig. 1. With the objective of maximizing incomes under technical and inertia constraints, the representative farmer exhibits pattern of land-uses $A_{r,k}(t)$ which are injected into the ecological model through the habitat $M_{s,r}(t)$: the agricultural states are the outputs of the economic model and the inputs of the ecological model. The farmer's economic choices thus condition bird abundances $N_{s,r}(t)$ associated with the habitats.

The third element of our modeling is the public stakeholder. The decision-makers impact the bio-economic system through an economic instrument: they use a set of incentives τ_k which affects land-uses, by modifying their profitability. Thanks to their economical model, the farmers shape their land-use patterns in order to maximize their income. These land-use rearrangements improve the global wealth while perturbing the evolution of the ecological model and bird community dynamics. Decision-makers define their incentive/tax politics depending on their ecological objectives and economic planning. For this purpose, the regulating agency must be able to evaluate the economic wealth and the biodiversity of the system that is governed. We assume that there is no holistic criterion, representing all dimensions of the system so various indicators are used.

From an economic viewpoint, we focus on two indicators:

- the national mean income per unit surface (Eq. (6)). It is computed from the mean gross margin of the 21 regions $\text{Income}_r(t)$ and the surfaces S_r. This represents a mean approach of the problem.

$$\overline{\text{income}}_{\text{France}} = \frac{\sum_{r=1}^{21} S_r.\text{Income}_r(t)}{S_{\text{France}}} \tag{6}$$

- the regional minimum income per unit surface (Eq. (7)). This indicator reflects the maximin analysis developed in economic studies (Solow, 1974).

$$\underline{\text{income}}_{\text{France}} = \min_r \left(\frac{\text{Income}_r(t)}{S_r} \right) \tag{7}$$

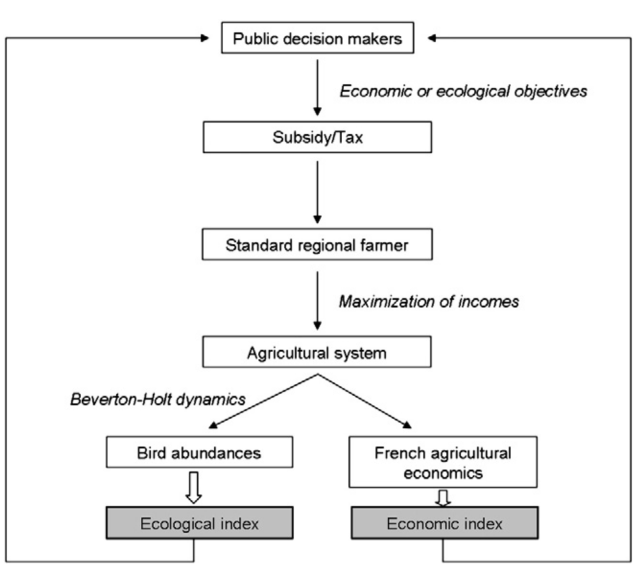

Fig. 1. Model coupling: farmers maximize their income and adjust their land-uses pending on subsidies. These choices affect French agricultural economics and bird's community dynamics.

For sake of clarity, we represent these two criteria after normalisation by their current value (2008).

From an ecological viewpoint, we have selected the STOC index, provided by the Vigie-Nature website.[1] We focus on this indicator which has been adopted as the Farmland Bird Index to analyze structural changes in biodiversity (Balmford et al., 2005). This is a variation index of abundances with respect to the reference year 2005. An aggregated STOC indicator is built for two bird groups: the generalist species and the farmland specialist species (Julliard et al., 2004). It is computed as the geometric mean of the indices of the species considered in the class exposed by Eq. (8). In these aggregated indices, the abundance variation of each species is taken into account similarly, independently from the abundance value:

$$\text{STOC}_{r,\text{class}}(t) = \prod_{s \in \text{class}} \left(\frac{N_{s,r}(t)}{N_{s,r}(2005)} \right)^{1/\text{Card}(\text{class})} \tag{8}$$

2.4. Scenarios

Once the ecological and economic models have been calibrated, we can use them to analyze the impact of public policies. The selected timeframe runs up from 2008 to 2050, i.e. a 43-year forecast. Selecting a shorter timeframe could consequently hide interesting long-term effects due to the inertia of the models.

We define scenarios for various incentive policies aimed at analyzing the impact of public decisions on both the economy and agricultural biodiversity. In all scenarios described, the surfaces allocated to the forest and non-farming area remain steady in all times: we focus only on the evolution of the farmland uses. This approach highlights the impact of the composition of farmland uses on biodiversity, the global surface remaining constant. However, we integrate the surrounding habitats (with the forest and non-farming agricultural surfaces) to compute the $M_{s,r}$ in bird dynamics (Devictor and Jiguet, 2007).

The key parameter which characterizes each scenario is the vector τ representative of the subsidy or the tax. We have developed 4 scenarios:

- Cereal scenario: subsidies for cereal, oleaginous, and proteaginous (COP) with $\tau_{\text{COP}}>0$.
- Grassland scenario: subsidies for the permanent grassland (GRASS) with $\tau_{\text{GRASS}}>0$.
- Double subsidy (DS) scenario: subsidies for COP, and subsidies for permanent grassland with $\tau_{\text{COP}}>0$ and $\tau_{\text{GRASS}}>0$.
- High Quality Environmental (HQE) scenario: taxes on the COP, redistributed to the permanent grassland with $\tau_{\text{COP}}<0$ and $\tau_{\text{GRASS}}>0$.

The first two scenarios are very simplified variants of current policies. The first scenario represents policies which support COP, for example with the objective of developing bioenergies. The second scenario corresponds to a policy of extensification by the development of permanent grasslands. The DS scenario is closer to the current situation of the Common Agricultural Policy giving subsidies both to COP and grasslands. The fourth scenario, the HQE scenario, slightly more complex, plays at two levels: the tax on the COP and the incentive for permanent meadows. The interest of the two last scenarios is to analyze possible synergies between two incentives: have the incentive on grasslands the same effectiveness alone or combined with a COP incentive? The fourth scenario is of specific interest for the planner: the required budget is lower than for the three first scenarios, as the incentives for the permanent meadows are compensated by the taxes on the COP. This scenario is the most realistic from an economic perspective in the sense that it is partially self-funded for the public stakeholder. In all four cases, this is a

[1] http://www2.mnhn.fr/vigie-nature/.

simplified model since the same policy is applied to all regions, whatever the economic or habitat features.

Furthermore we test two types of incentives: incentives can be constant for the projection or can decrease over the time. Incentives decrease linearly from previous levels in 2008 to achieve 0 in 2050 (Eq. (9)). The decreasing incentives correspond to the current trend of the CAP.

$$\tau_k(t) = \tau_k(2008)\left(1 - \frac{t-2008}{2050-2008}\right) \quad (9)$$

We study these scenarios from 3 points of view: a purely economic approach focusing on economic outcomes, a purely ecological approach studying ecological indicators and, finally, a combined bio-economic approach coupling both economic and ecological outputs. After the 43 years, the four scenarios lead to very contrasted situations as depicted by Fig. 3.

At the first stage we noted that the rigidity parameter ϵ of the economic model plays qualitatively a similar role on all the results. It does not modify the qualitative nature of trajectories, but only speeds up the process: dynamics accelerate when ϵ increases.

Figs. 4, 6–8 display the results similarly. Each trajectory is composed of 43 points, corresponding to the years of the timeframe $t_0 = 2008$ to $t = 2050$. All trajectories start from the same point at the lower left corner of the figure.

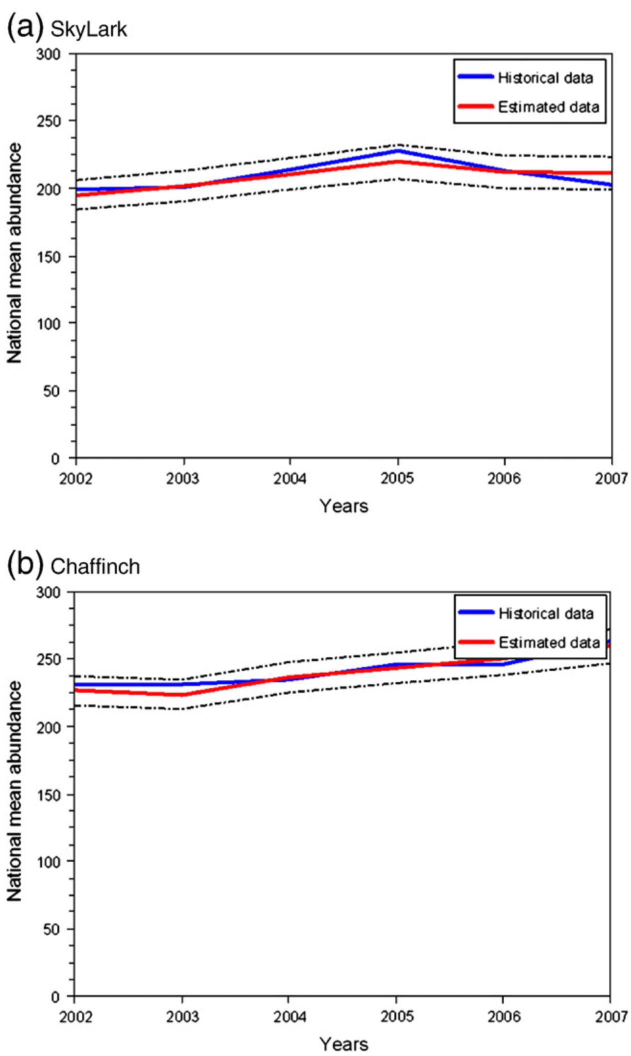

Fig. 2. Comparison of historical N_s and estimated $\widehat{N}_s$ abundances with the confidence interval (coming from the least square standard errors of calibration).

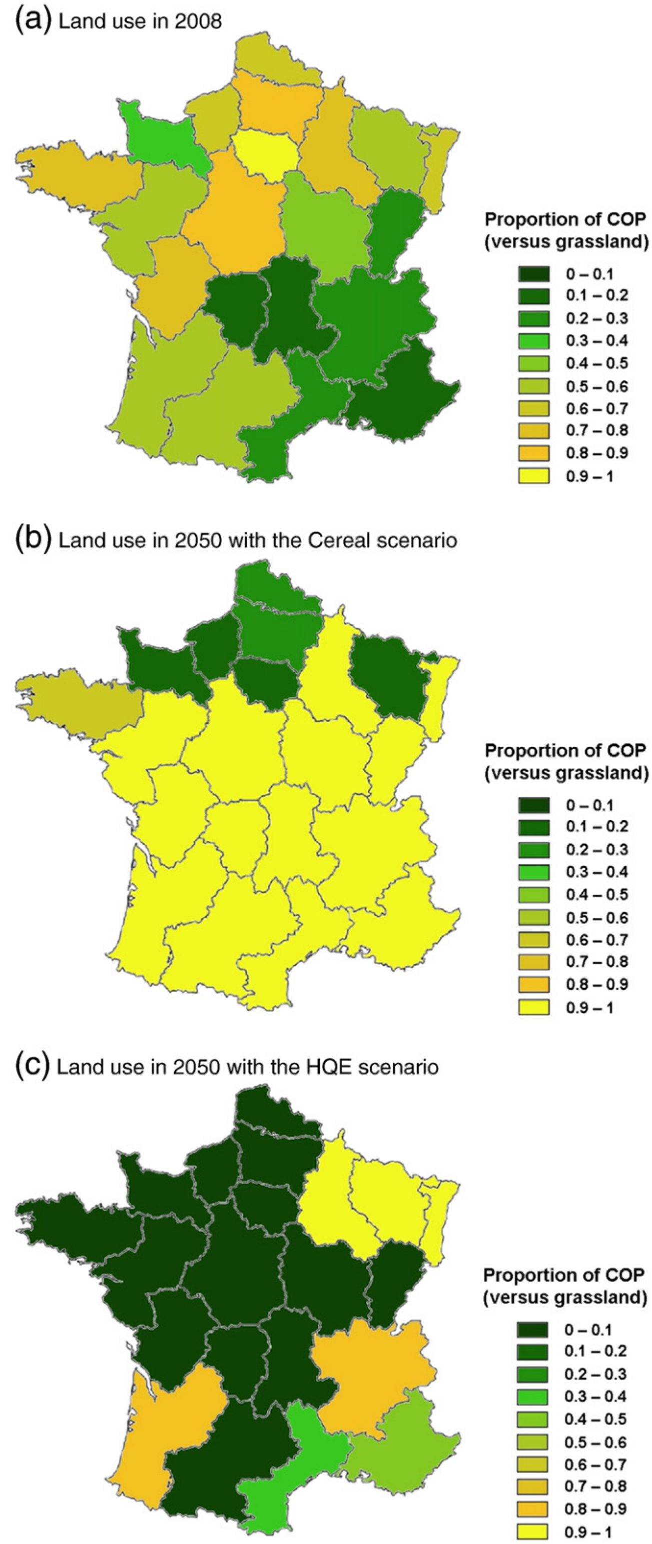

Fig. 3. Comparison of land uses before and after the projections, with the Cereal and HQE scenarios. The projections are calculated with a rigidity parameter $\varepsilon = 10\%$ and a level of incentives $\tau = 0.1$.

2.5. Model Calibration

2.5.1. Data

We considered the 21 regions of metropolitan France as the unit of spatial scale. To assess the ecological performance, we here chose to focus on common bird populations and related indicators (Gregory et al.,

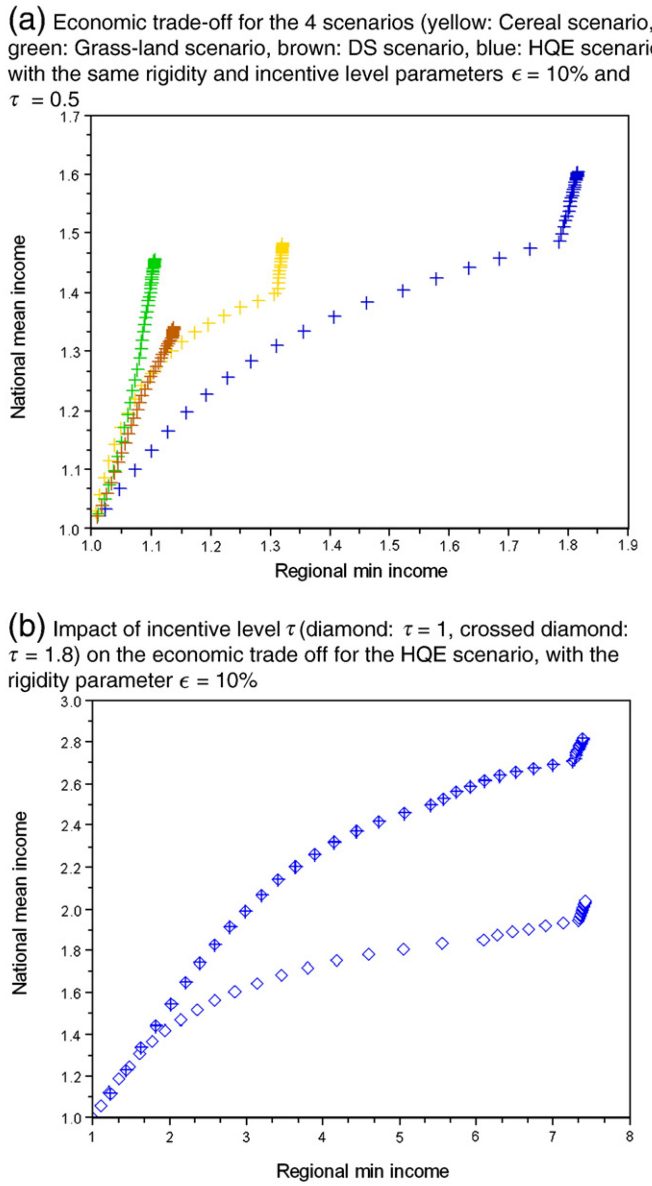

Fig. 4. Impact of scenarios and incentive level τ on the economic trade off between the national mean income ($\overline{\text{income}}_{\text{France}}$) and the regional min income ($\text{income}_{\overline{\text{France}}}$).

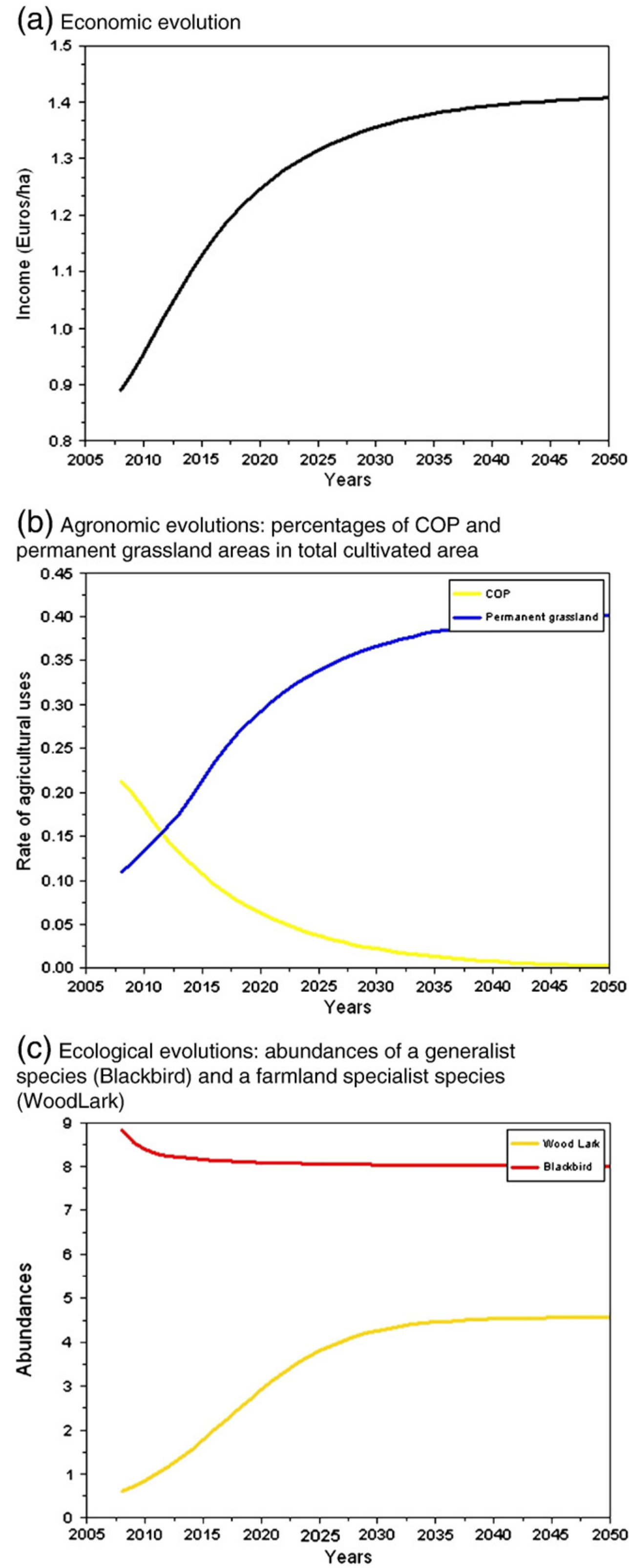

Fig. 5. One example of economic, agronomic and ecological trajectories in the Alsace region for the HQE scenario. The rigidity parameter is $\varepsilon = 10\%$ and the incentive level $\tau = 0.5$.

2009). Although the metric and the characterization of biodiversity remain an open debate (Le Roux et al., 2008; MEA, 2005), such a choice is justified for several reasons (Ormerod and Watkinson, 2000): (i) Birds lie at a high level in the trophic food chains and thus capture the variations in the chains. (ii) Birds provide many ecological services, such as the regulation of rodent populations and pest control, thus justifying our interest in their conservation and viability (Sekercioglu et al., 2004). (iii) Their close vicinity to humans makes them a simple and comprehensive example of biodiversity for a large audience of citizens.

The STOC database managed by the Museum National d'Histoire Naturelle provides the data related to the bird abundances (details in Jiguet et al., 2010). Among the species monitored by this program, we have selected 34 species which have been classified as farmland and habitat generalist species according to their habitat requirements at a Europe-wide scale (EBCC, 2007). Table 1 displays the 14 habitat generalist species and the 20 species used as a reference for the European Farmland Bird Index FBI (Gregory et al., 2009). Previous analyses have shown the relevance of the national FBI to reflect the response of farmland biodiversity to agriculture intensification (Doxa et al., 2010). The regional abundances for the years 2001 to 2007 are available for each of these species.

Agronomical data measuring the surfaces of the various agricultural practices are published by the French Statistics Service of the

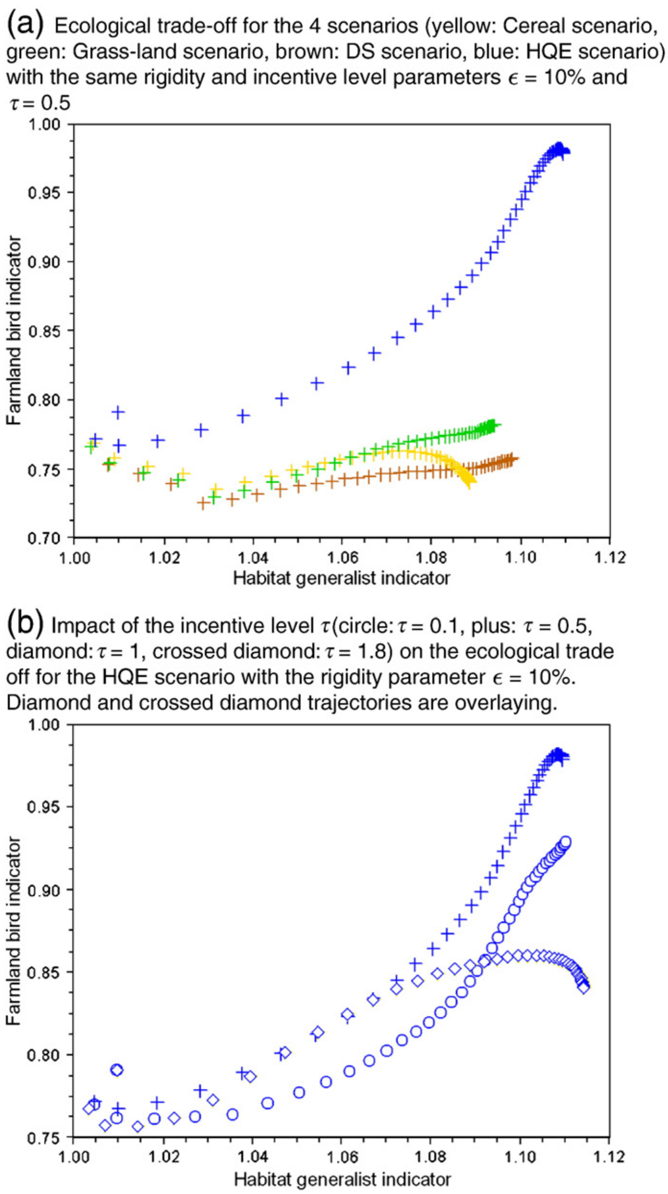

Fig. 6. Impact of scenarios and the incentive level τ on the ecological trade off between the farmland bird indicator ($STOC_{France, farmland}$) and the habitat generalist indicator ($STOC_{France, generalist}$).

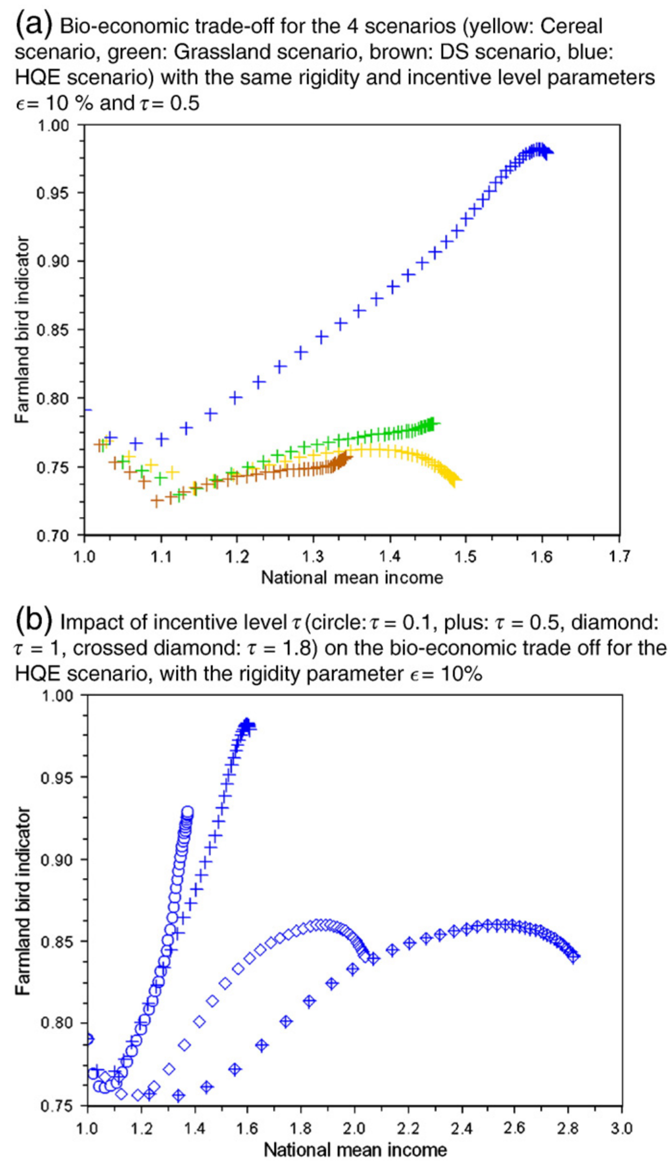

Fig. 7. Impact of scenarios and the incentive level τ on the bio-economic trade off between the farmland bird indicator ($STOC_{France, farmland}$) and the national mean income ($\overline{income}_{France}$).

Department of Agriculture[2] for the years 2002 to 2007. The agricultural surface is divided into 10 classes of land-uses as captured by Table 2. Finally the economic data relating to the gross margins are derived from the national FADN (Farm Accountancy Data Network)[3] and the European FADN[4] for France. They are computed for each activity in each region. To insure consistency between the two databases, we balanced the economic data (coming from the European FADN) by the ratio of the regional Utilized Agricultural Areas UAA(national FADN)/UAA(European FADN).

2.5.2. Calibration of the Bio-economic Model

This step consists in determining the Beverton–Holt parameters through a calibration. For each of the 34 species, we must estimate the growth parameter R constant over the region as well as the a and b parameters specific to each region. We use a least square method to minimize errors between the observed abundances $N_{s,r}$ as issued from STOC and the values derived from the model $\widehat{N}_{s,r}$:

$$\min_{R,a,b} \sum_{s,r} \|N_{s,r} - \widehat{N}_{s,r}\|^2 \tag{10}$$

Fig. 2 illustrates the results of this calibration with two species: the Sky Lark (farmland specialist) and the Chaffinch (generalist species). The errors of estimation are small (between 4% and 6% for the illustrated species) and the historical data do not go beyond the confidence interval (coming from the least square standard errors of calibration). Comparing the historical data with the model-generated data, we note that the model tends to smooth the variations of the observed data.

For the economic part, we computed the mean gross margin per surface $\widehat{mb}_{r,k}$ for each land use and each region as the arithmetic mean of the historical data between 2002 and 2007. We therefore use an average market situation for our simulations.

$$\widehat{mb}_{r,k} = \frac{\sum_{t=2002}^{2007} mb_{r,k}(t)}{6} \tag{11}$$

[2] http://agreste.agriculture.gouv.fr/.
[3] http://agreste.agriculture.gouv.fr/.
[4] http://ec.europa.eu/agriculture/rica/.

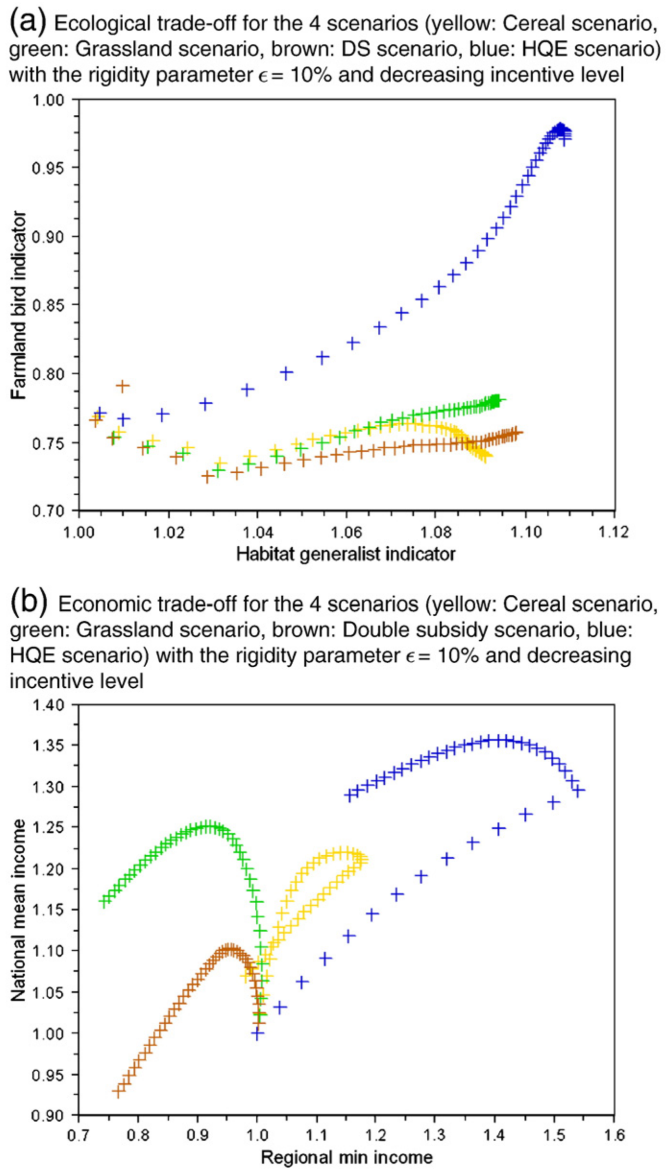

Fig. 8. Impact of decreasing incentives on ecological trade-off between the farmland bird indicator ($STOC_{France, farmland}$) and the habitat generalist indicator ($STOC_{France, generalist}$) and the economic trade-off between the national mean income ($\overline{\text{income}}_{\text{France}}$) and the regional min income ($\underline{\text{income}}_{\text{France}}$).

3. Results

3.1. Economic Analysis

Fig. 4(a) allows for a comparison of the 4 scenarios based on identical rigidity ε and constant incentive τ parameters, set respectively at 10% and 0.5: we use the indicators measuring the regional min income and the national mean income defined in Eqs. (6) and (7). It turns out that the economic value always increases since the farmers are maximizing their income. To illustrate this point, in Fig. 5 we represent the evolution of the regional income for one French region, Alsace. On the graph in Fig. 4(a), we note that the HQE scenario is the one which generates the best results on both indicators. The Grassland and DS scenarios are the least efficient. However, the differences between the policies are sensitive to the chosen index. The min regional income is more sensitive to the scenarios than the national mean gross margin.

Table 1
Distribution of the 34 common birds according to their specialisation.

Generalist	Farmland specialist
Woodpigeon	Common buzzard
Cuckoo	Common kestrel
Green woodpecker	Red-legged partridge
Blackcap	Grey partridge
Melodious warbler	Common pheasant
Rufus Nightingale	Common quail
Blackbird	Hoopoe
Dunnock	Sky lark
Eurasian golden oriole	Wood lark
Great tit	Meadow pipit
Blue tit	Yellow wagtail
Carrion Crow	Common whitethroat
Eurasian jay	Whinchat
Common chaffinch	Common stonechat
	Rad-backed shrike
	Rook
	Linnet
	Yellowhammer
	Cirl bunting
	Corn bunting

For the graph in Fig. 4(b), we focus on the effect of τ parameter on the HQE scenario which was more efficient. We compare the outcomes for two constant values of τ (1 and 1.8). By contrast to Fig. 4(a), the min regional income shows similar performances for the two taxation levels while the national mean income emphasizes their differences.

3.2. Ecological Analysis

The Fig. 6(a) allows for a comparison between the four scenarios thanks to two ecological indicators with same values for ε and τ, set respectively at 10% and 0.5, which we keep constant. We note that the HQE policy is the most efficient scenario from the point of view of both ecological indicators. Although the Cereal scenario was quite efficient on the economic side, it appears as the least ecological efficient from an ecological point of view. The two indicators do not distinguish the scenario with the same sensitivity. The levels reached at the end of the trajectories are rather similar for the four policies regarding the generalist species viewpoint, while their differences are significantly highlighted by the farming specialist species. Fig. 5 illustrates this difference of growth with two species in Alsace.

The graph in Fig. 6(b) focuses on the HQE policy and exhibits four levels of taxation. It shows that the STOC indicator for generalists does not distinguish the various levels of taxation. The STOC farmland bird index (FBI) is more sensitive. In addition, Fig. 6(b) captures a new effect that did not appear with the economic analysis: a non-monotonicity of the impact of taxation level on the FBI. For its low value, an increase of τ improves the ecological efficiency of the trajectory (with $\tau = 0.1$ and $\tau = 0.5$). On the contrary, for its high values, an increase of the taxation level has a negative marginal effect on the indicator as emphasized by the trajectory with $\tau = 1$ and $\tau = 1.8$.

3.3. Bio-economic Analysis

The most effective scenario for both ecological and economic dimensions is the HQE scenario as depicted in Fig. 7(a). Fig. 7(b)

Table 2
Distribution of the 10 land uses considered by the economic model.

Hay production	No hay production	Others
Annual hay	Cereals-Oleaginous-Proteaginous	Fallow
Temporary grassland	Industrial crop	Forest
Permanent grassland	Horticultural crop	No agricultural surface
	Permanent crop	

displays the trajectories of the HQE scenario for 4 constant levels of taxation. With respect to ecological and economic indicators, such a figure provides insights into the relationships and trade-offs between ecological and economic requirements. We remark that depending on the value given to τ, we get a full range of trajectories covering the set of possibilities. No trajectory exhibits an improvement of the system for both ecological and economic dimensions: some trajectories are more ecologically efficient (for example with $\tau=0.1$ and 0.5), while others show a better economic efficiency ($\tau=1$ and 1.8).

We note that some values of the national mean income can be obtained for all trajectories (for example margin = 1.3). However this value is not reached at the same speed for the four trajectories: with $\tau=1.8$ (1, 0.5, 0.1 respectively), this income is obtained after 4 years (6 years, 11 years, and 40 years respectively). The more stringent are the policies (higher level of incentive), the faster the income is reached. However, for a given income, the slowest trajectory is the most ecological efficient: for a national mean income of 1.3, the STOC indicator of farmland specialists provides a level of 0.93 with $\tau=0.1$, against only 0.77 for $\tau=1$.

3.4. Analysis of Decreasing Incentives

Fig. 8 illustrates the ecological and economic performances for the four scenarios with decreasing incentives (incentives start at $\tau=0.5$ and go linearly to $\tau=0$ at 2050 as defined in Eq. (9)). We observe on the graph in Fig. 8(a) that the ecological outcomes are quite similar to those with trajectories with constant τ (graph in Fig. 6(a)). By contrast, economic performances differ. The beginning of economic trajectories is similar to those of Fig. 6(b) but around 2020 both national mean income and regional min income start to decrease: agricultural choices done under strong subsidies become not profitable with low subsidies. For Cereal and DS scenarios, the national mean income is the most affected. But for HQE and Grassland scenarios, it is the regional min income which is the most sensitive to decreasing incentives.

4. Discussion

4.1. Model Construction

This paper presents an inter-disciplinary approach which is needed (Perrings et al., 2006) to develop sustainable management of biodiversity and agriculture. Despite divergences between economic and ecological disciplines and approaches (Dreschler et al., 2007), our model couples economic and ecological modeling to analyze bio-economic performances of French agricultural public policies at the national scale. This approach avoids the biodiversity monetary evaluation which is controversial (Rees, 1998). The coupling of economic (gross margins), agronomical (land uses) and ecological (bird abundances) data gives a strong realism to the modeling. Integrating these many data allows us to obtain robust and informative results. With the integration of regional economic and ecological features, the model is spatialized, which reinforces its relevance (Polasky et al., 2003). The choice to focus on common birds rather than one or two species leads to obtain more general results and constitutes a major step towards biodiversity analysis. Finally, the dynamic aspect which allows for an adjustment of carrying capacity through land uses lead to a precise representation of impacts of land-uses on avifauna evolution and transient dynamics. The initial integration of spatio-temporal elements and many databases creates a multi-criteria framework suggesting many developments without any modification of the basic modeling structures.

4.2. Ecological-economic Reconciliation

With this bio-economic prototype, we have shown that both the ecological and economic performance are impacted by the public policies for agriculture and land-use. A basic economic instrument (subsidy/tax) separates policies according to the two criteria. It suggests that managing the agricultural practices in bio-economic terms is possible thanks to a simple economic distortion of the marginal incomes as argued by Alavalapati et al., 2002 and Shi and Gill, 2005. The model illustrates that it is possible to build scenarios favourable on the long term to both ecological and economic criteria. It should therefore be possible to design public strategies improving both farmer incomes and the bird biodiversity.

4.3. Index Selection

The evaluation of the various policies is highly dependent on the selected criterion. On the ecological side, the situation is clear: the STOC indicator for the generalist community is not significant enough to distinguish the policies while on the contrary the STOC indicator of the farmland specialists is sensitive to the proposed scenarios. This result is in direct line with the historical abundances (Julliard et al., 2006). The generalist species are less farming-dependent since they can adapt, at least on the short term, to these perturbations by switching to other habitats. The farmland specialist species, the adaptation capability of which is lower, are more affected by the various scenarios. This result leads better understandings of the ecosystem, which is essential for the success of a sustainable policy (Dreschler and Wätzold, 2007; Hein and van Ierland, 2006). Hence, the STOC criterion of the farming species turns out as a relevant ecological metric for bird diversity to analyze impacts of public policies on biodiversity.

On the economic side, the two selected indicators relate to different methodologies: a global approach based on the national mean income, and a worst case approach based on the min regional income. Both indicators are sensitive to the policies but marginal impacts of the different policies depend on the economic criterion. The planner must choose the most adequate indicator for its target, keeping in mind the sensitivity of the two indicators to the scenario and to the level of incentives. Selection of the economic indicator is consequently a crucial stage before analyzing impacts of public policies on economy, since it partially influences the final conclusion.

4.4. The Ecology–economy Trade-off

The conciliation of ecological and economic performances under public policies is possible but not straightforward. Many points of this trade-off have to be discussed. This study focuses on three of them. Our study first suggests that synergies between adequate political incentives occur. Acting simultaneously on various incentives can improve performances from both the ecological and economic points of view as shown with the HQE scenario.

The second point is the time horizon of the incentives. Short-term incentives are sufficient to drive farmer choices and thus ecological performances but are not sustainable for the economic part. Farmers initially adopt activities which alter their rentability when the incentive level decreases.

The third point regards the priority between ecological and economic objectives. As depicted by graphs of the bio-economical approach (Fig. 7), no unique pareto optimum emerges: even if both criteria are improved with this scenario, it is always necessary to prioritise to ecological and economical objectives. Consequently, a set of admissible strategies is available to bring together ecological and economic performances. The challenge consists in selecting which farming activities should be subsidised or taxed and which magnitude of subsidy/tax is the most adequate in order to optimise trajectories for the set of ecological and economic criteria.

Other points of the ecological-economic reconciliation are underlying our study. Along the bio-economic trajectories, we have seen that the speed of change is very fluctuating. This variation gives another level of trade-off in terms of timeframe: how fast does the public agency want to reach the objectives? The total budget of the regulating agency is another key element of the strategy. In our model, we have not imposed budgetary constraint. However, in a larger perspective, decision-making support requires the integration of this budgetary limitation in the model. Some policies may be attractive from ecological and economic viewpoints but not feasible in terms of public balance. Considering this global budget limitation raises the question of budget allocation to the regions. Contrary to the micro-scale studies (Münier et al., 2004) and meso-scale studies (Holzkamper and Seppelt, 2007; Shi and Gill, 2005), our modeling at the national scale leads to study the budget regional allocation. This question is highly dependent on the selection of the economic indicator. Does the objective consist in reaching a maximal national mean, a maximal level for the poorest region or a minimal variability over the regions? This spatial share of the global budget highly conditions the economical and ecological performances of each region, as well as for the whole country.

5. Conclusion

This work explores joint managements of agriculture and biodiversity. A macro-regional model has been developed and calibrated by coupling several ecological and agricultural databases monitored at the French scale. The model articulates the dynamic of large community of bird species impacted by agricultural land-use and an economic decision model based on farming gross margins for each French region. Through different scenarios relying on national subsidies and taxes, we have examined and assessed the impact of public policies on both biodiversities, regional land-use and farming economic outcomes. It has been shown how simple economic instruments could be used to simultaneously promote economic performance and bird populations. The bio-economical analysis shows several solutions for such ecology–economy trade-off. These results suggest that different options are available to develop multi-functional sustainable agriculture. It is, as well, pointed out to what extent the sustainability of the different policies is sensitive to the ecological and economic indicators used by the decision maker.

As suggested by the results, this model contributes to evaluations of public decisions according to several dimensions: conservation performances, economic performances, public budget, synergies between incentives, timing for objectives, incentives and territoriality. The structure of this model allows for many developments. For the economic part, we can add risk aversion behavior (Quaas et al., 2007) and uncertainty on gross margins due to climatic or market uncertainty. On the ecological side, it is possible to add migrations between regions and evolutions of ecological niches in response to climatic change (Brotons and Jiguet, 2010), or test other abundance indicators. From the public policy point of view, many scenarios can be tested: dynamic evolution of incentives, budgetary constraint, and optimal policy. Finally, the use of inverse approaches including optimality in particular multi-criteria (Groot et al., 2007) or viability (constraints) methods (Baumgartner and Quaas, 2009; Tichit et al., 2008) instead of exogeneous incentive-based scenarios should be fruitful for the search of relevant incentive strategies.

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References

Alavalapati, J.R.R., Stainback, G.A., Carter, D.R., 2002. Restoration of the longleaf pine ecosystem on private lands in the US South: an ecological economic analysis. Ecological Economics 40, 411–419.

Balmford, A., Bennun, L., ten Brink, B., Cooper, D., Cote, I.M., Crane, P., Dobson, A., Dudley, N., Dutton, I., Green, R.E., Gregory, R.D., Harrison, J., Kennedy, E.T., Kremen, C., Leader-Williams, N., Lovejoy, T.E., Mace, G., May, R., Mayaux, P., Morling, P., Philips, J., Redford, K., Ricketts, T.H., Rodriguez, J.P., Sanjayan, M., Schei, P.J., van Jaarsveld, A.S., Walther, B.A., 2005. The convention on biological diversity's 2010 target. Science 307 (5707), 212–213.

Baumgartner, S., Quaas, M.F., 2009. Ecological-economic viability as a criterion of strong sustainability uncertainty. Ecological Economics 68, 2008–2020.

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology and Evolution 18 (4), 182–188.

Berge ten, H.F.M., Ittersum van, M.K., Rossing, W.A.H., Ven van de, G.W.J., Schans, J., Sanden van de, P.A.C.M., 2000. Farming option for the Netherlands explored by multi-objective modelling. European Journal of Agronomy 13, 263–277.

Beverton, R.J.H., Holt, S.J., 1957. On the Dynamics of Exploited Fish Populations, Fishery Investigations II (XIX). Ministry of Agriculture, Fisheries and Food.

Brotons, L., Jiguet, F., 2010. Climate change and bird communities. In: Møller, A.P., Berthold, P., Fiedler, W. (Eds.), Effects of Climate Change on Birds. Oxford University Press, Oxford.

Butler, S.J., Vickery, J.A., Norris, K., 2007. Farmland biodiversity and the footprint of agriculture. Science 315 (5810), 381–384.

Chamberlain, D.E., Fuller, R.J., Bunges, R.G.H., Duckworth, J.C., Shrubb, M., 2000. Changes in the abundance of farmland birds in relation to the timing of agricultural intensification in England and Wales. Journal of Applied Ecology 37, 771–788.

Devictor, V., Jiguet, F., 2007. Community richness and stability in agricultural landscapes: the importance of surrounding habitats. Agriculture, Ecosystems and Environment 120, 179–184.

Diamond, P.A., Hausman, J.A., 1994. Contingent valuation: is some umber better than no number? Journal of Economic Perspectives 8 (4), 45–64.

Dobbs, T., Pretty, J.N., 2004. Agri-environmental stewardship schemes and 'multi-functionality'. Review of Agricultural Economics 26, 220–237.

Donald, P.F., Green, R.E., Heath, M.F., 2001. Agricultural intensification and the collapse of Europe's farmland bird populations. Proceedings of Royal Society of London B 268, 25–29.

Donald, P.F., Sanderson, F.J., Burfield, I.J., van Bommel, F.P.J., 2006. Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. Agriculture Ecosystems and Environment 116 (3–4), 189–196.

Doxa, A., Bas, Y., Paracchini, M.L., Pointereau, P., Terres, J.-M., Jiguet, F., 2010. Low-intensity agriculture increases farmland bird abundances in France. Journal of Applied Ecology 47, 1348–1356. doi:10.1111/j.1365-2664.2010.01869.x.

Dreschler, M., Watzold, F., 2001. The importance of economic costs in the development of guidelines for spatial conservation management. Biological Conservation 97, 51–59.

Dreschler, M., Wätzold, F., 2007. Ecological-economic modelling for the sustainable use and conservation of biodiversity. Ecological Economics 62 (2), 203–206.

Dreschler, M., Grimm, V., Mysiak, J., Wätzold, F., 2007. Differences and similarities between ecological and economic models for biodiversity conservation. Ecological Economics 62, 203–206.

European Bird Census Council, 2007. The state of Europe's Common Birds. Ed EBCC.

Gatto, M., Leo, De., 2000. Pricing biodiversity and ecosystem services: the never ending story. Bioscience 50 (4), 347–355.

Gregory, R.D., Willis, S.G., Jiguet, F., Vorisek, P., Pazderová, A., van Strien, A., Huntley, B., Collingham, Y.C., Couvet, D., Green, R.E., 2009. An indicator of the impact of climate change on European bird populations. PloS ONE 4 (3), e4678. doi:10.1371/journal.pone.0004678.

Groot, J.C.J., Rossing, W.A.H., Jellema, A., Stobbelaar, D.J., Renting, H., Van Ittersum, M.K., 2007. Exploring multi-scale trade-offs between nature conservation, agricultural profits and landscape quality — a methodology to support discussions on land-use perspectives. Agriculture Ecosystem and Environment 120, 58–69.

Hammack, J., Brown Jr., G.M., 1974. Waterfowl and Wetlands: Toward Bioeconomic Analysis. Johns Hopkins University Press, Baltimore.

Havlík, P., Veysset, P., Boisson, J.M., Lherm, M., Jacquet, F., 2005. Joint production under uncertainty and multifunctionality of agriculture: policy considerations and applied analysis. European Review of Agricultural Economics PhD, Universite de Montpellier.

Hein, L., van Ierland, E., 2006. Efficient and sustainable management of complex forest ecosystems. Ecological Modelling 190, 351–366.

Holzkamper, A., Seppelt, R., 2007. Evaluating cost-effectiveness of conservation management actions in an agricultural landscape on a regional scale. Biological Conservation 136, 117–127.

Hughey, K.F.D., Cullen, R., Moran, E., 2003. Integrating economics into priority setting and evaluation in conservation management. Conservation Biology 17 (1), 93–103.

Irwin, E.G., Geoghegan, J., 2001. Theory, data, methods: developing spatially explicit economic models of land use change. Agriculture Ecosystem Environment 85, 7–23.

Jackson, L., Bawa, K., Pascual, U., Perrings, C., 2005. Agrobiodiversity: a new science agenda for biodiversity in support of sustainable agroecosystems. DIVERSITAS Report, 4, p. 40.

Jiguet, F., 2009. Method-learning caused first-time observer effect in a newly-started breeding bird survey. Bird Study 56 (2), 253–258. doi:10.1080/00063650902791991.

Jiguet, F., Devictor, V., Ottvall, R., van Turnhout, C., van der Jeugd, H., Lindström, Å., 2010. Bird population trends are linearly affected by climate change along species thermal ranges. Proceedings of Royal Society of London B. doi:10.1098/rspb.2010.0796.

Julliard, R., Jiguet, F., Couvet, D., 2004. Common bird facing global changes: what makes a species at risk? Global Change Biology 10 (1), 148–154.

Julliard, R., Clavel, J., Devictor, V., Jiguet, F., Couvet, D., 2006. Spatial segregation of specialists and generalists in bird communities. Ecology Letters 9, 1237–1244.
Kleijn, R.A., Baquero, Y., Clough, M., Díaz, J., De Esteban, F., Fernández, D., Gabriel, F., Herzog, A., Holzschuh, R., Jöhl, E., Knop, A., Kruess, E.J.P., Marshall, I., Steffan-Dewenter, T., Tscharntke, J., Verhulst, T.M., West, J., Yela, L., 2006. Mixedbiodiversity benefits of agri-environment schemes in five European countries. Ecology Letters 9 (3), 243–254.
Krebs, J.R., Wilson, J.D., Bradbury, R.B., Siriwardena, G.M., 1999. The second silent spring? Nature 400, 611–612.
Le Roux, X., Barbault, R., Baudry, J., Burel, F., Doussan, I., Garnier, E., Herzog, F., Lavorel, S., Lifran, R., Roger-Estrade, J., Sarthou, J.P., Trometter, M. (Eds.), 2008. Agriculture et biodiversité, valoriser les synergies. Expertise scientifiquecollective, synthèse du rapport. INRA, France.
Macmillan, D.C., Harley, D., Morison, R., 1998. Cost effectiveness analysis of woodland ecosystem restoration. Ecological Economics 27, 313–324.
Millenium Ecosystem Assessment, 2005. Ecosystems and Human Well Being: Current State and Trends. Chapter 26 : Cultivated Systems. Island Press, Washington, pp. 745–794.
Münier, B., Birr-Pedersen, K., Schou, J.S., 2004. Combined ecological and economic modelling in agricultural land use scenarios. Ecological Modelling 174, 5–18.
Ormerod, S.J., Watkinson, A.R., 2000. Editor's introduction: birds and agriculture. Journal of Applied Ecology 37, 699–705.
Pacini, C., Wossink, A., Giesen, G., Huirne, R., 2004. Ecological-economic modelling to support multi-objective olicy making: a farming systems approach implemented for Tuscany. Agriculture, Ecosystems and Environment 102, 349–364.
Perrings, C.P., Jackson, L., Bawa, K.S., Brussaard, L., Brush, S., Gavin, T., Papa, R., Pascual, U., de Ruttier, P., 2006. Biodiversity in agricultural landscapes: saving natural capital without losing interest. Conservation Biology 20, 263–264.
Polasky, S., Nelson, E., Lonsdorf, E., Fackler, P., Starfield, A., 2003. Conserving species in a working landscape: land use with biological and economic objectives. Ecological Applications 15 (4), 1387–1401.
Quaas, M.F., Baumgartner, S., Becker, C., Frank, K., Müller, B., 2007. Uncertainty and sustainability in the management if rangelands. Ecological Economics 62, 251–266.
Rashford, B.S., Dugger, B., Adams, R.M., 2008. Application of a bioeconomic production model to improve wildlife management. The Journal of Wildlife Management 72 (2), 510–517.
Rees, W., 1998. How should a parasite value its host. Ecological Economics 25, 49–52.
Sekercioglu, C., Daily, G.C., Ehrlich, P., 2004. Ecosystem consequences of bird declines. PNAS 101, 18042–18047.
Shi, T., Gill, R., 2005. Developing effective policies for the sustainable development of ecological agriculture in China: the cas study of Jinshan County with a systems dynamics model. Ecological Economics 53, 223–246.
Solow, R., 1974. Intergenerational equity and exhaustible resources. Review of Economic Studies (symposium) 41, 29–45.
Swihart, R.K., Moore, Jeffrey E., 2003. Conserving Biodiversity in Agricultural Landscapes Model-Based Planning Tools. Purdue University press.
Tichit, M., Doyen, L., Lemel, J.Y., Renault, O., Durant, D., 2008. A co-viability model of grazing and bird community management in farmland. Ecological Modelling 206, 277–293.
Van Wenum, J.H., Wossink, G.A.A., Renkema, J.A., 2004. Location-specific modelling for optimizing wildlife management on crop farms. Ecological Economics 48, 395–407.
Vickery, J.A., Bradbury, R.B., Henderson, I.G., Eaton, M.A., Grice, P.V., 2004. The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England. Biological Conservation 119, 19–39.